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Human Health and Physical Activity During Heat Exposure

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Editor

Human Health and Physical Activity During Heat Exposure

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Editor
Yuri Hosokawa
College of Sport and Health Science
Ritsumeikan University
Kusatsu, Shiga, Japan

Korey Stringer Institute
University of Connecticut
Storrs, CT, USA

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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.
January 5, 2018.

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

H. M. Jones (✉)
National Oceanic and Atmospheric Administration (UCAR Affiliate), NOAA Research, Climate Program Office, Silver Spring, MD, USA
e-mail: hunter.jones@noaa.gov

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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

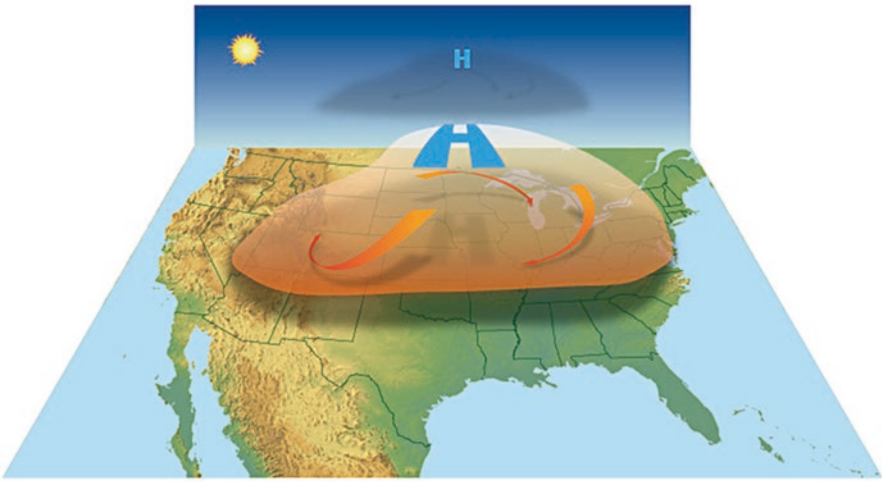

Fig. 1.1 Representation of the meteorological conditions driving a typical heat wave. A high-pressure system acts as a cap that traps hot air on the surface. Image from the National Oceanic and Atmospheric Administration (NOAA) http://www.srh.noaa.gov/jetstream/global/hi.htm (public domain)

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

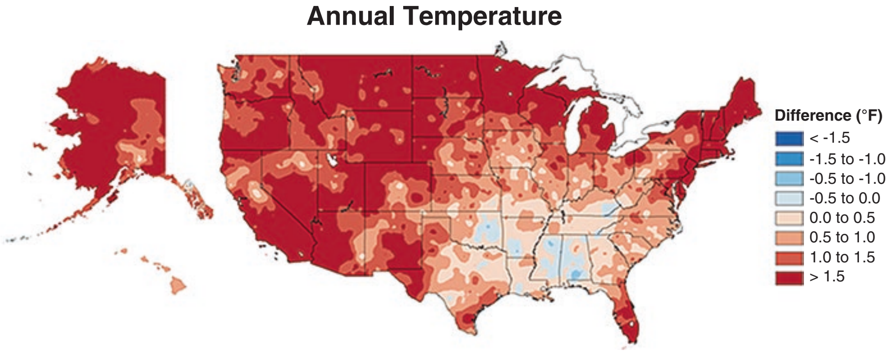

Fig. 1.2 Observed changes in annual temperatures from historical climatology (1901 to 1960 (1925–1960 for Alaska and Hawaii)) to present day climatology (1986–2016). The scale ranges from <− 0.83 °C to >0.83 °C. Figure from the Climate Science Special report of the Fourth National Climate Assessment [26]

and humidity), perceived temperature, wet-bulb globe temperature (i.e., temperature, humidity, wind, and solar radiation), duration, and other considerations [18]. Establishing a consistent definition of a heat wave is important, especially when considering a single event, because it will dictate the timing of alerts, watches, warnings, and other advisories to be issued to guide decision-makers and the public in taking appropriate actions to reduce extreme heat health risks.

The definition of heat waves is also important when considering them in aggregate – from a climatological perspective. The corpus of environmental health literature is replete with studies finding that the intensity, duration, frequency, seasonality, and character of heat waves are changing for the worse [16, 17, 19–25], but there is no standard definition for what a heat wave is across all of these studies. Nonetheless, the synthesis and harmonization of these findings, as performed by assessments such as the Intergovernmental Panel on Climate Change (IPCC) reports and the US National Climate Assessment, can be regarded as the best estimates we have of how heat waves have changed over time and how they may change in the future.

The Climate Science Special Report of the Fourth U.S. National Climate Assessment finds that the frequency of heat waves has increased since the 1960s and that the number of high-temperature records greatly exceeds the number of low-temperature records. Moreover, there is evidence of a nationwide increase in the intensity of heat waves since the 1980s. The annual average temperature over the contiguous United States increased by 1 °C, during the period from 1895 to 2016 [26]. Figure 1.2 shows how average temperatures across most of the United States have increased over the past century.

The long-term warming trend is predicted to continue in the future, with more recent studies suggesting that an increase of 1.3 °C globally may be inevitable for this century even with no increase in emissions [27] and that a more likely range of temperature increase since preindustrial times is 2.0–4.9 °C [28]. This warming trend sets up the context for exacerbated heat waves.

The US Global Change Research Program's Climate and Health Assessment finds that heat-related fatalities are very likely to increase by thousands to tens of thousands annually by the end of the century [29]. Furthermore, some studies suggest that due to the limits in human adaptability [30], if the warming trend continues unabated, some parts of the world may become unsuitable to host major sporting events like the Olympics [31], and the habitability of some regions of the world like Southwest Asia may become challenged [32].

These prognostications are foreboding; however, fatalities due to heat are also preventable. There are urban design, public health, infrastructural, and other interventions that could help mitigate the heat risk during, immediately prior, and well before a heat wave. While these interventions are not the subject of this chapter, the provision of meteorological and climate information to support these interventions is germane. Predictions for heat waves have improved on all timescales, and there is reason to believe they can continue to make great strides in this direction [33] – affording the opportunity to support the management of future heat risk.

Weather and Climate Modeling and Prediction

The ability to predict weather and climate is built upon decades of investment in observing systems [34, 35], scientific research to improve understanding of the climate system [36], model improvements [37], and the infrastructure for operationalizing these elements so that reliable and timely predictions can be issued [38].

Observing systems can take the form of satellites, radar, weather balloons, land based sensors, ship and airplane mounted sensors, dropsondes, and even human networks of observers such as CoCoRaHS (Community Collaborative Rain, Hail & Snow Network) [39]. These systems require large investments and require regular maintenance and upgrades. For example, the recently launched satellite in NOAA's Geostationary Operational Environmental Satellite-R (GOES-R) is part of a program costing over $10bn [40] but was urgently needed to replace existing satellites. The information that satellites and other observing systems provide is critical to accurate weather prediction and Earth system science. Gaps in coverage not only put lives and property at risk in the near term but also contribute to a data gap in the climate record which is difficult to bridge.

Research to improve understanding of the climate system is built upon empirical observations made possible by a sustained and reliable observing infrastructure. This includes additional observational inputs from targeted research projects, known as field campaigns, that probe phenomena such as the El Niño Southern Oscillation (ENSO) to improve our understanding of them [41]. The climate research portfolio is dynamic, diverse, and interconnected. It includes studies that examine ocean circulation, investigate causes of drought, and increase understanding of climate modes such as ENSO and the Madden-Julian Oscillation (MJO) and phenomena such as heat waves [42]. Much of this research is supported by federal research grants to universities or is performed in federal laboratories, including those overseen by NOAA, NASA, the Department of Energy, the National Science Foundation, and other agencies. All of this research is informed by societal needs for information, but some is exploratory and may take years to decades to be entrained into models to improve prediction skill.

Sustained observations and improved understanding of the climate system come together in climate and weather models. While these models have important differences, they both benefit from accurate and dense observations, improved understanding of the Earth system, and advances in supercomputing capabilities – and both are underpinned by the same fundamental equations that describe the physics of the Earth system. Weather models derive much of their skill from near-real-time observations, particularly of the atmosphere, which are input into the models as “initial conditions.” The model then uses finite mathematical equations for the physics of the Earth system to approximate the evolution of those environmental conditions over time. Weather models currently tend to issue skillful predictions with up to 10–12 days of lead time.

By contrast, climate models are used to generate climate information and statistics over a much longer period of time. They rely on slowly evolving, longer-term patterns (e.g., ENSO), ocean circulation, soil moisture, and chemical cycles, as well as accurate representation of boundary conditions and external forcings. Boundary conditions are fixed for the period of a climate model run and include such things as ocean bathymetry and orography. Forcings are those conditions which do change over the period of a climate model run but are set before the run – so they are not calculated during the model run in response to other variables in the model – such as greenhouse gas concentrations. Climate models are typically run at seasonal timescales and longer.

A critical distinction between weather and climate models as explained above is that weather models derive much of their skill from precise and accurate initial conditions, while climate models derive skill from representing slow-changing climate modes, boundary conditions, and forcings correctly. Weather models are used to produce deterministic information about the state of the atmosphere at a given place and time, while climate models are used to produce probabilistic information about weather norms that apply to a longer timescale and usually a coarser spatial resolution (Fig. 1.3). Because weather models are skillful to about 12 days and climate models are skillful at seasonal and longer timescales, a prediction skill gap exists at the timescale of about 3–4 weeks to monthly lead times in a forecast. This gap is known as the seasonal-to-subseasonal prediction gap [43] or S2S for short. Bridging this gap to enable seamless, skillful predictions at all timescales is a major research and operation goal of the international climate and weather community.

Integrating observations, understanding of the climate system, and modeling to provide accurate, timely, and useable climate and weather information require an operational infrastructure that reliably gathers, cleans, and injects observations into models that can reproduce outputs while accommodating new research findings, new observing systems, and improvements to computing infrastructure. Indeed, an underappreciated core competency of NOAA’s National Weather Service is bringing all of these elements together to produce reliable predictions on a continual basis.

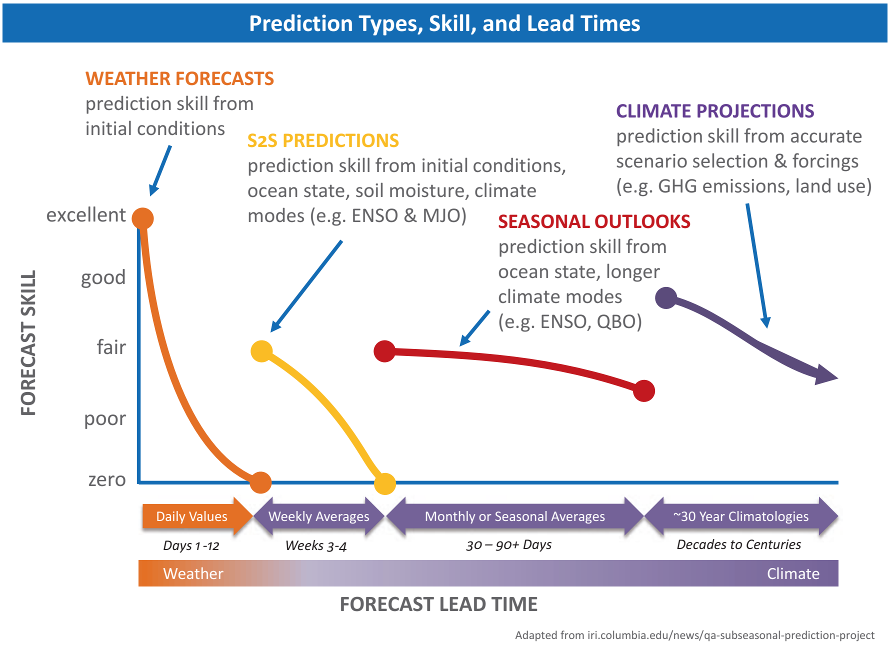

Fig. 1.3 Environmental predictions can be made at many timescales. Image adapted from: International Research Institute for Climate and Society (IRI). Weather forecasts are deterministic and have skill out to about 2 weeks. Seasonal-to-subseasonal (S2S) predictions are probabilistic, have modest skill, and can extend weather forecasts to bridge the gap to seasonal outlooks. Seasonal outlooks are probabilistic predictions that can go out several months. Climate projections have the longest lead times but present coarse multidecadal averages

Model Improvement and Assessment

A concerted effort to improve prediction skill along the weather-climate continuum is underway within the global Earth science research community. Within the United States, the NOAA is currently working to improve its Climate Forecast System (CFS) which is the operational model used to prepare climate outlooks from lead times of 2 weeks and beyond. At present, though the CFS produces a large number of environmental variables as output, only a small number are developed into tailored products for general use, such as precipitation and temperature outlooks. These outlooks are developed using not only output from the CFS but also empirical and statistical tools, consideration of the state of major climate modes including ENSO and MJO, and forecaster judgment.

The temperature outlooks, particularly within the S2S timescale, have improved greatly over time as a result of investments in observing systems, improved understanding, modeling, and infrastructure. As is shown in Fig. 1.4, there are various scores and metrics used to ascertain the skill of a prediction. The Heidke skill score (HSS) is one such metric, and it is used to quantify how much better a prediction

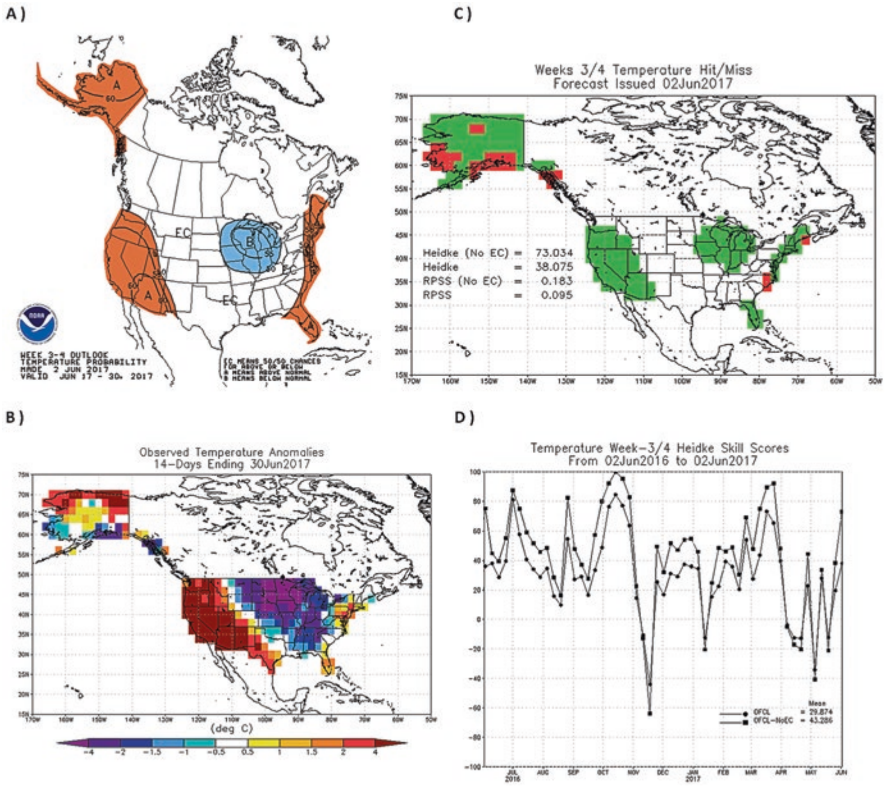

Fig. 1.4 New seasonal-to-subseasonal prediction products from NOAA's Climate Prediction Center. Panel (**a**) is an operational prediction released on 2 June 2017 for the period from 17 to 30 June; it shows a 50–60% likelihood that the Southwestern United States would experience above-average temperatures, with similar conditions possible along the East Coast and with a 50–55% chance that the Great Lakes region would experience lower temperatures. Panel (**b**) shows post hoc observed temperature anomalies for the same period, and panel (**c**) shows successful predictions in green. Panel (**d**) shows a running year-long Heidke skill score for the level of skill demonstrated by these operational predictions. Any value above 0 indicates more skill than randomly guessing, and a score of 100 indicates a perfect prediction

was than random chance. Any skill score over 0 is better than a random guess, and a score of 100 is a perfect prediction. With only some exceptions and understanding the caveat that skill is known to vary by time of year, the long-run skill of CPC's S2S predictions demonstrated in Fig. 1.4d is fair to good. An example of the product at a moment in time (Fig. 1.4a), compared to the observed temperature over the same period (Fig. 1.4b), leads to the resulting hit/miss ratio (Fig. 1.4c) for a prediction that was one of the recent bests. This product has been operational for a short period of time and will continue to improve.

The other environmental metrics of interest in athletics, occupational, and military settings, such as wet-bulb globe temperature (WBGT), will require more complicated modeling. Skillful prediction of the additional components needed to compute WBGT – humidity, insolation (or cloud cover), and wind speed – is currently limited to the weather timescale (1–2 weeks), which limits the prediction timescale of WBGT to this time window as well.

Looking Forward

As the US and global research communities push toward increasingly more skillful, seamless prediction of the environmental variables that are essential to heat wave early warning, initiatives to inform the environmental science research agenda and to integrate these climate services into decision-making processes along with health and other information are being developed and implemented.

Within the United States, the CDC and NOAA have launched the National Integrated Heat Health Information System (NIHHIS, pronounced [nīhis]). NIHHIS is a system applying meteorological, climate, and health information to support and inform decision-making by practitioners who reduce heat health risk and respond to save lives and livelihoods during heat waves. NIHHIS now officially includes several other US agencies, nonfederal partners, and a growing set of regional pilots across North America, which were created to understand the local context of extreme heat. These local pilots define the demand for information among decision-makers as diverse as architects, epidemiologists, and athletic directors. Information needs, risk tolerances, and lead times may all vary across disciplines and locations, and NIHHIS is using its regional pilots to characterize these needs to both inform research priorities and to develop climate services to support decisions.

Similar efforts are underway around the world, with many countries developing approaches to reduce heat risk taking the forms of information systems, early warning systems, or heat health action plans. Early warning systems often, but not always, are more narrowly scoped to the weather timescale, while heat health action plans document public heat alert trigger thresholds and the roles and responsibilities for responding to a heat alert when triggered. The approaches to addressing heat risk around the world are incredibly diverse, however, and often not well connected across national or even sub-national boundaries. As a result, a joint initiative between the World Health Organization/World Meteorological Organization (WHO/WMO) Collaborating Center and NOAA, called the Global Heat Health Information Network (GHHIN, pronounced [jin]), was formed to interconnect these efforts, so they might be advanced together. GHHIN has quickly grown to include additional institutional members from universities, NGOs, and government agencies in Germany, England, the United States, as well as other nations.

GHHIN and NIHHIS represent only a small sample of the government-driven efforts to address heat risk, but countless initiatives at the organizational, municipal, county, and state level are also being carried out. But one example of these efforts can be found when considering the upcoming Summer Olympics, which will be held in Tokyo, Japan in 2020. These games will occur at the height of summer heat, which can achieve temperatures over 35 °C in Tokyo [44]. In preparation, officials are actively taking interventions at a number of timescales, from planting trees to reduce the urban heat island effect to installing real-time monitors for fine-scale predictions of heat during events. These monitors will compliment Japan's existing heat early warning capability, which is administered by the Japan Meteorological Agency.

Though the climate system is warming and exacerbating conditions that can lead to heat-related illness, interventions and integrated information systems such as these can reduce the occurrence of such illnesses. If the aggressive risk reduction approach being taken by Japan can serve as an example for Olympic preparations for games to come, perhaps the worst prognostications that such events will no longer be able to be held in their current form in some cities will not come to pass. The subsequent chapters in this book will go further into the impact of heat stress on human physiology and elucidate how the meteorological and climate predictions and environmental monitoring are infused in current heat risk mitigation practices in public, occupational, military, and athletic sectors. Together, a robust understanding of the Earth system, accurate and timely predictions of extreme heat, and implementation of early and aggressive actions to reduce heat risk on human health can reduce the future incidence of heat-related illness and death.

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Chapter 2
Human Physiology in the Heat

Luke N. Belval and Ollie Jay

Abstract Safety and performance during exercise and physical activity in the heat are limited by the human body's physiological ability to balance heat gain and heat loss. Circumstances where heat gain from internal or external sources outweighs the ability to dissipate it can lead to dangerous increases in body temperature. Humans possess an ability to adapt to exercise in warm environments and minimize the deleterious effects through heat acclimatization. In situations where human physiology cannot overcome thermal challenges, exertional heat illnesses can manifest. These exertional heat illnesses can range from relatively benign to potentially fatal when left untreated. Technologies, techniques, and strategies to mitigate the consequences of exercise in warm environments should consider the existing physiological mechanisms to successfully promote health and maximize performance.

Introduction

From an evolutionary perspective, humans' ability to adapt to the thermal environment has allowed our species to thrive. The mechanisms that allowed for persistence hunting, the practice of hunting animals much larger and faster than humans by out-enduring them, have greatly shaped our physiology [1]. While this physiology allows us to succeed where other species may fail, thermal environments still exist that humans cannot overcome. Whether it is an internal or external limit, the human body can be restricted by the amount of heat it is able to dissipate. By understanding these limits, we can identify strategies and technologies to further human capabilities for exercising in hot environments.

L. N. Belval (✉)
Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, CT, USA
e-mail: luke.belval@uconn.edu

O. Jay
University of Sydney, Lidcombe, NSW, Australia

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This chapter will cover the biophysical and physiological mechanisms the human body employs for heat gain and dissipation. This examination of heat balance is fundamental to the understanding of the thermoregulatory challenges faced by athletes, laborers, and war fighters. We will also examine how the body adapts to thermal environments over time through heat acclimatization, a powerful tool in prevention and performance enhancement. Finally, we will discuss the dysfunctions of the thermoregulatory system and their manifestations as exertional heat illnesses.

Human Heat Balance

From a fundamental perspective, critical elevations in human body temperature (hyperthermia) arise from a sustained inability to balance the amount of heat generated from internal metabolic processes with a sufficient amount of heat dissipation from the skin surface to the surrounding environment.

In its simplest form, the human heat balance equation (Eq. 2.1) states that in order to prevent the storage of heat energy inside the body (i.e., $S = 0$) of zero, the rate of metabolic heat production (H_{prod}) must be offset by an equal rate of combined heat loss (H_{loss}), which is almost exclusively derived from heat transfer pathways at the skin surface:

$$H_{prod} = H_{loss} \pm S \tag{2.1}$$

To obtain a better understanding of the various physiological and biophysical mechanisms that lead to hyperthermia, H_{prod} and H_{loss} can be broken down into the following principal components.

Metabolic Heat Production

By definition, H_{prod} is the difference between metabolic energy expenditure (M) and the amount of this energy that is converted into mechanical work (W). As a rule, humans are very inefficient at this conversion, typically resulting in a high ratio of M to W (>3:1). Cycling is the most mechanically efficient activity with 30% of M used to create W [2] and the remaining ~70% liberated as heat energy inside the body that must subsequently be transferred to the skin surface and dissipated to prevent an increase in S. At the other end of the efficiency spectrum is running on flat ground, which creates approximately zero net external work as the propulsion and breaking forces of gait yield equivalent positive and negative work [3]. As such, all metabolic energy during running on a flat surface is released as heat (i.e., $H_{prod} = M$). The elevation in M during exercise is mainly determined by the rate at which oxygen is consumed (VO_2) with every 1 L of VO_2 per minute yielding approximately 21 kJ of energy per minute. It follows that activities requiring a greater VO_2 result in a higher H_{prod}. For example, military tasks such as intermittent marching for 3 h with standard combat gear and weapon (total load, ~25 kg) and digging soft sandy ground to a depth of 1 m at a self-regulated pace result in a VO_2 of 1.7–1.8 L·min^{-1} [4], which is equivalent to a M of 36–38 kJ·min^{-1}. In a sports-related context, elite marathon runners sustain VO_2 levels of ~3.5 L·min^{-1} and M of ~74 kJ·min^{-1} [5].

Combined Heat Loss

Heat transfer at the skin surface to the surrounding environment can be split into two primary subcomponents: dry heat transfer (H_{dry}) and evaporative heat loss (H_{evap}). As such, the simplest form of the human heat balance equation can now be reexpressed as:

$$H_{prod} = \left(H_{dry} + H_{evap}\right) \pm S \tag{2.2}$$

While H_{evap} almost exclusively arises from evaporation of sweat from the skin surface, H_{dry} occurs by a combination of three different pathways – conduction (K), convection (C), and radiation (R):

$$H_{prod} = \left(C \pm R \pm K\right) + H_{evap} \pm S \tag{2.3}$$

Dry Heat Transfer: K is the transfer of heat from direct contact with a solid surface and under most circumstances is considered negligible from a whole-body heat balance perspective [6]. C is the transfer of heat promoted by the movement of a fluid, usually air, and is proportional to (i) the difference in temperature between the air and the skin and (ii) the rate at which air passes across the skin [7]. Skin temperature is typically ~35°C in a fully vasodilated state; therefore when air temperature exceeds this value, convective heat loss becomes heat gain, contributing to an increase in S. R is the transfer of electromagnetic energy from a relatively warm body to a cooler one. In outdoor environments, the sun is usually the greatest source of radiant energy. R is proportional to the temperature difference between mean radiant temperature, derived using a black globe thermometer and air velocity, and mean skin temperature. R is also determined by the effective radiative area of the body and is altered by posture and the orientation of the person relative to the radiation source. R often serves as an environmental heat gain when skin temperature is lower than mean radiant temperature, which in the summertime can be more than 10°C greater than ambient air temperature (measured in the shade).

Evaporative Heat Loss: The rate of evaporation from the skin surface is determined by the absolute water vapor pressure difference between the skin (primarily dictated by eccrine sweating) and air. For the purposes of whole-body heat balance, negative evaporative heat loss (i.e., condensation) is negligible. The evaporation of sweat is also promoted by an increased rate of air flow across the skin, which can arise from a combination of self-generated (from physical movement) and ambient air flow. Humans have a finite capacity for evaporative heat loss, with the maximum rate of evaporation (E_{max}) of a person determined by the fraction of body surface area that they can physiologically cover with sweat. This relative value is called "skin wettedness" (ω) [8] and ranges from a minimum value of 0.06 at rest with no thermoregulatory sweating to a maximum value with maximal sweating of ~0.75–0.85 for an unacclimated person and 1.00 for a fully heat acclimated person [6]. As ω rises toward these maximal values, the volume of sweat that evaporates relative to what is produced (i.e., sweating efficiency) decreases due to a limited environmental humidity gradient [8]. For every gram of sweat that does evaporate from the skin, 2.426 kJ of latent heat is liberated from the body [9]. The same sweat rate in a humid environment will therefore result in a lower evaporative heat loss because a greater proportion of sweat drips off the body before evaporating. For example, a whole-body sweat rate of 15 g·min^{-1} in an arid (dry) climate yielding a sweating efficiency of 90% will result in a H_{evap} of 32.8 kJ·min^{-1}, whereas the same sweat rate in a tropical (humid) environment with a sweating efficiency of 50% will result in a H_{evap} of 18.2 kJ·min^{-1}.

For all heat loss components (dry and evaporative), the absolute amount of heat transfer for a particular person is determined by body surface area. That is, a person with a larger surface area, which is predominantly determined by height and weight, will have a greater absolute heat loss. Clothing also heavily influences dry and evaporative heat losses. In a cold environment, ensembles with large amounts of insulation limit convective and radiative heat loss, whereas in an environment with a high radiant heat load, these properties protect the wearer from excessive environmental heat gain and potential burn injuries. Clothing with a high evaporative resistance (e.g., nuclear, biological, chemical suits or American football pads) greatly reduces E_{max} under a fixed set of environmental conditions by slowing the rate at which water vapor passes through the clothing and can substantially add physiological heat strain, particularly when such clothing is worn during physical activity.

Body Heat Storage

If at any time H_{prod} is not matched by an equal amount of H_{loss} (i.e., the sum of H_{dry} and H_{evap}), a change in body heat storage (S) will occur. An accumulation of heat energy inside the body (i.e., a positive S value), as is often observed during exercise/physical activity in a hot environment especially when clothing with a high evaporative resistance is worn, results in a rise in internal body temperature. For a given person, a greater heat storage leads to a greater rise in internal body temperature; however, between people of different body sizes, a smaller individual will get hotter for a given S value [10]. For example, for a person weighing 65 kg, an S value of +320 kJ would cause a 1.4 °C rise in mean body temperature, whereas the same S

value for 95 kg person would only lead to a rise in mean body temperature of 0.95°C. The average specific heat capacity of the body (C_p) is typically assumed to be 3.47 kJ·kg^{-1}·°C^{-1}; however, because the C_p of fat is lower (2.97 kJ·kg^{-1}·°C^{-1}) than the muscle (3.64 kJ·kg^{-1}·°C^{-1}), these elevations in mean body temperature for a fixed S should be altered by the amount of body fat. While large differences in body fat (~20%) do seem to result in slightly higher rises in core temperature (~0.2°C), adipose tissue does not seem to interfere with the capacity to dissipate heat [11]. Indeed, while fat does serve as an insulator during cold exposure, a pronounced peripheral vasodilation of the skin during exercise and heat exposure renders these insulating properties ineffectual, and sweating capacity does not seem to be altered by the presence of body fat. This primarily can be attributed to the superficial nature of skin blood vessels relative to adipose tissue. Of note, however, is that extremely large individuals with a body surface area of >2.5 m^2 may exhibit reductions in ω_{max} and, therefore, reduction in E_{max} secondary to a lower sweat gland density [12].

Compensable and Uncompensable Heat Stress

During exercise/physical activity, H_{loss} is augmented to balance elevations in H_{prod}, primarily through increases in eccrine sweating and thus H_{evap}. The amount of evaporative heat loss required (E_{req}) to attain an S of 0 (i.e., heat balance) is determined by:

$$E_{req} = H_{prod} - \left(C \pm R \pm K\right) \tag{2.4}$$

If E_{req} is possible, the imbalance between H_{prod} and H_{loss} is transient, and core temperature will rise but then reach an elevated plateau (compensable heat stress; Fig. 2.1a–b). However, if E_{req} is greater than E_{max}, either because H_{prod} is very high or the prevailing climate and/or clothing worn does not permit a sufficiently high rate of evaporation, (i) H_{loss} fails to match H_{prod}, (ii) S continually occurs, and (iii) internal body temperature rises uncontrollably (i.e., uncompensable heat stress; Fig. 2.1c–d). This latter condition can prove to be potentially dangerous as eventually critically high levels of core temperature can be reached and the risk of heat-related illnesses rapidly develops.

Heat Acclimatization

Humans possess a profound ability to adapt to hot environments, greater than any other environment they encounter. In some circumstances, situations that create uncompensable heat stress can become compensable through repeated exposure. These physiological changes, labeled heat acclimatization, greatly increase the

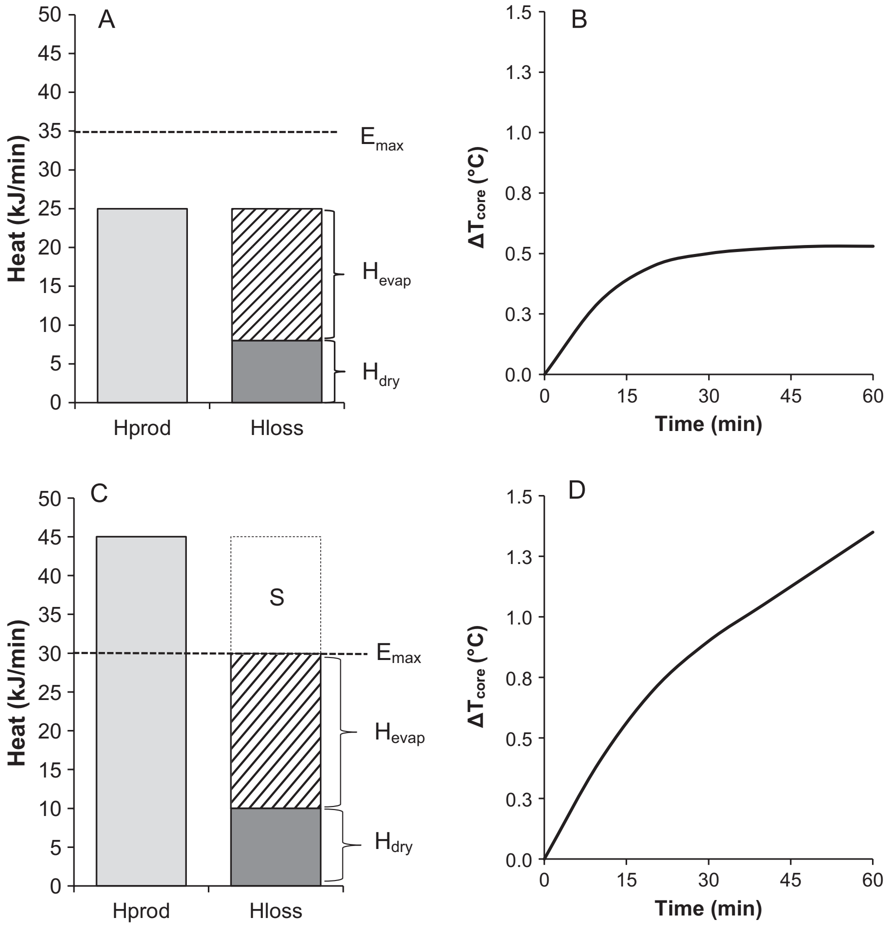

Fig. 2.1 (**a**–**d**) Examples of human heat balance status (left) and concomitant changes in core body temperature (right) during compensable (top) and uncompensable (bottom) heat stress scenarios

capacity for exercise in the heat [13]. The magnitude of heat acclimatization is so great that a lack of heat acclimatization is largely considered to be a risk factor for exertional heat illnesses.

The adaptations associated with heat acclimatization occur primarily in the cardiovascular and thermoregulatory systems through 10–14 days of repeated exercise heat stress [14]. It is also possible to induce these processes from simulated hot environments or clothing and equipment that inhibits H_{loss}; however, in these artificial situations, the changes are labeled heat acclimation [15].

Cardiovascular Changes

During exercise in the heat, the body must maintain adequate perfusion to the exercising muscles, the visceral organs, the brain, and the skin vasculature. Over the course prolonged exercise, where sweat fluid losses decrease the total plasma volume available, cardiovascular drift occurs as the body is not able to provide adequate perfusion to all of the above locations [16]. Cardiovascular drift occurs through a compensatory increase in heart rate to maintain cardiac output despite a decreasing stroke volume.

The cardiovascular adaptations that occur during heat acclimatization directly combat cardiovascular drift. Aldosterone and arginine vasopressin-induced fluid retention lead to an increase in total body water of 2–3 L (5–7%) [17]. Net increases in total intravascular protein facilitate fluid movement from the interstitial to the intravascular space, resulting in plasma volume expansion of 4–15% [17]. Therefore, to counteract the changes typically seen in cardiovascular drift, heart rate decreases via decreased myocardial autonomic tone and stroke volume increases to maintain a constant cardiac output at a given workload.

Thermoregulatory Changes

While the cardiovascular changes that occur through heat acclimatization allow for increased work output, they do not directly support an increased ability to maintain heat balance during exercise heat stress. Heat acclimatization decreases resting internal body temperature, theoretically creating a greater capacity for S during exercise [18]. In addition, skin blood flow during exercise increases, supporting greater H_{dry} [17].

Chiefly, the changes that occur in the thermoregulatory system's effector organs, eccrine sweat glands, support a further H_{prod} and diminished H_{loss}. In total, acclimatized individuals have been shown to have H_{evap} increase by 11% [19]. Sweat glands not only begin excreting at lower internal body temperatures in heat acclimatized individuals (decreased sweat onset), they will also excrete more (increased sweat rate) at a faster rate (increase sweat sensitivity) [17].

While these changes in sweat onset, rate, and sensitivity increase the capability for the H_{evap}, it also increases the fluid losses from sweat and increases the rate of dehydration. To a certain extent, the relationship between thirst and fluid needs also improves to diminish this effect [17]. To prevent concurrent large losses of sweat electrolytes due to greater sweat excretion, eccrine sweat glands increase electrolyte absorption along with increased electrolyte reabsorption in the kidney [18].

Benefits of Heat Acclimatization Beyond Heat Stress

The ability to perform a given amount of exercise with less physiological strain is a hallmark sign of the successful completion heat acclimatization process. Furthermore, the nature of the adaptations induced by heat acclimatization lead to changes that benefit exercise performance in both warm and cold environments [13]. Improvements in VO_2 and cycling power at a fixed heart rate are commonly observed following heat acclimatization [17].

Heat Acclimatization Protocols

Many strategies exist to induce heat acclimatization, ranging from short-term high intensity programs [20] to passive programs that utilize a sauna or hot water immersion post-exercise [21]. The most commonly studied protocols involve 90–120 min of treadmill walking in a warm environment for 10–14 days [18].What remains consistent is that the thermoregulatory and cardiovascular system must be stressed in order for adaptations to occur [22]. Furthermore, heat acclimatization is not permanent; some intermittent exposure to exercise heat stress is required to maintain heat acclimatization status [19]. From an athletic standpoint, American football has developed some of the most comprehensive policies for heat acclimatization, wherein exercise duration, intensity, and equipment worn are all gradually phased in over the first 2 weeks of practice [23]. Similar concepts can be utilized across the physical activity spectrum to reduce heat stress and improve performance.

Exertional Heat Illnesses

As a manifestation of dysfunctions in the thermoregulatory system, exertional heat illnesses constrain the ability to perform physical activity or labor. Exertional heat stroke may be the only fatal heat illness; however, even minor conditions can limit the ability to successfully compete, operate, or work in warm environments. While exertional heat illnesses cover a wide spectrum of severities, they do not exist in a continuum. It is a commonly propagated myth that a more severe heat illness is predicated on the previous presences of less severe one (Table 2.1).

Table 2.1 Exertional heat illness prevention strategies and physiological processes they affect

Strategy	Physiological process
Increase frequency and duration of rest breaks	Increase H_{loss} Decrease rate of H_{prod}
Gradually increase exercise intensity and equipment	Increase H_{evap} through heat acclimatization
Identify supplements and drugs that affect thermoregulation, and limit their use	Decrease H_{prod} from thermogenic substances
Encourage adequate hydration	Maintain adequate skin perfusion for H_{dry}, and maximize H_{evap}
Limit exercise with febrile illness	Increase capacity for S
Improve physical fitness	Decrease relative H_{prod}
Modify activities based on environmental conditions	Decrease environmental H_{gain}

Abbreviations: H_{dry} dry heat transfer, H_{evap} evaporative heat loss, H_{gain} combined heat gain, H_{loss} combined heat loss, H_{prod} metabolic heat production, S body heat storage

Minor Heat Illnesses

The minor heat illnesses, heat edema and miliaria rubra, are not directly limiting to exercise in the heat but rather are caused by heat exposure. Heat edema is the inflammation of the extremities caused by pooling of fluid in the interstitial space [24]. As it is a relatively benign one of the only treatments is to remove the heat exposure.

Miliaria rubra, typically called a "heat rash" or "prickly heat," is the presence of small erythematous papules caused by clogged sweat glands [24]. This condition also corrects itself to a certain extent when the heat exposure is removed, but proper hygiene can help limit the recurrence. Since the sweat glands become clogged in miliaria rubra, H_{evap} may be diminished leading to an increased risk of more severe exertional heat illnesses.

Heat Cramps or Exercise-Induced Muscle Cramps

The current understanding of the etiology of muscular cramps indicates that heat exposure is not a primary cause of cramps during exercise. Rather, it appears that most cramps occur as a result of neural fatigue, which may be exacerbated by either the increased physiological demands of exercise in the heat or sweat electrolyte losses [25]. This type of muscular cramp typically appears in a localized, visible fashion and can be very painful. Most instance of cramping respond well to stretching and rest. Individuals who repeatedly cramp during exercise in warm environments should monitor their hydration and sodium intake as cramping may be indicative of a fluid or electrolyte imbalance [26].

Heat Syncope

Postural hypotension from either prolonged standing or a sudden of cessation of exercise in warm environments defines heat syncope. The condition is often exacerbated by dehydration, which further contributes to poor venous return [24]. Syncope that is not a collapse associated with a more serious exertional heat illness is typically rapidly reversed by placing the patient in Trendelenburg's position. This supine position with the feet elevated 15–30 degrees above the head coupled with fluid replacement allows for a normalization of central blood pressure and facilitates a rapid recovery [27].

Heat Exhaustion

Heat exhaustion is primarily a diagnosis by exclusion. Broadly defined as the inability to continue exercise in the heat, the fundamental cause of collapse from heat exhaustion is cardiovascular insufficiency [28]. The individual with heat exhaustion will exhibit an elevated body temperature, but will not have persistent central nervous system dysfunction. Care for heat exhaustion includes removing the patient from exercise and any heat. It may also be beneficial to provide some cooling [27]. In cases where patients do not rapidly improve, healthcare providers should evaluate for exertional heat stroke.

Exertional Heat Stroke

Exertional heat stroke is the most severe of the exertional heat illnesses and is a medical emergency. Contrasted to classical heat stroke, which normally occurs in individuals with compromised thermoregulatory systems during heat waves, exertional heat stroke is caused by exercise-induced hyperthermia. Most cases occur in a warm environment; however, cases have been reported in cooler conditions where sufficient exercise stress dangerously elevates internal body temperature.

The current understanding of exertional heat stroke pathophysiology is that hyperthermia induces leakage of endotoxin from the gastrointestinal tract into the systemic circulation, causing acute kidney and liver failure, rhabdomyolysis, and disseminated intravascular coagulation [29, 30]. Heat-shock proteins, chaperone molecules within the body, demonstrate a limited ability to minimize the damage for short durations of extreme hyperthermia [31].

The risk factors for exertional heat stroke can be dichotomized as either intrinsic, internal to the individual, or extrinsic, a factor imposed on the individual. Intrinsic risk factors can further be delineated as temporary or permanent. Poor fitness, febrile illness, and sleep deprivation are all risk factors that may preclude individuals from safely exercising in the heat until they are corrected [27, 32]. Meanwhile individuals with certain genetic factors (e.g., malignant hyperthermia), taking drugs or supplements that affect thermoregulation, or who are overweight should be closely monitored during periods of intense exercise [33, 34].

Extrinsic risk factors include both organizational and environmental components. From an organization standpoint, the risk of exertional heat stroke can be minimized by changing activities to parts of the day, providing more frequent and longer rest breaks and enacting heat acclimatization protocols [23, 27]. In most cases, the environmental risk factors for exertional heat stroke cannot be modified but rather monitored. Conditions with high ambient temperatures, high humidity, and direct sunlight exposure increase the likelihood of heat gain from the environment. Abnormally extreme conditions may require activity modification to allow for participants to safely complete their tasks [35].

The two pathognomonic criteria of exertional heat stroke are an internal body temperature greater than 40.5 °C and end organ dysfunction, typically manifesting as neuropsychiatric dysfunction [27]. A wide variety of conditions from concussion to hypoglycemia also display neuropsychiatric dysfunction, making an accurate assessment of body temperature crucial for exertional heat stroke diagnosis. Furthermore, some exertional heat stroke patients have a lucid interval where central nervous system dysfunction is not immediately obvious. The only field expedient measure of body temperature that has been validated for exercise-induced hyperthermia and exertional heat stroke diagnosis is a rectal temperature [36–39]. Other temperature modalities may falsely indicate normothermia, delaying appropriate treatment.

Survival from exertional heat stroke requires that the extreme state of hyperthermia is reversed before irreversible organ damage occurs. Inappropriate, ineffective, or absent treatment is deadly for the exertional heat stroke patient [40]. As stated above, the body has a limited ability to tolerate extreme hyperthermia; optimal prognoses from exertional heat stroke occur when the body temperature is reduced shortly after collapse [41]. The most effective treatment for exertional heat stroke has been found to be cold-water immersion [42]. When cold-water immersion is initiated shortly after the patient collapses, survival is likely [43]. In more remote situations, tarp-assisted cooling may be used as an adjunct for cold-water immersion [44, 45]. Ice packs in the axillary and groin or misting water with fans are not effective cooling modalities for an exertional heat stroke patient [46].

Conclusion

In summary, human physiology dictates the limits of safety and performance during exercise in the heat. Situations where excessive heat gain or limited heat loss create uncompensable heat stress can lead to performance decrements or exertional heat illnesses. Overall, the strategies to mitigate heat stress for athletes, laborers, and war fighters should focus on these physiological limitations while utilizing the body's own adaptations to maximize safety and optimize performance in the heat (Table 2.1).

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Chapter 3
Heat Exposure and the General Public: Health Impacts, Risk Communication, and Mitigation Measures

Andrew J. Grundstein and Castle A. Williams

Abstract Extreme heat is the number one cause for weather-related death and poses a serious public health problem. Sensitivity to heat, however, may vary based on sociodemographic factors such as age, health status, availability of air-conditioning, and/or one's degree of exposure to oppressive heat. To mitigate these heat hazards, various governmental agencies such as the National Weather Service have developed heat-health warning systems to communicate the dangers of heat *and* inform individuals of the appropriate actions to take during extreme heat conditions. Studies of these warning systems suggest that these heat-related warnings often fail to motivate behavior change, with individual differences in risk perception and inconsistent messaging between warning systems being two prominent factors in the literature. To gain greater insight into decision-making processes and behavior change associated with heat-health warning systems, future research should utilize social and behavioral theoretical frameworks.

Introduction

Extreme heat poses a serious public health problem. In the USA, for instance, more people die on average each year from extreme heat than from other weather-related hazards such as hurricanes, lightning, tornadoes, and floods [69]. Heat waves or strings of unusually oppressive days can lead to dramatic health impacts and stresses on the health-care infrastructure. Dramatic examples include the 2003 European and 2010 Russian heat waves that killed over 50,000 people, a 2015 heat wave in India that killed over 2000 people, and a 1980 heat wave in the USA that is estimated to have killed over 10,000 people [25, 82, 83, 91]. Despite this, heat waves

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A. J. Grundstein (✉) · C. A. Williams
The University of Georgia, Athens, GA, USA
e-mail: andrewg@uga.edu

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have been described as "silent killers" because they do not lead to visibly obvious destruction like natural disasters such as hurricanes or earthquakes [61]. This may contribute to a lack of awareness of the dangers of extreme heat and inadequate preparedness measures in many locations [61]. A better understanding of the impacts of heat on human health, including geographic and sociodemographic differences in vulnerabilities, will aid in developing effective heat safety policies.

Heat Exposure and Health

The relationships between exposure to extreme heat and increases in both mortality and morbidity resulting from cardiovascular disease, respiratory disease, renal diseases, and heat-related causes have been well established (e.g., [9, 42, 47, 51, 54, 57, 72, 73, 93, 103]). Morbidity and mortality rates are associated with the air temperature in a nonlinear relationship that is illustrated as U-, V-, or J-shaped curves (e.g., [22, 57–59, 107]). The thresholds for increasing morbidity and mortality vary geographically where cities in cooler climates tend to have lower minimum mortality thresholds than those in warmer climates (e.g., [4, 22, 46]) due to physical acclimatization and behavioral adaptations such as greater prevalence of having air-conditioners in hotter climates. Also, thresholds for increased mortality and morbidity may vary by the particular disease. For instance, Kovats et al. [50] found that, in London, hospital admissions for renal patients increased at 18 °C but at > 23 °C for respiratory diseases.

A variety of sociodemographic factors have been documented to make some populations more sensitive to heat exposure and therefore vulnerable. The elderly has been found to be particularly sensitive to extreme heat with both greater hospital admission rates and greater mortality during heat waves compared with younger populations (e.g., [21, 27, 49, 71], Stafoggia et al. [94]). Some studies have also indicated that children may be more sensitive to heat as well, particularly in relation to exertional heat illnesses (e.g., [7, 28, 51]). Vulnerability to heat stress is increased for people with pre-existing health conditions such as cardiovascular disease, diabetes, renal disease, obesity, and neurologic or psychiatric diseases. Patients who are taking certain medications that impair sweating are also more vulnerable due to their reduced ability to thermoregulate during extreme heat stress [61, 89]. Some literature suggests that educational attainment may be a useful indicator for socioeconomic status with more educated members of the community having greater wealth and better living conditions. As such, heat-related mortality has been observed to be greater for those with less education (e.g., [65, 74]). There have been mixed results regarding differences in heat vulnerability by race. Some US studies indicate an increased risk for African-Americans compared with Caucasians (e.g., [32, 51, 64, 88]), while others have found no significant difference (e.g., [31, 32, 62, 75]). Discrepancies among studies may occur because many of these studies did not control for other concurrent vulnerability factors such as income, physical health, air-conditioner ownership, or residing in hotter areas with little green space [32].

Living conditions can also modify heat vulnerability. Air-conditioning is a powerful protective factor, with central air-conditioning having a stronger protective factor than room air-conditioning (e.g., [16, 17, 22, 71, 74, 89]). The increasing prevalence of air-conditioning has also been linked in part to increased population resilience over time to heat in cities across the USA [6, 13, 23]. Yet, higher air-conditioning prevalence does not always imply greater usage as the high cost of using air-conditioning systems may be prohibitive for some members of the population [90]. Beyond air-conditioning, indoor temperature and humidity may vary among households even with the same outdoor weather conditions based on fixed attributes like building type and window placement as well as behavioral factors such as cooking and bathing [77]. Additionally, living arrangements may influence vulnerability. Studies of the 1995 and 1999 Chicago heat waves have also shown people living alone are at greater risk for heat-related health impacts (e.g., [48, 71, 89]). Investigations using "single," "widowed," or "divorced" as proxy's for living alone support these findings of greater mortality for heat among those living alone compared to those who are married (e.g., [27, 94]). However, other studies in the UK and Italy do not indicate greater deaths from heat for those living alone (e.g., [26, 36]).

Finally, differences in exposure to oppressive weather may influence risk for heat-related illnesses. Many studies have identified the importance of land cover in affecting microclimates. Urbanized locations often have temperatures that exceed surrounding rural environments. These "urban heat islands" (UHIs) are due to a combination of anthropogenic heat emissions from industry, vehicles, and air-conditioning systems, reduced evaporative cooling due to less vegetation, and heat-absorbing surfaces [24]. The severity of heat waves may be magnified in such urban environments and lead to an increase in heat-related fatalities (e.g., [43, 56, 95, 96, 108]). Even within cities, however, there can be diverse degrees of heat exposure based on settlement density and amount of green space. In the Phoenix metropolitan area, for instance, distinct variations in thermal stress were observed among eight neighborhoods that were studied [37]. Importantly, while urban residents may have greater heat exposure due to the UHI effect, heat-health relationships cannot be viewed in isolation from other factors. Personal heat exposure within given geographic areas may vary greatly among individuals based on occupation. For example, office workers may spend more time in climate-controlled environments than others such as outdoor laborers [51, 52]. Some studies also indicate greater vulnerability to heat in rural areas which may be relatively cooler but whose residents may lack air-conditioning or have poorer overall health (e.g., [30, 41, 92]).

Given that many physical, environmental, sociodemographic, and health factors may influence sensitivity to heat, some authors have developed heat vulnerability indices (HVIs) that blend multiple variables (e.g., [5, 18, 38, 44, 78, 105]). HVIs are designed to identify heat vulnerability geographically to aid in focusing intervention strategies to heat-sensitive communities [105]. These indices consider multiple variables that have been identified in epidemiological literature as associated with heat illnesses, including sociodemographic, health, and land cover data [5]. An HVI by Reid et al. [78], for instance, employs ten variables associated with poverty, educational attainment, race, living circumstances, age, green space, diabetes prevalence, and air-conditioning. Using health data, several of these HVIs have been shown to be effective indicators of observed variations in morbidity and mortality in different cities (e.g., [20, 38, 62, 79, 106]). Maier et al. [63], for instance, examined heat-related mortality in Georgia, USA, and found that a higher HVI was associated with increased mortality rates on oppressive days relative to non-oppressive days. Counties with an HVI of 12, for example, had a 4.6% (relative risk [RR], 1.0458) increase in mortality on oppressive days compared with a 7.7% (RR 1.0767) increase for areas with an HVI of 15.

While these HVIs are promising, Wolf et al. [105] observed a gap between the science of vulnerability mapping and the implementation of risk prevention strategies. A major factor that limits the application of HVIs is the lack of studies that assesses the reliability of the HVIs and their ability to account for uncertainty in the estimates. Wolf et al. [105] note that there are multiple factors that may influence the magnitude of the HVI, including the size of the dataset, measurement errors in input data, how the data are normalized and transformed in the analysis, and how the variables are weighted in the HVI. Also, many of the HVIs do not incorporate information on microclimates and qualities like social cohesion that may be important when considering heat sensitivity. At present, HVIs have not been widely employed in preventative actions such as heat-health warning systems, as described in the next section [105]. Ultimately, more collaboration between developers of HVIs and policy-makers is needed before HVIs can be effectively employed in practice.

Heat-Health Warning Systems

To combat the morbidity and mortality associated with extreme heat events, cities across the USA, Canada, and the UK sought a policy-driven solution known as a heat-health warning system. Heat-health warning systems (HHWS) are plans that have been implemented at the local level that explicitly illustrate the societal impacts of excessive heat, in order to mitigate the dangers and harms of extreme temperatures [97]. Although HHWS differ between cities, they all address three major concerns in the scope of extreme heat events: (1) the monitoring of weather forecasts to determine the point at which these conditions become dangerous to residents (meteorological component), (2) releasing heat-related warnings and alerts to members of the public (communication component), and (3) promoting public health activities and recommended actions to prevent injury or death (public health component; [87]). The adoption of HHWS has been well received in the USA since their creation in 2005 [68]. Currently, 28 weather forecast offices (WFOs) across the country utilize these systems [39], with most of them occurring in urban areas with populations of 500,000 or more [68]. Since their inception, the HHWS literature has assessed several metropolitan cities (e.g., Phoenix, New York City, Philadelphia) to both evaluate and encourage the development of HHWS in other urban areas (for a review see [40, 45, 84, 97, 104]).

Within the USA, the National Weather Service (NWS) uses three distinct heat-related alerts to warn the general public: the excessive heat watch, heat advisory,

Table 3.1 Formal definitions of the National Weather Service (NWS) heat alerts from the NWS Glossary (NWS [70])

NWS heat alert	Definition
Excessive heat warning	[a]Heat index (HI) values forecast to meet or exceed locally defined warning criteria for at least 2 days (typical values: (1) maximum daytime HI ≥ 105 °F in the north to 110 °F in the south and (2) minimum nighttime lows ≥75 °F
Heat advisory	[a]Heat index (HI) values forecast to meet or exceed locally defined warning criteria for 1 to 2 days (typical values: (1) maximum daytime HI ≥ 100 °F in the north to 105 °F in the south and (2) minimum nighttime lows ≥ 75 °F
Excessive heat watch	Conditions are favorable for an excessive heat event to meet or exceed local excessive heat warning criteria in the next 24–72 h

[a]Note: The excessive heat warning/heat advisory criteria are highly variable in different parts of the country due to climate variability and the effect of excessive heat on the local population. Weather forecast offices are strongly encouraged to develop local criteria in cooperation with local emergency and health officials and/or utilize heat-health warning systems based on scientific research

and excessive heat warning (Table 3.1; [70]). Each alert is issued if heat index temperatures are forecast to meet or exceed a specific threshold and usually encompass temporal criteria (i.e., 2+ days) as these events often persist across multiple days. Due to geographic, climatological, and local factors, the suite of excessive heat alerts is designed with varying issuance criteria unique to each HHWS and WFO county warning area (CWA; [39, 70]). Similar to other weather warnings, these heat alerts are issued using an orthogonal warning system that has been established by NOAA. For example, if an extreme heat event is forecast for a given area (e.g., Philadelphia), then an excessive heat watch may be issued followed by a possible upgrade (i.e., an increase in certainty) to either a heat advisory or excessive heat warning depending on the predicted overall impact and heat index temperature criteria used in that area [39, 70].

While these heat-related warnings are consistently issued by the NWS, it is important to question whether they are being received, processed, *and* acted upon by members of the general public. According to several publications examining risk communication in the heat-health domain, awareness of heat-related warnings (i.e., excessive heat warnings and heat advisories) was almost universal across all studies [8, 45, 55, 90]. However, Bassil and Cole [8] and Lane [55] observed a lower-level of awareness among the "most vulnerable" participants in their sample, such as the elderly (75+) and less educated. Even though a majority of individuals reported receiving heat-related alerts, the studies by Sheridan [90] and Kalkstein and Sheridan [45] reveal that knowledge of the details of the heat-related warnings, specifically the protective action statements, showed less retention. Further, very few people indicated that they had modified their behavior due to an extreme heat event or receiving a heat-related alert [90]. As a result, there appears to be a disconnect between receiving and acting upon the heat-related alert. The heat-health literature provides some insight into this dissociation and offers two areas of potential misinterpretation when receiving heat-related messages and warnings: the co-occurrence of air quality alerts and the inconsistency of messaging within the HHWS.

Concurrent health warnings for separate hazards such as air quality alerts issued during a heat wave may cause confusion about appropriate actions. Sheridan [90] and Bassil and Cole [8] observed confusion among respondents between protective actions of heat and air pollution, and the overlapping of air quality and excessive heat warnings caused difficulty interpreting the heat-related public health message. Thus, organizations issuing these alerts must strive to coordinate their messaging and effectively communicate the most appropriate response during the co-occurrence of smog days and extreme heat events [8, 12]. A second area of confusion that is often described in the literature is the inconsistency of communicative alerts issued within a HHWS. For example, during an extreme heat event, the NWS may issue an "excessive heat warning," while the city's public health department issues a "heat alert" [90]. Both of these warnings possess different thresholds for issuance; however, they may be consistent in the protective actions they are communicating. Misunderstandings may also arise in the dissemination of the message to the general public. What is the difference between a "heat alert" and an "excessive heat warning"? Which is worse, and how should I respond? Recently, local emergency management agencies, public health officials, broadcast meteorologists, and other partners that constitute a HHWS "indicated the desire for simpler [NWS heat product] definitions and a clear connection to the protective actions that should be taken" [39]. Therefore, HHWS should consider using uniform warning paradigms for meteorological and health impacts to promote consistency in the communication of relevant heat information and protective actions. Lastly, this disconnect between receiving and acting on a heat-related alert may simply be due to the lack of belief or recognition in their vulnerability to extreme heat.

An individual's perceived risk is an important factor that determines behavior [90]. Only two heat-health studies have examined risk perception and/or perceived vulnerability from an all-encompassing public perspective and have generally found that most of the respondents believed they were vulnerable to extreme heat events [2, 3]. However, when focusing specifically on vulnerable populations (i.e., elderly, children, homeless individuals), there was large variability in their depiction of risk perception with many failing to identify themselves as a member of that vulnerable population ([1, 10, 45, 84, 90, 102]). For example, Abrahamson [1] interviewed elderly respondents that would be classified as "vulnerable" in the UK and found that "most respondents did not perceive themselves to be old and often pointed out that age is a relative concept… and that increasing chronological age should not be assumed to be directly associated with increasing vulnerability." Therefore, these elderly individuals would likely not respond to a message targeted specifically at vulnerable, elderly populations and would fail to act in the event of extreme heat.

Another example of disproportionate perceived risk is observed when assessing parents/caregivers and their child's vulnerability to heat. A recent study by Williams and Grundstein [102] interviewed parents/caregivers about forgetting children in hot cars and found that a majority (52%) of parents/caregivers denied being able to forget their child in the backseat, indicating low perceived risk. The participants described what they perceived as a vulnerable category of parents/caregivers who were "unfit" or possessed various "lifestyle" factors (e.g., low-income status, a single parent, and/or a working parent) that increased their risk of forgetting a child. By creating this conception of vulnerability, the parents/caregivers in the study were able to dissociate themselves from the risk and distance themselves from this vulnerable identity. In a similar vein, a study by Benmarhnia et al. [10] interviewed participants with schizophrenia and drug/alcohol addiction to better understand how the current heat-health policies could be better adapted to consider these specific vulnerable individuals. Interestingly, an overwhelming majority of individuals diagnosed with schizophrenia acknowledged their vulnerability to extreme heat; however, those facing addiction identified as less vulnerable in comparison to the public [10]. As a result of this variability in heat risk perception, it is imperative that future HHWS explore two messaging strategies: (1) create more generalized messaging (e.g., this can happen to anyone) and protective actions (e.g., avoid strenuous activity outside) that can widen the threshold for perceived risk and/or (2) clearly communicate specific characteristics of vulnerable populations in future messaging (e.g., avoid using "elderly" and instead identify the vulnerable population as "people 65 years and older").

Finally, in the event that an individual receives a heat-related message and perceives themselves to be "at risk" or "vulnerable," it is important to also provide information on recommended protective actions or behaviors that an individual can perform. Currently, HHWS across the country have developed and implemented policies that disseminate and activate these protective actions during extreme heat. For example, cities convert public shelters into cooling centers for residents without air-conditioning or if the city loses power during an extended heat event [11]. Other activated protective measures include a designated help line with heat-related information and safety tips (e.g., "Heatline"), health messaging providing injury prevention behaviors (i.e., avoid strenuous outdoor activity), and encouraging individuals to check on their friends, family, and neighbors (e.g., the buddy system; [90]).

In assessing these protective action statements, it is important to consider willingness to perform these behaviors, as well as any barriers that might limit an individual's ability to follow the recommendations. Many cities, for instance, will provide cooling centers during periods of extremely hot weather. Yet, utilization of these facilities is often limited by several factors. The most frequently reported barrier is transportation to the cooling center or public shelter [84, 90]. However, more recently public transportation has become less of an issue for individuals in need of cooling centers [11]. Instead, many respondents, especially elderly individuals in larger metropolitan cities, reported concerns of crime and/or physical mobility issues (e.g., maneuvering downstairs) as reasons for not leaving their home or evacuating to a cooling center [55]. Other barriers include the perception of public shelters as being *only* for people experiencing homelessness [84], a lack of knowledge surrounding the existence of cooling centers and/or their location within a city [3], and not perceiving extreme temperatures as a relevant personal risk [11]. In addition to cooling centers, a study by Lane [55] examined extreme heat awareness and protective actions of New York City residents and found several barriers for air-conditioning use. While most elderly citizens owned an air-conditioner, "the majority report [ed] using air-conditioning either never or less than half the time during hot weather" [55]. When asked to describe the reasoning behind their limited use of air-conditioning, the elderly respondents discussed not liking the feel of air-conditioning, the cost of utilities, and being environmentally and energy conscious [55]. Further, many senior citizens reported a preference for using a fan over the air-conditioning as they believed the air-conditioning may impact individuals with pre-existing health problems (e.g., arthritis and asthma; Lane [55]). To improve and encourage individuals to take protective action and alter their behavioral approach to extreme heat, it is imperative to overcome these barriers.

Theoretical Frameworks and Novel Methods for Future Research

While previous studies that assessed heat-related messaging and warnings, risk perception, and protective actions provided unprecedented insight into human decision-making and behavioral outcomes during extreme heat events, the use of social and behavioral theoretical frameworks could bolster their methodological approach and produce more compelling results. Due to the interdisciplinary nature of extreme heat and its relationship to health, several theoretical frameworks frequently used in the disciplines of health communication, health promotion and behavior, risk communication, and psychology are directly applicable for improving heat-related messaging, understanding risk perception, and ultimately encouraging behavior change. Only a few a studies to date have employed social and behavioral theoretical frameworks; however, there is a growing interest in applying theory to better understand knowledge and risk perception, as these qualities have been shown to influence behavior change [2].

The most frequently used theoretical framework in the context of extreme heat is the Health Belief Model (HBM; [2, 34, 80, 101]). The HBM is a behavior change theory that assesses threat perception and behavioral intentions using six distinct cognitive variables: perceived susceptibility, perceived severity, perceived benefits, perceived barriers, cues to action, and self-efficacy. Put simply, this theoretical framework measures risk perception (perceived susceptibility and perceived severity), as well as motivation and willingness to perform a behavior (perceived benefits, perceived barriers, cues to action, and self-efficacy). Previous studies in the heat-health literature have employed the HBM to better understand air-conditioning practices of vulnerable groups [80], identify risk perception and adaptive behaviors to heat waves [2], examine risk perception and injury prevention behaviors of parents/caregivers in relation to children being forgotten in hot cars [101], and finally determine the best communication practices for extreme heat events [34].

A second theoretical framework that has been utilized to approach heat-related messaging and risk communication is known as the Mental Models Approach [66]. Mental model studies help describe a particular group's (e.g., the general public) current knowledge and understanding of a particular issue (e.g., extreme heat).

Because the knowledge of experts often differs from their audience, "mental model studies closely examine the differences between these groups in order to promote the improvement of risk communication materials that better align with the knowledge of the lay audience" [102]. For example, if current heat-related messaging is providing contradictory protective actions associated with air quality alerts or the general public is reporting confusion due to the inconsistencies with HHWS alerts (e.g., heat alert vs. excessive heat warning), then these mental model studies can be used to depict these concerns and improve public health messaging [102]. While only two studies to date have examined extreme heat events using a Mental Models Approach to risk communication [102], this framework has been employed for other meteorological and climate-related hazards such as flood risk [100], climate change [14, 60], and hurricane forecasts and warnings [15].

Even though the HBM and Mental Models Approach are common theoretical frameworks, there are several socio-cognitive theories that have been suggested by previous works and have yet to be explored [2, 97]. For example, a recent study by Grothmann et al. [34] offers the protection motivation theory [76] and norm activation theory [86] as potential conceptual frameworks to further examine the motivation attached to heat-related behavior change. Other studies have recommended the use of the entertainment as education theory [67] to explore the applicability of heat-related messaging in television programs [1], as well as the use of narrative communication theories [81] to increase the risk perception of the general public [102]. Due to the complexities of human behavior, it is becoming ever-important to cross disciplinary boundaries in search for novel theoretical and methodological approaches to combat the lack of perceived vulnerability and willingness to perform protective actions during extreme heat events.

While the use of survey and interview methodologies has provided an abundance of information on the human element of extreme heat events, Bassil and Cole [8] call for the development of "novel methods to assess awareness and practices" to further refine, predict, and improve behavioral performance. Recently, the growing field of biometeorology [33] has contributed numerous methodological advances that capture meteorological measurements at the individual level [53]. In other words, these studies are focused on measuring personal heat exposure (PHE; [53]) and individually experienced temperatures (IET) using a portable digital thermometer (e.g., iButtons) [29, 52], global positioning system (GPS) watches [29], and other personal devices [99]. These technologies allow researchers to merge the meteorological observations with a proxy for human behavior using GPS coordinates or supplementary survey/interview methodologies. Similarly, longitudinal monitoring using mobile and smartphone technologies via crowd sensing is becoming an optimal methodology for assessing behavioral change [35, 98]. Even though no studies to date in the heat-health literature have employed this methodology, it is suggested that this could be a novel approach for assessing the receipt of heat warning messages and willingness to perform protective actions (i.e., stay inside for the duration of the extreme heat event). Similar to the personal monitoring technologies, supplementary methodologies (e.g., mobile phone surveys, monthly interviews/focus groups) could be utilized to further assess behavior change.

Conclusions

As the climate warms and communities experience more frequent extreme heat events due to anthropogenic climate change, it is increasingly important for academics, government stakeholders, and policy-makers to continue focusing on the societal impacts of extreme heat to better prepare populations for this hazard [85]. Many areas have HHWS in place to warn the general public and promote public health activities. These systems may be refined to better target heat-sensitive populations and to communicate heat-health risks. In particular, as HVIs develop, they may be built into HHWS to better identify heat-sensitive populations. Further, continued social and behavior science research may help improve heat-health communication by framing messages to increase perceived risk and to help overcome barriers to taking appropriate protective actions.

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Chapter 4
Heat Exposure and Impact on Occupational Settings

Richard J. Thomas and Alan L. Williams

Abstract Environmental heat stress in the occupational setting requires aggressive heat illness prevention programs to reduce heat-related injuries (HRIs). In order for a heat prevention program to be successful, worksite managers, safety specialists, labor organizations, health care providers, and employees must work together to modify HRI risk factors. These individuals should strive to address not only the unique risk factors of the workers, such as age, medications, and previous history of HRIs, but also implement global safety precautions such as using environmental indices to adjust work/rest cycles, implementing heat acclimatization program, ensuring adequate supply of clean water for hydration, and implementing a formal safety plan for HRI prevention that is shared with all employees. With an aggressive heat illness prevention program, occupational injuries and deaths can be reduced or prevented.

Introduction

In this chapter, the occupational and environmental effects of heat on the workforce will be discussed. Both population-based and individual effects and strategies will be considered in our exploration of thermal stresses and how they are rapidly changing around the world.

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R. J. Thomas (✉)
Department of Preventive Medicine and Biostatistics, Uniformed Services University of the Health Sciences, Bethesda, MD, USA

A. L. Williams
Occupational Health Clinic, Directorate of Public Health, Walter Reed National Military Medical Center, Bethesda, MD, USA

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Heat as a Population-Based Risk Factor

Mora et al. reviewed scientific papers published between 1980 and 2014 about global risk of excessive climatic heat on human health [1]. They identified 783 cases of excess mortality worldwide associated with heat from 164 cities located in 36 countries. Based on surface air temperature and relative humidity, they identified a global threshold where thermal conditions can become deadly to humans. This involved modeling daily atmospheric conditions in lethal heat periods such as temperature, humidity, solar radiation, wind speed, and other candidate metrics vs. randomly selected periods on nonlethal weather days in the same cities. The best model pair to predict lethal vs. nonlethal thresholds was average daily temperature vs. average daily relative humidity. Currently about 30% of the world population is exposed to climactic conditions at or above these thresholds for at least 20 days a year. By the end of this century, this percentage is projected to increase to ≈50% if greenhouse gas emissions are reduced or as high as 74% if greenhouse gas emissions continue to rise. The authors concluded with a rather ominous warning that the cost to the quality of human life and subsequent deaths due to excessive heat is almost inevitable. This increase in mortality will continue to accelerate if greenhouse gases are not controlled or reduced [1]. Im et al. looked at the projected effects of exposure to heat and deaths throughout this century [2]. Their worldwide thermal models projected that the greatest impact will be on the densely populated regions of South Asia, which include Pakistan, Nepal, India, Bangladesh, and Sri Lanka. The northern part of this region is the second hottest after Southwest Asia and is home to 20% of the world's population. Due to high percentages of agricultural workers exposed to direct sun and limited electrical cooling capabilities such as air-conditioning and fans, the population in this region is susceptible to the extremes of rising temperatures that may reach the upper limit of survivability by the end of this century [2]. Climate change may also cause dramatic effects in the developed world and the ability of the workforce to find stable places to work. In North America, the current oceanic shorelines may need to be moved further inland. The US Department of Defense estimates that 31 major military facilities in the United States will need to be relocated to more inland sites during the remainder of the twenty-first century [3, 4]. The military forces and security organizations including customs and border patrol of nations around the world may also have to adapt to an entire new coastal strategy based on changes to the depth and breadth of the littoral waters where inland freshwater and seawater merge into the oceans.

Heat as an Occupational Risk Factor

Schulte and Chun from the National Institute for Occupational Safety and Health (NIOSH) reviewed categories of climate hazards as they relate to occupational safety and health [5]. Their investigative framework includes seven elements: (1)

increased ambient temperature, (2) air pollution, (3) ultraviolet exposure, (4) extremes of weather (attempting to study associations between weather disasters and injuries, communicable diseases, mental health disorders, and deaths), (5) vector-borne diseases and expanded habitats, (6) industrial transitions and emerging industries, and (7) changes in the built environment (as buildings become more "energy efficient," the inhabitants may be exposed to indoor air pollution which may be irritating or increased carcinogen levels such as radon) [5].

NIOSH is the preeminent center for the study of workers' health and safety within the US Centers for Disease Control and Prevention (CDC) for the US government. Their first heat criteria document was published in 1972 within 2 years of the establishment of NIOSH, with revisions published in 1986 and 2016. This latest NIOSH heat criteria document includes a very complete discussion of the factors of heat balance in humans, heat exchange, and the biologic effects of heat. The NIOSH concept of total heat stress is related to the sum of heat generated by the human body through metabolic processes and the environmental factors that may either add to or reduce the transfer of heat from the body to the environment [6]. Figure 4.1 displays the multidimensional aspects of heat-related illnesses and deaths. These risk factors could be either additive or multiplicative in their effect on human health from heat exposure.

Temperature and Humidity

Quantification of the thermal strain from temperature and humidity on human health has been one of the most difficult challenges to researchers in the field. In 2006, Epstein and Moran identified 46 different methods to assess thermal stress in the world's scientific literature dating from 1905 to 2005 [7]. They collated these measures of thermal stress into three general categories: rational, empirical, and direct indices. Authors concluded that rational indices and empirical indices were difficult to calculate and were not designed for daily use, while direct indices such as the Wet Bulb Globe Temperature (WBGT) developed by Yaglou and Minard for the US military in 1957 [8] and the discomfort index (DI) proposed in 1959 by Thom et al. with modifications by Sohar et al. in 1963 may be more fitting for field usage. The DI is primarily used in Israel, while the WBGT has wider international use [7]. In the United States, the heat index (HI) is widely used. The HI uses heat risk values from air temperature and relative humidity to predict the heat hazard to workers [9].

Direct Sun Exposure

Heat gained from radiant sources, such as direct sunlight, affects workers in outside work areas and those indirectly in indoor work locations depending on the amount of ventilation and air-conditioning of the enclosed space [10]. Xiang et al. described in

Fig. 4.1 Examples of heat-related illness risk factors in occupational setting [6]. This figure has previously been published in federal government documents and is considered part of the public domain and is not subject to copyright restrictions

their review article that outdoor workers in agriculture, construction, mining, and manufacturing industries along with firefighters and the armed forces are particularly at risk for occupational heat-related illnesses (HRIs) [11]. Farmers and their transiently employed migrant field workers are at great risk for heat-related illnesses [11, 12]. These agricultural workers are exposed to direct sunlight and extreme temperatures for long periods of time, particularly in the late summer months during harvest time. There are often little or no nearby occupational safety and health resources or programs, particularly for migrant workers who move around as the demand and locations for harvest work changes. Mirabella and Richardson studied 161 heat-related fatalities in North Carolina from 1977 to 2001. Forty of the deaths (25%) were occupationally related. Farm work (16 of 40 deaths) and construction (10 of 40 deaths) accounted for the majority of these 40 occupationally related deaths in this study from one state [12]. Gubernot et al. reviewed 359 occupational deaths in the

United States reported in US Department of Labor (DOL), Bureau of Labor Statistics data from 2000 to 2010. The two highest North American Industry Classification System (NAICS) codes of occupational deaths included agriculture, forestry, fishing, hunting (two-digit NAICS code 11), and construction (two-digit NAICS code 23) [13]. Both of these studies identified occupations with a high-potential risk of fatalities while working under direct sun exposure and in humid conditions. This data led the US Occupational Safety and Health Administration (OSHA) to begin their Water-Rest-Shade Heat Illness Prevention campaign in 2011 [14].

Indoor Radiant Heat Sources and Limited Air Movement

Workers in facilities that contain heat-generating machinery are also at risk for HRI. For example, temporary indoor workers in Central American sugarcane mills work 12 h shifts with only the water they bring to work. The monthly mean maximum outside temperature during the "Zafra" season of harvesting and production was 32.6 °C (December) to 36.0 °C in April. The highest temperatures recorded between outdoor harvesting and indoor mill production workers were in oven cleaning assignments [15]. Furthermore, data from the same mill demonstrated that work to rest ratio activity modification would be required in that work setting by midmorning [16].

Lack of air movement and increased humidity may also increase the thermal strain in an enclosed work setting. For example, heat exhaustion and exertional heat strokes have been reported in underground mines during the warm parts of the year in a variety of locations including Australia, South Africa, and the United States [17, 18].

Hydration

Lack of adequate fluid intake in a hot environment and the degree and pace of physical exertion are important contributing factors for a HRI. Heavy industries such as construction and mining are particularly noted for the exertional component of their work. Dehydration was identified as one of the primary risk factors for heat exhaustion in a prospective yearlong study of Australian underground miners [17]. Bates and colleagues studied three trades of construction workers in the United Arab Emirates working 12 h shifts during extreme heat conditions. They were able to keep heart rates in heavy workloads below the World Health Organization (WHO) recommended level of 110 beats per minute with active monitoring of fluid intake and periodic measurements of urine specific gravity (USG). The study goal was to maintain USG below 1.015 through aggressive hydration and self-pacing of work in extreme high temperatures [19].

The assessment and quantification of physical exertion are important components of the American Conference of Governmental Industrial Hygienists (ACGIH) heat stress threshold limit values (TLVs ©) [20]. Activity modification based on threshold limit values is described below.

Personal Protective Equipment and Clothing

Personal protective equipment (PPE) and clothing may influence the rate of heat dissipation and heat gain in working persons. The National Fire Protection Association (NFPA) and the US Department of Homeland Security have a series of standardized PPE ensembles for a variety of first responders [21]. For example, firefighter PPE consists of fire-resistant “turnout gear” which includes boots, pants, jacket, head covering, mask, and a self-contained breathing apparatus (SCBA). The estimated weight of common firefighter PPE with SCBA ranges from ~44 to 51 pounds. Dreger et al. demonstrated a mean decline in maximal oxygen uptake (VO2) of 9.2 ml/min/kg ($p < 0.05$) while wearing full firefighter PPE and wearing an SCBA compared to light clothing in parallel treadmill studies [22]. Fehling et al. conducted a study to investigate the influence of hydration status in addition to the firefighter PPE and found the greatest cardiovascular and thermoregulatory strain when the subjects were asked to complete an exercise trial with firefighter PPE, in a mean 3% by body weight dehydrated state. However, their perceived strain did not differ between hydrated and dehydrated trials, which highlight the importance of a predetermined individualized hydration plan to adequately meet the hydration needs [23]. Increased sweating and loss of manual dexterity from PPE and SCBAs are also reported by firefighters. Park and colleagues interviewed 54 firefighters in a survey looking to improve firefighter PPE and SCBAs. On a one to five scale, the most serious complaint related to the effects of heat exposure was described as the loss of manual dexterity due to sweating of the upper extremities into their gloves [23]. Similar concerns were reported by the medical and mortuary workers working with Ebola virus disease victims in West Africa in 2014 [24]. In a high-volume crisis situation under extreme adverse temperature and humidity conditions, such as the Ebola epidemic, the requirement to wear PPE impacts effectiveness. While essential, the use of PPE to prevent disease transmission to the health-care workers and its associated physical demands limits the length of work shifts, decreasing their capacity to provide service. There is ongoing research to find new and better PPE ensembles that will allow for more efficient heat dissipation and potentially longer stay time in safe working conditions while wearing the full PPE ensemble [24, 25].

Reproductive Effects

Chronic heat exposure may have detrimental reproductive effects to both males and females. Relatively little is known about the physiologic effects of heat on working populations and reproductive health compared to other body systems [10].

Regulation of the testicular temperature can be affected by heat transfer through the thin skin of the scrotal sac and between incoming arterial blood and departing venous blood vessels. Thonneau et al. conducted a retrospective survey and studied the reproductive outcomes of couples in France. In this study, males in two occupations (bakers and welders) were associated with a decreased percentage of successful pregnancies during the period of observation. A major limitation in studying male reproductive effects of heat exposure is that the majority of these studies are retrospective and are based on self-reporting. Job classification and heat stress assessments were performed by the research team weeks to months after the recorded exposure period [26].

Karin Lundgren and colleagues from the Thermal Environmental Laboratory at the Lund University in Sweden wrote an extensive review article on the effects of heat stress in working populations and concluded that there was a lack of information on vulnerable populations such pregnant women and the elderly [10]. Although not an occupational finding, the immersion of pregnant women in hot tubs has been discouraged since 1981 [27, 28].

The influence of excessive heat exposure on the pregnant mother, fetus, and newborn should not be neglected. The adverse effects of heat on pregnancy are more difficult to quantify:

> There are three potent points of risk during the pregnancy related to potentially excessive heat exposure: the mother; the fetus; and the newborn. The mother may or may not be a paid employee during pregnancy and is often also working at home to take care of her family in the pre and post-partum periods. Much is not known about the danger of adverse heat during pregnancy [6].

Acclimatization and Lack of Exposure

Lack of acclimatization was observed in 47% of the HRIs documented among outdoor workers during the heat waves from 2010 to 2014 in South Korea [29]. Arbury with her team of OSHA and NIOSH investigators studied 20 cases of occupational HRIs which included nonfatal ($n = 7$) and fatal cases ($n = 13$) in the United States from 2012 to 2013. The majority of these deaths occurred in the first 3 days of working in a new job, which consisted of moderate to heavy work outdoors. Heat acclimatization programs were not present in any of these 20 cases [30]. This finding occurred despite the introduction of the OSHA Work-Rest-Shade program in 2011 [13]. OSHA guidance on acclimatization calls for work intensity to be reduced by 80% on the first day of an exposure to occupational heat for new employees or those employees returning to work after an extended absence. OSHA also recommends that the workload should be gradually increased over the course of the first 7 days [31].

Age

Age as a specific risk factor in occupational HRI has not been extensively studied [5, 12]. The effects of heat on the general population may affect both the younger and older ends of the age spectrum. The majority of HRIs in younger ages are related to exertional and recreational activities. Nelson et al. studied heat injury records from the National Electronic Injury Surveillance System (NEISS), a joint system run by the CDC and the Consumer Product Safety Commission, collected at emergency departments around the United States from 1997 to 2006 [31]. A large proportion of patients aged ≤19 years sustained exertional heat-related injuries during sports and recreational activity, whereas a majority of patients aged 40–59 years and ≥60 years sustained exertional heat-related injuries from yard work. HRIs in younger age workers have also been reported when new employees are assigned to strenuous tasks or are not acclimatized to the heat [32].

Epidemic Case Study

The preceding risk factors explored for HRI were reviewed individually. The studies of workers handling sugarcane in Central America previously cited by Crowe and Wesseling [15] [16] and others have identified an interesting and as of yet incompletely understood clinical syndrome referred to as Mesoamerican nephropathy (MeN). This disease cluster has been recognized over the last 20 years in regions along the Pacific Ocean side of Central America. Large numbers of primarily young men working in sugarcane fields have developed a progressive chronic kidney disease (CKD) that could not be attributed to known risk factors such as diabetes and hypertension. The First International Research Workshop on Mesoamerican Nephropathy was held in Costa Rica in November 2012. This first scientific gathering explored the epidemiology, clinical features, and disease burden of the outbreak [32]. Among the additive risks considered were exposure to heat, dehydration, strenuous work, and other potential cofactors such as nonsteroidal anti-inflammatory drugs (NSAIDS), high levels of sugars such as fructose, chemical exposures (arsenic and hard water), pesticides, and infectious agents (leptospirosis in contaminated water) [32, 33]. By 2016, an estimated 20,000 deaths in Central America have been reported with chronic recurrent dehydration and elevated uric acid levels in urine resulting in tubular injury of the kidneys leading to CKD in a region where dialysis resources are scarce [34]. An alternate hypothesis has been put forth that chronic recurrent dehydration interspersed with rehydration with contaminated ground water is the cause of MeN [35]. The age distribution of this MeN form of CKD differs in Sri Lanka where more females have been reportedly affected by a similar syndrome called chronic kidney disease of uncertain etiology (CKDu) [36, 37]. A recent publication regarding MeN speculated that this is the beginning of an occupational epidemic related to global climate change, as increasing CKD cases have been reported in multiple tropical countries including India, Bangladesh, Sri Lanka, Egypt, Mexico, and Central America. Further work is needed to understand if there are similarities in the epidemiology, exposure factors, and clinical outcomes of these worldwide CKD cases [38].

Activity Modification Guidelines

In order for a heat prevention program to be successful, worksite managers, safety specialists, labor organizations, and employees must work together to modify HRI risk factors. To locally assess days of increased risk to HRIs, temperature readings should be measured by management and safely specialists at the worksite. If these resources are not available, local temperature, humidity, and heat index readings are available through the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) data on the World Wide Web and local media such as television and radio broadcasts. OSHA and NIOSH have developed a free heat app entitled the “OSHA-NIOSH Heat Safety Tool” for a cell phone that provides current heat information [39].

These weather advisories are based on HI values using a combination of temperature and humidity stratified into four heat stress caution levels. HI is created under assumptions such as working in a shady area under light wind conditions. Working in direct sunlight can increase the heat index by up to 15 °F. Working in hot dry conditions with strong winds can also increase the heat index value [15].

The HI does not account for additional heat strain that will be induced from wearing heavy, protective, or impermeable clothing. There are four HI categories of likelihood of heat disorders with prolonged exposure or strenuous activity. These include caution, extreme caution, danger, and extreme danger. The level of work or physical activity is also not taken into account also with the four HI risk categories (see Table 4.1 and Fig. 4.2).

The NOAA NWS is developing a prototype model of geographic WBGT measurements in the Tulsa, Oklahoma, area and may be available to the general public in the near future [41]. This may promote increased usage of WBGT in US occupational settings, since the lack of specialized thermometer inhibited the wide usage of WBGT (Table 4.2).

Table 4.1 OSHA guidance on the stratification of heat risk groups and protective measures that should be implemented. This figure has previously been published in federal government documents and is considered part of the public domain and is not subject to copyright restrictions [40]

Heat index	Risk level	Protection measures
Less than 91 °F	Lower (caution)	Basic heat safety and planning
91 °F to 103 °F	Moderate	Implement precautions and heighten awareness
103 °F to 115 °F	High	Additional precautions to protect workers
Greater than 115 °F	Very high to extreme	Triggers even more aggressive protective measures

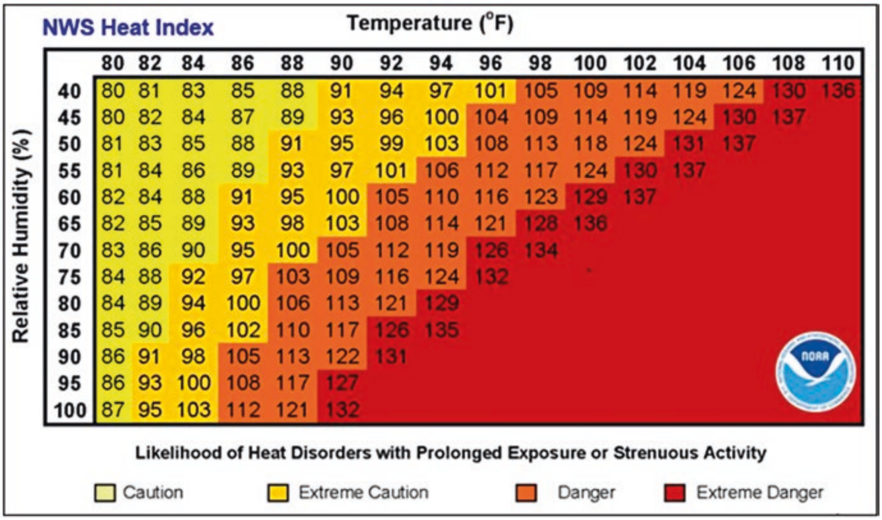

Fig. 4.2 NOAA National Weather Service Heat Index Chart. This figure has previously been published in federal government documents and is considered part of the public domain and is not subject to copyright restrictions [9]

Table 4.2 Elements of Heat Index vs. WBGT. This information has previously been published in federal government documents and is considered part of the public domain and is not subject to copyright restrictions [41]

Comparison with heat index	Wet Bulb Globe Temperature	Heat index
Measured in the sun	Yes	No
Measured in the shade	No	Yes
Uses temperature	Yes	Yes
Uses relative humidity	Yes	Yes
Uses wind	Yes	No
Uses cloud cover	Yes	No
Uses sun angle	Yes	No

The WBGT may also require an adjustment for work in direct sunlight or strong winds with hot dry air. The WBGT may be calculated directly using a WBGT meter or estimated from tables developed by Bernard [42] or Liljegren [43]. Workers in close proximity to a radiant heat source will experience a greater heat burden and thus more risk. Consideration for the specific duties of an individual employee may result in different levels of activity modification even for workers of the same job title in the same workplace. This type of thermal environment is better approximated by the use of a direct reading WBGT and the American Conference of Governmental Industrial Hygienists (ACGIH) work-rest cycles based on a heat stress threshold limit values (TLVs). TLVs are another index activity guideline that is used in occupational settings. The goal of these TLVs is to maintain the core body temperature of the worker to within one degree of 37 °C. Among the factors used to determine the work TLV are four categories of metabolic rate (in watts): light/moderate/heavy/ and very heavy with work examples provided in each category. An additional ACGIH factor in calculating the estimated metabolic rate is added if the body weight differs from the body weight of 70 kilograms (154 pounds), which was used to establish this model [25, 41]. Another factor that can modify the measured or calculated WBGT is clothing. The worker's clothing used in this model includes long sleeve shirt and pants or coveralls, which was shown to not add additional heat strain. An additional corrective factor is suggested by ACGIH for outer clothing worn such as double woven coveralls (+3 degrees Celsius) up to (+11 degrees Celsius) for vapor barrier coveralls [20, 42] .

Heat-Related Illness Prevention Program

A successful heat illness prevention program must include cooperation and technical expertise from management, worker representatives, safety, industrial hygiene, and medical personnel. If worksites are to accept the OSHA premise that all heat-related injuries and deaths are preventable, a comprehensive heat illness prevention program must be developed. This starts with a written commitment from management to a safe and healthy workplace with a formal safety plan for heat illness prevention. Preexposure training should be held annually with additional sessions for each new employee. This training should include (1) ways to monitor heat (temperature, humidity, heat index, and WBGT with NOAA warnings); (2) early signs of potential HRIs; (3) acclimatization schedules; (4) the need for aggressive hydration; (5) scheduled work breaks based on a validated heat tool such as the WBGT and ACGIH, NIOSH, or OSHA recommendations; and (6) the close monitoring of coworkers (especially new unacclimatized employees). During the first warm days of the year, short "tailgate safety" briefings should review the projected weather conditions for the day, the key factors of HRIs, and the logistics of where fluids can be obtained, times for mandatory work breaks, and how safety and/or medical help can be obtained. Reporting of all HRIs, including deaths, is crucial in our efforts to better quantify the risk and validate the effectiveness of heat prevention programs. In the United States, this includes the appropriate reporting of heat stress injuries on the OSHA 300 log and the immediate reporting of all occupationally related hospitalizations and deaths through the OSHA severe injury reporting system [44].

Medical personnel responsible for the occupational medicine examinations and acute care of employees must be conversant with all aspects of this prevention program. This may include individual counseling of employees regarding risk factors such as previous or current medical conditions, use of medications, pregnancy, and previous history of HRIs either at work or during recreational events. The latest NIOSH criteria document provides guidance for medical monitoring of employees through (a) preplacement medical evaluation (Sect. 7.3.1.1), (b) periodic medical evacuations (Sect. 7.3.1.2), and communication of medical findings and recommendation (Sect. 7.3.1.3) to both management and employees [12]. Furthermore, the latest document suggests organizations include the following four strategies to mitigate heat stress: (1) modification of the work intensity, (2) modification of the surrounding environment, (3) modification in the heat acclimatization status of the workers, and (4) modification in the clothing or equipment [12].

Summary

Heat-related illnesses in occupational settings appear to be an increasing risk around the globe with global warming and increasing industrial production in the developing world. With an aggressive heat illness prevention program, these occupational injuries and deaths can be prevented. Feasible methods of hazard reduction include:

1. Work-rest cycles based on validated measures of heat stress such as a Heat Index or Wet Bulb Globe Temperature.
2. Acclimatizing workers by gradually increasing the exposure to heat or a hot environment.
3. Assigning company management and/or safety personnel to closely monitor employees for adequate hydration, work-rest cycles on a predetermined schedule. This is particularly important in employees new or returning to a worksite.
4. Accurate and timely reporting to the cognizant governmental organization. In the United States, this includes the appropriate reporting of heat stress injuries on the OSHA 300 log and the immediate reporting of all occupationally related hospitalizations and deaths through the OSHA severe injury reporting system [44].

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Chapter 5
Exertional Heat Illness in the Military: Risk Mitigation

Josh B. Kazman, Francis G. O'Connor, D. Alan Nelson, and Patricia A. Deuster

Abstract This chapter focuses on exertional heat illness (EHI) in the military and covers common scenarios of EHI, the epidemiology, and guidelines related to risk mitigation and physical activity modifications. EHI risk is particularly high among new military recruits and those in combat occupational specialties. Other extrinsic and intrinsic factors are reviewed, including sickle cell trait and medications, which have received more attention recently. Military leaders are responsible for mitigating EHI risk at both the unit and individual level. The five steps of risk management are identify hazards, assess hazards, develop controls and make risk decisions, implement controls, and supervise and evaluate. Each step is discussed and elucidated with examples of work/rest hydration cycles by heat categories and Army risk management matrices. Military leaders need to remain vigilant and adapt risk management strategies; as the military's demographic/occupational makeup changes, the evidence base for EHI risk mitigation evolves, and new technologies become available.

Disclaimer: The views expressed here are those of the authors and do not represent the official policy of the Uniformed Services University of the Health Sciences, the Department of Defense, or any other government agencies.

J. B. Kazman (✉) · F. G. O'Connor · P. A. Deuster
Uniformed Services University of the Health Sciences, Department of Military and Emergency Medicine, Bethesda, MD, USA
e-mail: josh.kazman.ctr@usuhs.edu

D. A. Nelson
Stanford University School of Medicine, Department of Medicine, Stanford, CA, USA

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Introduction

The US Department of Defense is one of the world's largest employers, and its needs and requirements are constantly changing. It has over 1.3 million active duty personnel and over 0.6 million reservists (as of March 2017) [1]. These individuals perform countless job duties, with some unique to the military and others not. However, one of their primary responsibilities is to maintain a state of force readiness [2]. Readiness spans logistic, psychological, physiological, and physical factors. It refers to the ability to deploy to combat zones and extreme climes should the need arise. Decrements in fitness, such as obesity, are particular threats to readiness, because secular trends in obesity are similar across military and nonmilitary personnel [3]. Conditions related to physical exertion – such as heat illness, musculoskeletal injury, or cardiovascular disease – are regular dangers in any military operation, be it a training exercise or a combat mission. This chapter focuses on exertional heat illness (EHI) in the military and covers common scenarios of EHI, its epidemiology, and related risk mitigation and physical activity guidelines.

Across the entire US military, 2536 incident cases of EHI were reported in 2016, a rate of 1.96 per 1000 person-years [4]. Rates of EHI were particularly high among recruits in basic training (13.63 per 1000 person-years) and among Marines (3.99 per 1000 person-years) compared to other services (Army: 3.05; Air Force: 0.66; Navy: 0.48). It is no surprise that Marine Corps basic training represents one of the largest risks for EHI in the US military. Following a series of studies that began in the 1950s [5], Marine Corps basic training is also one of the most widely studied scenarios of EHI risk in the military. Therefore, we begin our discussion of scenarios of EHI with Marine Corps basic training.

Common Scenarios of EHI

Marine Corps basic training consists of 12 grueling weeks wherein recruits are indoctrinated into Marine culture and taught skills that range from first aid to marksmanship, all while undergoing extreme physical conditioning and being pushed to their physical limits in geographic regions where it is often extremely hot. A lower estimate of 10% of recruits is discharged from basic training, and about half of the discharges are medical in nature [6]. Marine Corps leadership came under increased pressure to reduce EHI after the summer of 1952, when there were 600 EHI cases, most of which occurred during basic training at Parris Island, SC [5]. Minard approached this problem by classifying causes of EHI as "agent factors" (i.e., instituting a flag policy related to wet-bulb globe temperature [WBGT]), environmental factors (e.g., training schedule, meals, sleep, leadership/indoctrination), and "host factors" (e.g., acclimatization, physical fitness, water/salt consumption, inoculations). After instituting a series of changes targeting each of these factors, the weekly incidence of EHI per 10,000 recruits was reduced from 12.4 in the summer of 1955 to 4.7 in the summer of 1956.

Versions of basic training (or "boot camp") exist for each service and for occupational specialties within each service (e.g., Ranger School); these comprise some of greatest risks for EHI in the military [4, 7, 8]. Recent research among soldiers suggests that EHI rates spike in the second month after Army enrollment, sharply reduces, and then remains relatively low for the remainder of their Army career [8]. Once completed, warfighters are expected to be able to confront enemy combatants, with the additional challenge of working under environmental extremes. Added to the complexity of modern asymmetric warfare is the requirement of carrying significant combat loads, including body armor, ammunition, and weaponry. Although body armor and helmets have proven protective against penetrating thoracic and head trauma [9], respectively, they not only add to the workload by generating more body heat but make it more difficult to dissipate heat into the surrounding environment [10]. These challenges can place the warfighter and, importantly, the mission, at risk, unless appropriate precautions are implemented. Efforts to reduce EHI rates in the military necessarily start with a better understanding of their risk factors, an area that has long been of interest to military leadership.

Minard's paradigm of classifying intrinsic versus extrinsic EHI risks is widely used in current military research, including exertional heatstroke (EHS) case series from US [11, 12], Israel [13, 14], France [15], and UK [16] militaries. Across these different countries, commonly identified EHS risks include having recently joined the military [11, 13–16] and previous history of heat illness [4, 15]. EHS is most likely to occur during summer months; however, as Epstein et al. wrote [13], EHS results mainly from "exercise rather than climate," and this has been supported in subsequent research [15, 16]. Group marches appear to pose a greater risk than self-paced runs, although both are frequently cited as causes [13, 15, 16]. Risk for EHS also increases when performing activities with combat gear, body armor, and/or a rucksack [13, 15, 16]. EHS has been reported both at the start and at the end of vigorous training exercises, which demonstrates the need for monitoring throughout a bout of exercise [13, 15]. Activity over consecutive hot days has also been shown to have cumulative effects on EHI risk during recruit training, which makes it important to account for recent weather and activity trends when assessing the risk of EHI and amount of physical activity on a given day [17].

With regard to intrinsic risk factors, it is important to consider the spectrum of EHI: it can range from mild EHI to severe EHS. Low levels of fitness and excessive body fat have been well-cited as risks for EHI, among both Marine [12, 18] and Army [19, 20] recruits, and a recent study by Bedno et al. [20] provided evidence that fitness and body fat independently contribute to EHI risk. Intrinsic risks for EHS include lack of acclimatization [16], sleep deprivation [15, 16], high levels of motivation [15], and recent illness [15, 16], although these can be difficult to capture systematically. However, studies of *EHS* patients have had less consistent results and generally suggest that body fat is not a primary risk factor for EHS [11, 13, 16, 21], albeit with some exceptions [22]. Additional risk profiles for EHI, along with trends over time, are reported in the Medical Surveillance Monthly Report (MSMR), which is discussed next.

Epidemiology of EHI

The MSMR uses electronic medical records to publish incidence estimates of many health conditions for the US military. Its reports are freely available at https://health.mil/MSMR, and this section begins by focusing on MSMR reports for 2010–2016 [4, 23–27]. Trends in EHI are updated annually and presented for both EHS (ICD-9: 992.0; ICD-10: T67.0) and “other EHI” (defined as heat exhaustion [ICD-9: 992.3–992.5; ICD-10: T67.3–T67.5] and “unspecified effects of heat” [ICD-9: 992.8, 992.9; ICD-10: T67.3–T67.5, T67.8, T67.9]); they include statistics for various demographics and career-related variables. The largest risk factors are career-related factors (e.g., recruit status, military occupational specialty, officer status), which highlights the importance of extrinsic or organization-related risk for EHI in the military (although certainly intrinsic factors serve an indirect role).

New military recruits (defined as those within pay grades E1–E4 and assigned to recruiting training stations) consistently have the highest rates of EHS and other EHI compared to more seasoned enlisted and officer personnel. In 2016, recruits had a rate of 0.76 EHS and 12.88 other EHI per 1000 person-years compared to other enlisted personnel’s rates of 0.30 EHS and 1.60 other EHI and officers’ rates of 0.29 EHS and 0.58 other EHI [4]. From 2012 to 2016, enlisted personnel had slightly higher rates of EHS than officers, but rates of other EHI for enlisted personnel are two to three times greater than rates for officers [4, 23–27].

Differences in military members’ home of record tend to be minimal, suggesting that once acclimated, military members’ risk profiles do not necessarily differ by the climate of their home [4, 23–27]. High-risk occupations include combat-specific specialties, where individuals have rates of EHS that are two to three times greater than those for other military personnel and rates of other EHI that are one to two times greater. Strenuous activities frequently involved in combat-specific specialties include group marches, which were previously discussed as conferring higher risk of EHIs. Further, rates of EHI in the Marines and Army tend to be much higher than those in the Navy and Air Force, again because of occupational tasks.

Although consistent demographic differences are noted with EHI, these tend to be more subtle than occupational differences and further are likely confounded by occupational differences as well. Between 2011 and 2016, males had slightly higher rates of EHS (ranging from 0.24 in 2013 to 0.33 in 2016 per 1000 person-years) than females (ranging from 0.10 in 2011 to 0.19 in 2016), although females had higher rates of other EHI (ranging from 1.30 in 2013 to 2.63 in 2011) than males (ranging from 1.19 in 2013 to 1.68 in 2011) [4, 23–27]. These gender differences support the importance of distinguishing EHS from milder forms of EHI in epidemiology research, especially because females are likely to have to greater body fat and less cardiovascular fitness than males [28]. However, over recent years, females have begun to integrate into more physically demanding combat roles [29], obscuring these gender comparisons.

Recent research by Nelson et al. [22] lends further support for the distinction between EHS and milder EHI. In their study, heat illness events were segregated into severe and mild cases based on total case complexity. Severe cases included patients with (1) heatstroke or (2) other syndromes with a "992" ICD-9 diagnosis code prefix (i.e., heat cramps, heat exhaustion, and heat syncope) *if* these other diagnoses involved complications such as rhabdomyolysis, hospitalization, and/or lengthy work restrictions ($\geq$ 60 days). Milder heat injuries were defined by non-heatstroke heat illness diagnoses with the same "992" code prefix that did not involve these complications. The findings of the study included increased adjusted odds of either heat illness form at extremes of body mass index (BMI) but especially for low BMI (< 18.0) and even greater odds of severe heat illness at these extremes.

Two additional risks that are receiving more attention in military research include sickle cell trait and medications.

Sickle Cell Trait

A variety of articles suggest that having sickle cell trait is associated with increased risk of heat illness and guidelines for health-care provider cite sickle cell trait as a risk factor of concern [30–34]. For example, the American College of Sports Medicine publication in 2005 entitled "Youth Football: Heat Stress and Injury Risk" [30] states that "More alarming is the growing evidence that sudden, maximal exertion – especially in hot weather or when new to altitude – can evoke a grave syndrome of red blood cell sickling, fulminant rhabdomyolysis, lactic acidosis, and hyperkalemia, resulting in collapse and acute renal failure." However, this and other statements are based on case reports rather than population-based studies among active individuals. This critical evidence gap was filled in 2017 by Nelson et al. [22] who showed no statistically significant associations between sickle cell trait and either mild EHI (hazard ratio (HR), 1.15; 95% confidence interval (CI): 0.84, 1.56; $n = 45{,}999$) or EHS (HR, 1.11; 95% CI: 0.44, 2.79; $n = 46{,}183$) among over 45,000 Army soldiers. However, this was in a setting where universal precautions were utilized to mitigate risk of exertion-related illnesses.

Medications and Non-prescription Drugs

Although it has been suggested that selected medications and drugs place service members at risk for EHI, the suggestions may not be firmly based on evidence. In a series of studies in the US Army, several medications and drugs were identified as increasing heat illness risk [8, 22]. Mild EHI risk was substantially higher among African-American soldiers with recent prescriptions for antipsychotics (HR, 3.25, 95% CI: 1.33, 7.90) [22]. The HR for taking stimulants and EHI was suggestive for mild (HR, 1.67, 95% CI: 0.41, 6.73) and large for severe EHI (HR, 5.19, 95% CI: 0.70, 38.8), but the imprecise HR indicates the need for a larger sample [22]. Given that warfighters regularly consume products containing multiple stimulants (e.g., caffeine, synephrine) [35], this finding deserves further attention. In addition, use of nonsteroidal anti-inflammatory drugs (HR, 1.31; 95% CI: 1.05, 1.64), opioids (HR: 1.92; 95% CI: 1.08–3.40), and methylphenidate (HR, 5.68; 95% CI: 1.41, 22.9) puts soldiers at significantly great risk of mild EHI than not using such agent [8].

Risk Mitigation and Activity Modification Guidelines

In the thermophysiology literature, it is well described that during exercise the body elevates its temperature in response to the increase in metabolic heat production [36]. A modest rise in temperature is thought to represent a favorable adjustment that optimizes physiologic functions and facilitates heat loss mechanisms to preserve homeostasis in the heat; this observation is described as exercise-induced hyperthermia. With exercise-induced hyperthermia, also known as compensatory heat stress, the body achieves a new steady-state core body temperature that is usually proportional to the increased metabolic rate and has the ability to dissipate heat.

Uncompensated heat stress, on the other hand, results when cooling capacity is exceeded and the warfighter can no longer maintain a stable core body temperature. Continued exertion in the setting of uncompensated heat stress increases heat retention, which causes a progressive rise in core body temperature and increases the risk for severe EHI. Warfighters, accordingly, need well-integrated physiologic systems to leverage exertion-induced hyperthermia, as well as environmentally prudent workload strategies, so as not to succumb to transitioning to EHI. The remainder of this chapter section describes how the military currently utilizes risk management strategies to mitigate uncompensated heat stress. Discussion will include acclimatization, guidelines for working in a heat-challenged environment, and intra-event cooling.

Currently, four key factors are seen as essential for mitigating the risk of EHI: (1) climate (temperature and humidity), (2) intensity and duration of activity, (3) clothing and equipment (e.g., body armor), and (4) individual risk factors. Therefore, EHI prevention requires a comprehensive approach that implements a systematic process to risk management, including both primary and secondary prevention strategies. Primary prevention attempts to prevent EHI from developing, while secondary prevention seeks to prevent mild illness from progressing to severe EHI (e.g., EHS).

Military personnel systematically approach risk management strategies for environmental stress comparable to those utilized for other stresses, through a series of clearly defined steps [37]. The five steps of risk management – identify the hazards, assess the hazards, develop controls and make risk decisions, implement controls, and supervise and evaluate – are used across the services to help them operate as a joint force and optimize readiness.

When leadership determines an environmental risk for EHI, the aforementioned risk management process is carefully planned to assess risk and implement strategies to mitigate that risk. Activities implemented to reduce risk include education, acclimatization, appropriate adjustment of activities to include work/rest and hydration strategies, and being prepared for early EHI management to mitigate the risk of EHS. Dependent upon the degree of assessed risk, leaders of increasing rank are required to review and sign off to approve training plans. Arguably the military's most important tool in preventing EHI is leadership. All leaders are expected to proactively implement preventive measures to mitigate the threat of heat casualties.

Identify the Hazards

Core to risk management is the initial assessment of the individual training event threat. Risk assessment requires careful appraisal of the extrinsic environmental loads and the intrinsic risks of the individual. In the military, doctrine requires the environmental assessment of the WBGT. Conducting operations in hot and humid environments (even with temperatures as low as 75°F [13, 15]) has been demonstrated to produce the most heat casualties.

The hazard assessment includes both the unit and the individual. Leadership must carefully assess unit workload over the previous days as well as exposure to prior heat loads, because military research has established that the prior day's heat load functions as an independent risk factor for EHI [17]. The leader must know the unit's acclimatization status to the environment. Vigorous training of unacclimatized personnel under a compressed timeframe in a warm and humid environment increases the risk of incurring heat casualties. The leader must also assess the planned training and the clothing requirements; protective clothing and body armor impede heat transfer from the body, which increases the risk of EHI.

Heat acclimatization is a critical factor that should not be overlooked by the military leader. Heat acclimatization is best defined as adapting/improving the body's ability to appropriately respond to and tolerate heat stress over time [38]. It is the most important factor determining how well a warfighter can withstand extreme heat. Thus, allowing sufficient time and using optimal training strategies that enable warfighters to acclimatize are critical for improving performance and mitigating the risk for EHI. Observational studies have found that the first week of training in high heat and humidity, for both warfighters and athletes, is the period of greatest risk for developing EHI [39]. Heat acclimatization of warfighters requires at least 1–2 weeks and is accomplished through a combination of environmental exposure coupled with exercise.

The major physiologic adjustments that occur during heat acclimatization include plasma volume expansion, improved cutaneous blood flow, earlier initiation

Work/Rest Times and Fluid Replacement Guide

Heat Category	WBGT Index (°F)	Easy Work: Walking on hard surface, 2.5 mph, <30 lb. load; weapon maintenance, marksmanship training.		Moderate Work: Patrolling, walking in sand, 2.5 mph, no load; calisthenics.		Hard Work: Walking in sand, 2.5 mph, with load; field assaults.	
		Work/Rest (minutes)	Fluid Intake (quarts/hour)	Work/Rest (minutes)	Fluid Intake (quarts/hour)	Work/Rest (minutes)	Fluid Intake (quarts/hour)
1	78° - 81.9°	NL	½	NL	¾	40/20 (70)*	¾ (1)*
2 (GREEN)	82° - 84.9°	NL	½	50/10 (150)*	¾ (1)*	30/30 (65)*	1 (1¼)*
3 (YELLOW)	85° - 87.9°	NL	¾	40/20 (100)*	¾ (1)*	30/30 (55)*	1 (1¼)*
4 (RED)	88° - 89.9°	NL	¾	30/30 (80)*	¾ (1¼)*	20/40 (50)*	1 (1¼)*
5 (BLACK)	> 90°	50/10 (180)*	1	20/40 (70)*	1 (1¼)*	10/50 (45)*	1 (1½)*

NL = No limit to work time per hour.

*Use the amounts in parentheses for continuous work when rest breaks are not possible. Leaders should ensure several hours of rest and rehydration time after continuous work.

This guidance will sustain performance and hydration for at least 4 hours of work in the specified heat category. Fluid needs can vary based on individual differences (± ¼ qt/hr) and exposure to full sun or full shade (± ¼ qt/hr).

Rest means minimal physical activity (sitting or standing) in the shade if possible.

Body Armor - Add 5°F to WBGT index in humid climates.

NBC (MOPP 4) - Add 10°F (Easy Work) or 20°F (Moderate or Hard Work) to WBGT Index.

CAUTION: Hourly fluid intake should not exceed 1½ qts. Daily fluid intake should not exceed 12 qts.

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Fig. 5.1 Work/rest and hydration cycle based on Army guidance in TB MED 507 [44]. (Available at US Army Public Health Center website, https://phc.amedd.army.mil/topics/discond/hipss/Pages/HeatInjuryPrevention.aspx)

of sweating, increased sweat output, lower salt concentration in sweat, and lower skin and core temperatures for a standard exercise bout [39]. These adaptations allow for better dissipation of heat during exercise and limit increases in body temperature compared to not being acclimatized. Importantly, any improved tolerance to heat stress generally dissipates within 2–3 weeks of returning to a more temperate environment [40, 41].

Individuals who are determined to be at increased risk of EHI may require a marker that designates "high risk" or a medical profile prohibiting certain activities in a heat-challenged environment. Recent research has indicated that soldiers in regions with more seasonal variation are at lower adjusted odds of EHI than soldiers in consistently warm regions [8]; this reinforces the importance of heat acclimatization as a critical factor which the leader must consider for mitigating EHI.

Assess the Hazards

Assessing hazards begins with using the WBGT in order to determine the heat category. The heat category is then used with the planned workload to calculate the work/rest and hydration cycle schedule (Fig. 5.1). The WBGT value may also be modified depending on uniform requirements. For example, if individuals are wearing a rucksack or body armor, 5 °F are added; for chemical protective equipment, 10 °F are added. As previously stated, the WBGT of the prior days' workload should

Example Heat Illness Risk Management Matrix				
Risk Factors	**Risk Level**			
	0 points/circle Low Risk	**1 point/circle Medium Risk**	**2 points/circle High Risk**	**3 points/circle Extreme Risk**
Risk Management Worksheet	All controls implemented			Not all controls implemented
WBGT (°F)* *Add 5°F backpack, body armor; 10°F CPE	< 78°	78° – 81.9°	82° – 87.9°	≥ 88°
Back-to-back Cat 5 days (>90°F)	0	1	2-3	>4
Heat Illnesses in past 2 days	0	Heat Cramps	Heat Exhaustion	Heat Stroke/ Death
Workload in past 2 days (see TR 350-29 workload classification chart)	Easy	Easy or Moderate	Moderate or Hard	Hard
Projected workload	Easy	Easy or Moderate	Moderate or Hard	Hard
Heat acclimatization days	>13	7-13	3-6	<3
Leader/NCO presence	Full Time	Substantial	Minimal	None
Cadre duty experience	18 months	7-18 months	1-6 months	<1 month
Communication System (tested at training site)	Radio and landline phone	Landline phone only	Radio only	None
Previous 24 hours sleep	>7 hours	5-7 hours	2-4 hours	<2 hours
Food/salty snacks every 4 hours	<4 hours	4-6 hours	6-7 hours	>7 hours
Onsite 68W/CLS and iced sheets (min. 8 single bed sheets/company in cooler)	Both iced sheets & Medic, EMT, or CLS	Only Iced sheets	Medic, EMT, or CLS	None
Add Circled Blocks with points/circle				
Total Score: 0-7 = Low Risk; 7-15 = Medium Risk; 16-24 = High Risk; 25-39 = Extreme Risk >11 Total Score should have onsite Medic, EMT, or CLS and organic evacuation transportation.				

Fig. 5.2 Example of risk management matrix based on Army guidance. (Available at US Army Public Health Center website, "Training Slides," https://phc.amedd.army.mil/topics/discond/hipss/Pages/HeatInjuryPrevention.aspx

be assessed, as these are known hazards [17]. The military leader then uses a risk management matrix to assign weights to various risks. These risks in turn can be mitigated, based on the implementation or availability of resources (e.g., medics, communication system). A risk management matrix is available at https://phc.amedd.army.mil/topics/discond/hipss/Pages/Heat-Related-Illness-Prevention.aspx (Fig. 5.2). As additional research is published, these guidelines will be updated. Recent research, for example, calls into the question the efficacy of ice sheets used for cooling [42].

Develop Controls and Make Risk Decisions

After a careful assessment of the hazards, the leader develops a plan to implement EHI risk mitigation strategies, which may target both the unit and the individual. High-risk individuals may be marked using red beads worn on a boot or uniform. At the military unit level, the leader can implement work/rest schedules, and water consumption should be modified in accordance with published guidance in TB MED 507 Table 3.1 [43] (Fig. 5.1). The military planning process additionally includes scheduling high-intensity training at cooler times during the day and arranging for adequate hydration points and intra-event cooling sites. The military utilizes prefilled barrels and ice coolers with ice sheets in the event of an EHI event. In the event of a collapse, a communication system should be in place in order to ensure rapid treatment (i.e., rapid cooling) and triage to an appropriate level of care.

Implement Controls

Once the decision is made to proceed with any training, military leadership implements the aforementioned controls. Additional key aspects include warfighter education and intra-event cooling. Education is core to EHI prevention. Early recognition and treatment of military personnel presenting with symptoms of heat illness are key to saving lives. All warfighters are educated about risks and early signs and symptoms of EHI. Examples of educational topics [44] include but are not limited to ensuring adequate hydration, conducting physical fitness training and testing during cooler parts of the day, providing adequate sleep prior to training and adequate rest periods during training, and educating warfighters about the dangers of supplements, particularly those with stimulant effects which may increase their risk for heat illness.

Improving performance in the heat also leverages many proactive strategies to keep the warfighter cool and mitigate the risk of heat illness. A common strategy is "heat dumping," whereby heat is transferred to the environment using techniques such as cool mist showers. One novel intervention used in the military is the arm immersion cooling system (AICS) [7]. The AICS is a simple, efficient method for facilitating body (core and skin) temperature cooling and reducing the risk of serious heat illness. The AICS takes advantage of the rapid rate of heat transfer from the skin directly into cool water (compared to transfer into evaporative sweat or air), and the large surface area-to-mass ratio of the forearms. Several studies have reported that hand and forearm immersion in cool (50–68 °F) water reduces core body temperature faster (at a rate of 0.07 °C/min) than a non-cooling control, as well as extending tolerance time and increasing total work time [7, 45].

Supervise and Evaluate

The final phase of risk management is the identification and treatment of EHI. The military leverages not only educated leaders but "buddies" to be alert for the signs and symptoms of EHI. Spot checks can be performed during training to assess warfighter status. Tying knots in small cords or moving beads along cords each time that water is consumed can help monitor hydration status [46]. If a warfighter collapses or is thought to have sustained an EHI event, cadres are trained to notify emergency management system and initiate immediate onsite cooling with ice sheets.

Conclusion

The military is a unique environment to study and impact heat illness risk, given the availability of large medical record databases and military leaders' control over daily physical activities. Steps taken to understand EHI risk in the military have directly translated into procedures to prevent and mitigate EHI, going back to Minard's work in the 1950s [5]. At the same time, risks for EHI in the military are dynamic, given the constant shifts in the nature of warfare, warfighters' fitness levels, and makeup of the military (e.g., integration of women into combat roles) [28, 29]. Ongoing and future efforts to research EHI will focus on leveraging ever larger medical databases [22], developing blood assays to predict susceptibility to and recovery from EHS, and testing new technologies in the field to better monitor heat strain [47] and treat EHI [7, 45]. Despite these ongoing developments, it is important to remember the fundamentals of EHI and that it is completely preventable [48]. Toward this end, concrete steps to prevent EHI in the military setting have been laid out.

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Chapter 6
Heat Risks in Athletics

Yuri Hosokawa and William M. Adams

Abstract Features that are unique to sports participation, such as the timing of the season, use of protective equipment, and prolonged exposure to the sun, make athletes no exception to the risk of extreme heat. In order to attenuate the heat strain imposed on the body during exercise in the heat, heat acclimatization and activity modification guidelines are commonly utilized to enhance the physiological adaptations to the heat and control work-to-rest. Implementation of such guidelines has effectively reduced the numbers of exertional heat stroke fatalities among athletes; however, further research is warranted in establishing policies that account for the ever-increasing threat of climate change and promote the proactive use of weather and climate data to modify athletic activities.

Introduction

Extreme heat exposure not only adversely affects athletic performance but also compromises the health and safety of athletes by placing them at risk for exertional heat illness (EHI) and dehydration. It has been well documented within scientific literature that prolonged exercise in the heat increases ratings of perceived exertion, exacerbates cardiovascular and thermoregulatory strain, and reduces overall running speed and distance covered in sports such as American football, Australian rules football, distance running, cycling, baseball, and soccer [1–10]. However, despite the increased physiological strain associated with exercise in the heat, the

Y. Hosokawa (✉)
College of Sport and Health Science, Ritsumeikan University, Kusatsu, Shiga, Japan

Korey Stringer Institute, University of Connecticut, Storrs, CT, USA

W. M. Adams
Department of Kinesiology, University of North Carolina at Greensboro, Greensboro, NC, USA

Korey Stringer Institute, University of Connecticut, Storrs, CT, USA

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competitive and self-motivated culture associated with athletics participation may not necessarily hinder athletes from moderating their behaviors, lending to the increased vulnerability to EHI.

Scenario of Heat Risks

Rules of the sport define the type (i.e., intensity, duration and mode) of exercise athletes perform. Consequently, this makes some sports inescapable from extreme heat scenarios due to extrinsic factors such as timing of season, duration of exercise, and frequency of rest breaks. It is not uncommon for an athlete's internal body temperature to exceed 39.2–39.5 °C during a bout of intense exercise in the heat due to significant metabolic heat production during exercise, especially when the sport requires continuous running or explosive power [1, 7, 11–14]. Evidence also suggests that performing a bout of exercise in the heat in sports such as tennis [14], Australian rules football [1], and participation in a summer time road race [15] increases the likelihood of internal body temperature to exceed the aforementioned thresholds than in cooler conditions. Specifically, during match play in Australian rules football, the likelihood of athlete's internal body temperature exceeding 40 °C was nearly doubled when playing in hot (WetBulb Globe Temperature [WBGT], 28 ± 3 °C) versus cool (WBGT, <22 °C) conditions [1]. Furthermore, evidence from an 11.3 km summer road race suggests that as environmental conditions become more extreme, there is a positive relationship in the overall incidence of EHI and exertional heat stroke (EHS) cases [15].

Protective equipment requirements in sport, such as wearing a standardized uniform that includes a helmet and/or other protective pads, are also unique aspects of sports participation. Kulka and Kenney [16] modeled the critical combination of ambient temperature and relative humidity for one to maintain thermoregulation while exercising at 35% of maximal oxygen consumption under three different American football uniform ensembles: full football uniform, practice uniform (i.e., shorts instead of football pants with pads), and shorts only. As the area of skin exposed to the environment is reduced (i.e., full football uniform), the allowable environmental heat load in terms of ambient temperature and relative humidity to maintain compensable heat stress is reduced [15]. The increased heat stress placed on the body while wearing a full American football uniform has also been shown to limit the total time to exhaustion [17] and perceptual responses [18]. Humidity has also been shown to independently reduce the exercise capacity due to the diminished ability to exchange heat via evaporative heat loss, leading to a faster rate of rise of internal body temperature [9].

Outdoor athletic events conducted during the daytime hours add additional thermal strain via radiative heat gain (i.e., direct sunlight), resulting in reduced net heat loss [4]. This brings up an organizational delimitation for many secondary school student athletes since their practice times are usually constrained to after school when direct sun exposure is difficult to avoid.

In individual sports such as running, the lack of awareness about heat risk directly increases the vulnerability to heat injuries since there is a lack of bystanders who are able to provide alerts and feedback to runners that would prompt them to self-modulate their exercise intensity in heat. As these athletes are often self-driven and highly determined to accomplish their predetermined workout, they may ignore the early signs and symptoms of EHI [19]. Similarly, team sports are not immune from organizational factors; in fact, the team culture may increase the peer pressure from the coaches and teammates, which may delay the athlete who is suffering from EHI from notifying their peers. Therefore, it becomes critical for individual athletes and sport teams to learn about the existing heat modification guidelines and how to implement them during practice and competition. For team settings, use of heat modification guidelines will serve as a universal precaution to help ensure safety of athletes in the heat.

Heat Injury Epidemiology

Exertional heat injury epidemiology in American football is one of the most studied in scientific literature [20–28]. American football players are particularly vulnerable to heat injury during the first 7 days of the preseason training when athletes are still adapting to both heat and exercise stress [21]. EHI incidence rates vary between youth (1.82/10,000 AE), secondary school (0.57/10,000 AE), and college (1.67/10,000 AE) football; however, it is clear that the incidence of EHI in these settings increases dramatically during the preseason with an incidence rate of 2.76, 1.47, and 3.66/10,000 AE in youth, secondary, and college football settings, respectively [22]. Since 1955, there have been 137 recorded EHS fatalities in American football, with 46 (35 secondary school, 8 college, 2 professional, and 1 sandlot) EHS deaths occurring from 1995 to 2010 alone [29]. At the collegiate level, the rate of EHI was six times greater when the WBGT was at 28–29 °C compared to 25–26 °C [21]. Furthermore, evidence shows that American football athletes are 11.4 times more likely to suffer from EHI than all other sports combined [27]. Grundstein et al. [20] investigated 58 American football fatalities documented in the United States, which showed that meteorological conditions that are atypically warm to the geographical region were commonly observed on the day of collapse.

While American football exhibits the greatest risk of EHI due to the various factors related solely to the sport (i.e., time of year the sport is played, the protective equipment that must be worn, and the size [muscle and fat mass] of the athletes), other sports are not without risk [27, 28, 30, 31]. Data examining the incidence of EHI in secondary school athletics in the United States show that girl's field hockey had the second highest incidence rate (1.88/100,000 AE) compared to American football (4.42/100,000 AE), while the remaining secondary school sports observed incidence rates <0.82/100,000 AE [27]. Evidence also shows that roughly two third of all EHI cases occur during the month of August [27, 28], which may be due to the hotter environmental conditions observed in the United States at this time of the calendar year. Similarly, tennis match play from the Australian Open clearly shows the increased incidence of heat-related medical issues as environmental conditions as measured by WBGT [30].

The Falmouth Road Race, an 11.3 kilometer (7.1-mile) road race that takes places in mid-August in Falmouth, Massachusetts, has documented 2.13 ± 1.62 cases EHS per 1000 finishers, with one of the highest recorded years reaching 6.57 cases per 1000 finishers in 2003 [32]. The EHI incidence data from this race exhibits a clear relationship with the environmental conditions on the day of the race, with the average air temperature and heat index (calculated from the air temperature and relative humidity) demonstrated strong association with the incidence rate of EHS (ambient temperature, $R^2 = 0.65$; heat index, $R^2 = 0.74$) and EHI (ambient temperature, $R^2 = 0.71$; heat index, $R^2 = 0.76$) [15].

Activity Modification Guidelines in Athletics

There are two types of heat modification guidelines in athletics: heat acclimatization guidelines and WBGT-based activity modification guidelines. Both guidelines may serve as universal precautions to ensure the health and safety of athletes, which becomes particularly important when working with team sports where each athlete may present with different heat tolerance and fitness levels. Both guidelines were created by expert consensus among sport medicine physicians, athletic trainers, and sports scientists [33–35] and designed so that nonmedical personnel, such as coaches and managers of athletics events, may follow the standard of care that would have been provided with on-site medical personnel.

Heat acclimatization guidelines were systematically implemented first in the National Collegiate Athletic Association (NCAA) in 2003 [36]. The premise of heat acclimatization is to gradually introduce athletes to exercise in the heat by predesigning the exercise bout to not exceed a set duration and also modifying the amount of equipment worn [33–35]. Fall sports, such as American football, warrant such an intervention because the rapid reintroduction to exercise in the heat in the summer months (July, August) positions them at high risk for EHI. Within collegiate athletics, the heat acclimatization rule mandates American football teams to limit their practices to single 3-h practice or one 2-h practice and one 1-h field session, and no multiple practice sessions are permitted during the first 5 days of pre-fall season practices (Table 6.1) [34]. Athletes are also limited to wearing only helmets on days 1 and 2, gradually increase their equipment to helmets and shoulder pads (days 3 and 4), and allowed to wear full pads after the day 5 [34].

Secondary school athletics have followed suit to the NCAA heat acclimatization guidelines in 2009, where an interassociation task force for preseason secondary school athletics introduced the use of 14-day heat acclimatization period [35]. The recommendations for secondary athletics are more conservative than that of collegiate setting by extending the guideline duration to full 2 weeks, which is equivalent of days of heat exposure required to fully attain the physiological benefits of heat acclimatization [38]. The secondary school guidelines are also structured to fit other

Table 6.1 Heat acclimatization protocol in athletics

<table>
<tr><th rowspan="2">Day</th><th colspan="2">National collegiate athletics association [37]</th><th colspan="3">Secondary school recommendation [35]</th></tr>
<tr><th>Practice considerations</th><th>Equipment considerations</th><th colspan="2">Practice considerations</th><th>Equipment considerations</th></tr>
<tr><td>1</td><td rowspan="5">• Single 3-h practice
or
• One 2-h practice and one 1-h field session</td><td rowspan="2">• Helmets only</td><td rowspan="5">• <3 h total practice time
and
• 1-h maximum walk through with at least 3-h recover period between the practice and the walk-through</td><td rowspan="2"></td><td rowspan="2">• Helmets only</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td><td rowspan="2">• Helmets and shoulder pads</td><td rowspan="3">• Contact with blocking sleds and tackling dummies</td><td rowspan="3">• Helmets and shoulder pads</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td><td rowspan="10">• Full pads</td></tr>
<tr><td>6</td><td rowspan="9">• One day between days with multiple practices
• <5 h total practice time
• Walk-through <2 h</td><td rowspan="9">• <3 h total practice time
• Full, live contact drills
• Double-practice days must be followed by a single-practice day</td><td rowspan="9">• On single-practice days, 1 walk-through is permitted, separated from the practice by at least 3 h of continuous rest</td><td rowspan="9">• Full pads</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td></tr>
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</table>

fall sports that do not require equipment (e.g., cross country), which improves the external validity of the guidelines to sports other than American football. Currently, only eight state secondary school athletics associations mandate the heat acclimatization guidelines outlined in the 2009 interassociation task force document be followed by each state association member school (Arizona, Connecticut, Iowa, Mississippi, New Jersey, North Carolina, Rhode Island, and Utah) [39]. The lack of a nationwide rule requiring heat acclimatization for all secondary school athletics is concerning since the epidemiology suggest that secondary school athletes are not discounted from vulnerability to exertional heat illness [22]. For example, the odds ratio for EHI incidence during August practice was 9.8 times greater when the practice duration exceeded the recommended 3-h limit within secondary school athletics [40].

WBGT-based activity modification guidelines were first introduced to the athletic world in distance running events [41]. The need to alert sponsors and participants of mass participation events for the risk of thermal stress was proposed to have a preestablished plan to orchestrate resources and to preempt the local medical system to be ready for a potential influx of patient admittance. Since then, various WBGT-based activity modification guidelines have been published that are followed by the collegiate [33], secondary school [34, 42], pediatrics [43], and mass participation event settings [44] (Table 6.2). All guidelines break down the level of

Table 6.2 Wet Bulb Globe Temperature-based activity modification guidelines in athletics

WBGT (°C)	ACSM–Distance running[40]	ACSM–Continuous activity[33]	ACSM–Acclimatized fit person[33]	NATA[34]	AAP[42]	IIRM[43]
35	Rescheduleing or delaying the race until safeer condition prevail (>28.0 °C)	Cancel level for EHS risk (≥27.9 °C)	Cancel exercise uncompensable heat stress exists for all athletes (≥32.3 °C)	No outdoor workouts, cancel exercise, delay practices until a cooler WBGT reading occurs (≥33.4 °C)	Cancel all athleic activities (if >29 °C)	Extreme: event cancelled/extreme and dangerous conditions. Participation stopped/Follow event official instruction. (>28.0 °C)
34						
33						
32				Maximum length of practice is 1 h. (≥32.2 °C)[a]		
31			Limit intense exercise and total daily exposure to heat and humidity (≥30.1 °C)	Maximum practice time is 2 h. (≥30.5 °C)[b]		
30				Use discretion for intense or prolonged exercise. Watch at-risk players carefully. Provide ≥3 separate rest breaks per hour of minimum duration 4-min each. (>27.8 °C)		
29			Plan intense or prolonged exercise with discretion; watch at-risk individuals carefully (≥27.9 °C)			
28					Stop activity of unacclimatized persons and high-risk persons; limit activities of all others (disallow long-distance races, cut the duration of other activities) (≥26.0 °C)	
27	Red flag (high risk): all runners should be aware that heat injury is possible an dany person particularly sensitive to heat or humidity should probably not run (23.0–28.0 °C)	Risk for unfit, nonacclimatized individual is high (≥25.7 °C)	Monitor fluid intake (≥22.3 °C)	Normal activitiesl provide ≥3 separate rest min each during workout (≤27.8 °C)		High: potentially dangerous conditions. Slow down/Observe course changes/ Follow event official instructin/ Consider stopping. (22.0–28.0 °C)
26						
25		Risk for all competitors is increased (≥22.3 °C)			Longer rest periods in the shade; enforce drinking every 15 min (≥24.0 °C)	
24						
23					All activities allowed, but be alert for prodromes of heat-related illness in prolonged events (<24.0 °C)	

22	Amber flag (moderate risk): it should be remembered that the air temperature, probably humidity, and almost certainly the radiant heat at the beginning of the race will increase during the course of the race if conducted in the morning or early afternoon (18.0–23.0 °C)				
21		Risk of EHS and other heat illness begins to rise; high risk individuals should be monitored or not compete (≥18.4 °C)	Normal activity (≤22.2 °C)		Moderate: less than ideal conditions. Slow down/Be prepared for worsenign conditions. (18.0–22.0 °C)
20					
19					
18					
17	Green flag (low risk): this is no way gurantees that heat injury will not occur, but indicates ony that the risk is low (<18.0 °C)	Generally safe: EHS can occur associted with individual factors (≥10.1 °C)			Low: good conditions. Enjoy the event/Be alert. (10.0–18.0 °C)
16					
15					
14					
13					
12					
11					
10					
9	White flag: Low risk for hyperthermia, but possible risk for hypothermia (<10.0 °C)	Generally safe: EHS can occur associted with individual factors (≤10.0 °C)			
8					

Abbreviations: *WBGT* wet bulb globe temperature, *ACSM* American College of Sports Medicine, *NATA* National Athletic Trainers' Association, *AAP* American Academy of Pediatrics, *IIRM* International Institute for Race Medicine, *EHS* exertional heat stroke

[a]No protective equipment may be worn during practice and there may be no conditioning activities. There must be 20 min of rest breaks provided during the hour of practice

[b]For football: players restricted to helmet, shoulder pads, and shorts during practice. All protective equipment must be removed for conditioning activities. For all sports: provide 4 separate rest breaks/h of minimum duration 4 min each

risk in four to six categories. Guidelines by the American College of Sports Medicine (ACSM) for distance running [41], National Athletic Trainers' Association (NATA) [34], and International Institute for Race Medicine (IIRM) [44] further provide sport-specific behavioral modification, such as reducing the total duration of exercise and increasing the number of rest breaks.

The WBGT threshold for event cancelation ranges from 27.9 °C to 33.4 °C, which is largely due to the context in which these guidelines were developed. For example, guidelines developed for distance running have ≈28 °C as the cutoff threshold for event cancelation or extreme heat risk. This is likely due to the combination of the greater amount of metabolic heat that is produced during this type of activity and the logistical difficulty in providing optimal medical supervision to all athletes at all times since endurance running is usually conducted in a mass participation event setting. Therefore, it would be prudent to be relatively conservative in the activity modification guidelines to account for all participants. On the contrary, guidelines for team sports and competitive athletes have ≈32–33 °C as the cutoff threshold for event cancelation. In these guidelines, different activity modification recommendations are enacted every 1–2 °C increase in WBGT, which warrants coordination of the team staff to designate a person, such as an athletic trainer, to activity monitor environmental condition and modify exercise duration and intensity accordingly.

Temperature thresholds for activity modification guidelines are also highly dependent on the geographical region in which the guideline is used. Roberts [45] examined the medical tent admittance data and number of unsuccessful finishers from eight different marathons around the world and investigated the inflection point in which these rates showed rapid increase under various WBGT conditions. The data suggest that a start WBGT of >21 °C was associated with midrace cancelation in several races, and the number of medical tent admittance and unsuccessful finishers reached the mass casualty incident level (i.e., exceeding the limit of medical tent capacity that may overwhelm local medical services) in marathons that were hosted in the northern latitudes (>40° lattitude) [45]. This suggests the need for regionally specific WBGT guideline so that the temperature thresholds accurately detect unseasonably warm conditions. Grundstein et al. [46] divided the continental United States to three different regions, by using the median 90th percentile WBGTs as a guide to establish regionally specific WBGT activity modification guidelines and adjusted the guidelines by the ACSM and NATA downward by 1.3 °C and 3.3 °C. In other words, in regions where extreme heat is pervasive, such as the Southeast, the temperature thresholds were kept the same from the original guidelines by the ACSM and NATA (*Category 3*). The thresholds for Midwest, northern Ohio Valley, and the Northeast were adjusted downward by 1.3 °C (*Category 2*), and the northern area of the contiguous United States where the observed absolute WBGT is the lowest among the established categories, the thresholds were adjusted downward by 3.3 °C (*Category 1*) [46].

Conclusion

The number of days that reach extreme heat categories in existing activity modification guidelines are projected to become more prevalent and experienced in a greater area of the continental United States in the future (2041–2070) [47]. Despite this inclement heat risk that we will be facing in near future, no standardized activity modification guidelines that encompasses all levels and types of sport exists. Policy makers at the state and national levels must view this as a valid threat to the athletic community. Proper knowledge on heat safety among coaches and athletes will become imperative than it ever has. Inability to proactively modify activity accordingly to the environment will place participants at danger, and the need for alternative measures becomes more critical.

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Chapter 7
Behavioral and Technological Adaptation

W. Jon Williams

Abstract Maintaining a euhydrated state is critical for normal biochemical and physiological function. Hydration is normally a dynamic process of the constant loss of water from the body (insensible as well as dynamic water loss from sweating) being replaced through drinking, eating, and the metabolism of food. Significant water loss from sweating during exercise must be replaced to avoid heat and other related injuries. Monitoring of physiological processes has occurred from ancient times but has become sophisticated in the last 100 years. Wearable wireless monitoring has been developed allowing the wearer to determine their physiological status under a variety of conditions (exercise, environmental). Monitoring may help avoid injury that may occur when physiological limits are exceeded (e.g., heat stroke). In addition to physiological monitoring, wearable cooling technologies have been developed which limit the effects of environment on the physiological burden of the environment reducing the risk of heat injury to workers.

Introduction

Behavioral and technological adaptations play critical roles in reducing thermal strain during physical activity in extreme heat. For example, modifying drinking and hydration behaviors to maintain a euhydrated state is critical for normal biochemical and physiological function. This chapter aims to provide an overview of

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W. J. Williams (✉)
National Personal Protective Technology Laboratory, National Institute for Occupational Safety and Health (NIOSH), Center for Disease Control and Protection (CDC), Pittsburgh, PA, USA
e-mail: aun7@cdc.gov

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fluid and thermoregulatory regulation in humans and methods that are commonly utilized among the physically active population to protect or augment physiological capacity to optimize physical performance in the heat.

Hydration

Body Water

The human body is composed of approximately 60% water depending on age, fitness, and degree of acclimatization [1]. Body water contains dissolved solutes (electrolytes, proteins, etc.) necessary for cellular function and provides the aqueous medium in which all biochemical and physiological processes occur [2]. There is a dynamic turnover of body water due to several processes that can result in water gain or loss from the body. Water loss through behavioral or physiological mechanisms (not trauma) can be due to a voluntary or involuntary reduction in water intake, insensible water loss across the skin and respiratory tracts, sweating during hyperthermia or high work rates, diarrhea, and vomiting. Replacement of body water usually occurs through the ingestion of water, food-containing water, and water produced through metabolic processes [3]. In a curious coincidence, the amount of water produced solely from metabolism equals the loss of water through respiratory evaporative processes [1, 4]. However, water production from metabolism alone is not generally enough to replace the water lost through other physiological processes (sweat, urination, respiration). Thus, additional water must be consumed by drinking and eating in order to maintain a relatively euhydrated state [3, 5]. Human daily consumption of water varies greatly and can range from approximately 2.5 L to between 5 and 10 L of water per day depending on activity levels and the thermal environment [3]. For example, it is common to lose as much as 6–8 L of sweat during intense or prolonged exercise in hot and humid environments [6]. Thus, the consumption of water increases (or should) with increased physical activity to replace water loss due to sweating. However, this level of water loss through sweating is difficult to replace on a short-term basis and can result in as much as a 3% deficit in body water by weight over time even with a high level of water intake. Under most circumstances, the balance between average water loss and gain is such that the average human euhydrated state usually remains stable over an extended period of time due to several mechanisms including hormonal control of renal fluid conservation [2, 7].

Electrolyte/Carbohydrate Regulation and Control of Hydration

Plasma electrolyte concentrations (primarily sodium, potassium, and chlorine) are under renal control through several hormonal pathways, including the renin-angiotensin-aldosterone system (RAAS) as well as antidiuretic hormone (ADH) [7]. The synthesis and release of those hormones occur through changes in plasma volume and plasma concentration of sodium chloride. ADH secreted from the pituitary gland, which has direct neural connections with the hypothalamus, may also receive neural input from other sources. The function of ADH is to reduce water loss by the kidney, but it has no effect on the water loss through sweat glands. Body water, including plasma volume in the vascular compartment, is also regulated by the RAAS. Changes in fluid volume or electrolyte (sodium) concentration will activate the RAAS to conserve fluids and electrolytes at the level of the kidney and sweat glands through the action of aldosterone [8]. The control of fluid (especially plasma) volume is also important in the maintenance of blood pressure and organ perfusion. Another product of the RAAS is angiotensin II, a powerful vasoconstrictor that helps maintain blood pressure and overall cardiovascular function in the presence of significant fluid loss from the vascular compartment, as well as a significant stimulator of the release of aldosterone from the adrenal glands [7].

Hydration is essential for life regardless of activity level. As thirst is not a reliable indicator of hydration status, it is important to follow guidelines for rehydration during normal activity, during exercise, and during exposure to hot and/or humid environments. A general guideline for those exercising in the heat for 1–2 h is to drink plain, cool water (containing no electrolytes). To avert heat injury, it may be necessary to consume sufficient quantities of water containing electrolytes including sodium [Na^+] to prevent dehydration, hyponatremia, and cardiovascular stress [3]. Generally, a 1.0 kg decrease in body weight represents a 1.0 L decrease in body water (mostly plasma volume as well as extracellular compartments) that should be replaced through the consumption of fluids. Unfortunately, vomiting, which can occur during heat injury, may result in between 1.5 and 5.0 L of fluid loss, thus further dehydrating the individual. However, a victim of heat injury who has been vomiting may not be able to consume fluids by mouth. Rehydration may have to occur through an intravenous (i.v.) route. [9, 10].

It should be noted that fluid replacement during prolonged sweating by consuming large quantities of plain water may result in a condition known as hyponatremia [3]. Hyponatremia is generally the result of a poor fluid-replacement strategy before, during, and after prolonged exercise. Plasma sodium (Na^+) concentrations are regulated to remain between 135 and 145 $mmol \cdot L^{-1}$ under normal physiologic conditions because of its importance in cellular volume and function. Thus, hyponatremia (low plasma sodium) is defined as a Na^+ concentration < 135 $mmol \cdot L^{-1}$ (mild) and severe hyponatremia as a plasma Na^+ concentration of 120 $mmol \cdot L^{-1}$. Hyponatremia, aggravated by significant loss of Na^+ from prolonged sweating, may become a potentially life-threatening condition [11].

Outside of the patient population, hyponatremia usually occurs in high-endurance athletes participating in marathons, ultramarathons, and Ironman triathlons, but it can also occur in persons working for long periods of time in hot environments [12]. The incidence of hyponatremia in high-endurance athletes ranges from 13% to 18%. Symptoms of hyponatremia can range from none to minimal (~70% of cases) to severe, including encephalopathy, respiratory distress, and death [10]. During these events or work periods, hyponatremia develops when the athlete or worker consumes too much plain water in an attempt to rehydrate after copious sweating. The excess water results in a dilution of plasma Na^+, which, in turn, causes an osmotic disequilibrium that can lead to cerebral edema and pulmonary edema. These conditions have proven fatal in a small number of patients [12].

Risk factors for the development of hyponatremia are exercise durations of greater than 4 h, gender (females are more likely to develop hyponatremia), low body mass, excessive consumption of water (>1.5 $L \cdot h^{-1}$), pre-exercise hydration, consumption of nonsteroidal anti-inflammatory medications (although not all studies have shown this), and extreme environmental temperature [12]. Consumption of large quantities of plain water is highly correlated with the development of hyponatremia [13]; the majority of athletes or workers in hot environments become at least mildly hyponatremic. However, not all those with hyponatremia become symptomatic [12]. Therefore, the presence of mild hyponatremia may not be harmful. Nevertheless, hyponatremia can have devastating consequences, such as death, for the individual [12]. Prevention of this condition involves appropriate use of fluid-replacement strategies including the consumption of balanced electrolyte/carbohydrate "sports drinks" such as those discussed previously [10]. However, consumption of large quantities of water alone may be enough to cause hyponatremia. A condition known as primary or psychogenic polydipsia, a medical condition in which the patient consumes large quantities of water (>3 $L \cdot d^{-1}$), may result in hyponatremia, coma, and seizures [14, 15].

The issue of hyponatremia aside, there is a popular notion that sodium loss from sweating is significant and must be replaced on a regular basis after the commencement of exercise. Notwithstanding this belief, actual sodium loss is limited because much of the sodium reaching the sweat glands is returned to the plasma through active transport mechanisms [3]. Therefore, sweat is hypotonic to the plasma, and only insignificant amounts of sodium are lost in the first hour or two of exercise [16]. However, during prolonged sweating lasting several hours, significant amounts of sodium may be lost, and it is advisable to consume a sports drink that contains balanced electrolytes to replace those lost during sweating, as long as the concentration of electrolytes and carbohydrates does not exceed 8% by volume. Exceeding the 8% limit will slow absorption of fluids from the gastrointestinal (GI) tract [1]. The situation is complicated by the fact that the water absorption from the duodeno-jejunal section of the gastrointestinal (GI) tract is somewhat rate limited (~ 8.1 $ml \cdot h^{-1} \cdot cm^{-1}$). The rate of water absorption in the gut does *no*t seem to be influenced by intensity of exercise or sweat rate [17]. Thus, depending on circumstances, the intake of plain water could exceed the capacity for the GI tract to absorb it. The addition of carbohydrate/electrolyte to the water can increase the fluid absorption to ~12.0 $ml \cdot h^{-1} \cdot cm^{-1}$ [17].

Electrolyte and carbohydrate sports drinks should be as palatable as possible and cool but not cold (~15 °C). Small quantity taken at frequent intervals, i.e., about 830–1180 mL (28–40 oz.) every 15–20 min, is a more effective regimen for practical fluid replacement than the intake of large amounts of fluids per hour [3]. Communal drinking containers may not work as well as individual bottles since individuals are seldom aware of just how much sweat they produce or how much water is needed to replace that lost in the sweat (~1 $L \cdot h^{-1}$ is a common rate of water loss). Consuming individual bottles of replacement fluids provides a visual indication of the volume of fluid intake (replacement).

Therefore, in an environment with a high heat index coupled with copious sweating, it would seem prudent to provide the subjects with carbohydrate/sodium containing drinks to assure that sufficient water is absorbed by the GI tract to replace that lost due to sweating. Finally, severe sweating for a period of hours can induce a phenomenon known as sweat gland fatigue, which may ultimately contribute to the reduction the ability to regulate core body temperature [1, 3].

Physiological Consequences of Dehydration and a Poor Hydration Strategy

From a practical standpoint, it has been suggested that there is an inverse relationship between body core temperature (T_{core}) and a decrease in body water beyond 3% [18]; however, recent studies have challenged this assertion [19]. In fact, during some athletic events, athletes may voluntarily hyperhydrate (consume extra fluids) prior to heavy or prolonged exercise which may improve performance and be protective against thermal stress. In principle, the increased fluid would allow for increased heat loss from sweat evaporation and provide a buffer against hypohydration [18]. However, poor hydration habits among nonprofessional athletes (e.g., casual joggers, high school athletes), heat exposure during outside work, and those exposed to heat in occupational settings can lead to heat-related illness and injury [20].

Dehydration can occur due to substantial sweating followed by a failure to rehydrate during exposure to a hot environment, with or without high humidity. Rates of water loss from sweating may reach as much as 1.0 $L \cdot h^{-1}$ for moderate exercise in the heat up to a maximum of 3.7 $L \cdot h^{-1}$ and, if this fluid is not replaced, may have serious physiological consequences [21]. The initial decrease in plasma volume can lead to an increased plasma osmolality, which can cause muscle cramps [4]. As dehydration worsens, the result may be a compromise in cardiovascular function since the water lost through sweating may result in a general decrease in plasma volume. The decreased plasma volume further leads to a reduction in stroke volume resulting in an increased heart rate and myocardial oxygen demand, which may, in the susceptible individual, trigger ischemic events in those with underlying coronary artery disease [22, 23]. The reduced plasma volume also leads to a reduction in cutaneous blood flow in order to redirect blood to more central regions (presumably to maintain cardiovascular stability). Consequently, the reduction in blood flow leads to a reduction in heat loss through the skin. The reduction in heat loss from the skin may contribute in a significant way to heat injury and heat stroke [24].

Origin and Control of Core Body Temperature

The existence of internal body heat is the result of the metabolic conversion of substrate – primarily carbohydrates, fats, and to a lesser extent proteins – into energy in the form of adenosine triphosphate (ATP) (the so-called energy currency of the body). ATP is central to the energy driven process of the body. Energy in the form of ATP is used by muscle in the performance work [25]. Although the metabolic production of ATP may occur in the absence of oxygen (anaerobic metabolism), the vast majority of ATP is produced in the presence of oxygen (aerobic metabolism) [25]. The process is not efficient (<25%), and, after a portion of the energy is consumed in supporting various physiological and biochemical processes, the remaining energy (>75%) is converted into heat [20]. For example, at rest the average aerobic metabolic energy production is about 4.2 $kJ \cdot kg^{-1} \cdot h^{-1}$ (or 1.0 $kcal \cdot kg^{-1} \cdot h^{-1}$). Therefore, a 75 kg man would generate about 315 $kJ \cdot h^{-1}$ (75 $kcal \cdot h^{-1}$) of metabolic energy. An increase above the basal level of activity will result in an increase in the metabolic energy production and, thus, an increase in core body temperature. Should the O_2 consumption during exercise increase to ~500 $ml \cdot min^{-1}$, this would result in the production of 656 $kJ \cdot h^{-1}$ (156 $kcal \cdot h^{-1}$) of energy. Should only ~25% of this energy be used for physiological and biochemical processes and the remaining 75% be released as heat, then ~492 $kJ \cdot h^{-1}$ (123 $kcal \cdot h^{-1}$) of core body heat must be exchanged with the external environment in a balanced manner such that the core body temperature remains more or less constant.

Body core temperature (T_{core}) is controlled to within a narrow range because nearly all physiological and biochemical mechanisms operate within this optimal temperature [4]. T_{core} is maintained primarily through a balance between metabolic heat production and the transfer of heat to the environment through four biophysical/physiological mechanisms, namely, conduction, convection, radiation, and sweat evaporation. In thermoneutral environments, radiation, convection, and, to a lesser extent, conduction, are the primary mechanisms involved in heat transfer from the body to the external environment [1]. In hot environments, or during physical exercise (as core body temperature increases ~ 0.5 °C above baseline), sweat evaporation becomes the most important mechanism for heat transfer to the environment [1]. The contribution of each of these physical and physiological mechanisms involved in human thermoregulation can be described using the basic heat balance equation, as follows:

$$S = \left(M - W\right) \pm C \pm R \pm K - E$$

where S = change in body heat content (changes in T_{core}); (M-W) = total metabolism minus external work performed; C = convective heat exchange; R = radiative heat exchange; K = conductive heat exchange; and E = evaporative heat loss. By determining the values of each of these factors, one can establish the flow of heat from the body to the environment and further determine if there will be an increase (or decrease) in T_{core}. Note that the term W represents the amount of metabolic energy used to perform work. The energy used to perform external work (W) is subtracted from the total amount of energy produced since mechanical work does not create heat [1]. In addition, nonphysiological (behavioral) strategies (leave the area, don or doff clothes, etc.) are also used in human thermoregulation [1].

During strenuous exercise or during exposure to hot environments, sweating followed by evaporative heat loss is the primary means of transferring heat in humans from the body to the environment. For every liter of water that evaporates, 2436 kJ (580 kcal) is extracted from the body and transferred to the environment [3]. The enormous capacity for heat loss through sweat evaporation is more than adequate to dissipate metabolic heat generated by a subject both at rest (~315 kJ·h^{-1} for a 75 kg man) and at high levels of activity. For example, mean sweat rate in endurance athletes during exercise ranges from 1.5 to 2.0 L·h^{-1} [26]. This magnitude of sweat loss, which translates into an evaporative heat loss capacity of 3654–4872 kJ (~11.6–15.5 times the amount of heat produced at rest), easily transfers sufficient heat to the environment to prevent or minimize increases in T_{core}. An ambient wet-bulb temperature (to account for humidity) of 35 °C can result in a body fluid loss at rest (80 kcal·h^{-1}) of 0.8–1.0 L·h^{-1} through sweating. This fluid loss would be correspondingly greater with activity and in those individuals acclimatized to hot environments [1].

Human beings have 2–5 million eccrine (sweat) glands asymmetrically distributed over the body not all of which are active [4]. The physiological process of acclimatization involves, in part, recruitment and activation of previously dormant sweat glands in order to increase the sweat rate and, potentially at least, heat transfer to the environment [27, 28]. Acclimatization also involves triggering of the sweating response at a lower T_{core} and at an earlier point during the exposure to heat or exercise [29]. In addition to dehydration from sweating, significant water loss from the respiratory tract at rest can be as great as ~350 mL·d^{-1} under mild conditions of heat and humidity. Respiratory water loss will also contribute to the overall dehydration of an individual exposed to heat or during exercise [3]. Therefore, physiological acclimatization to heat will result in a greater loss of body water in any particular hot environment compared with no acclimatization.

Although a generally extremely effective means of heat transfer, heat loss through the vaporization of sweat can be defeated in environments with high humidity [3]. The evaporation of sweat is inhibited, and heat transfer to the environment is reduced, if not completely blocked, in humid environments where the atmosphere is saturated with water. For example, when the *heat index* (a combination of heat and humidity as described in tables produced by National Oceanic and Atmospheric Administration [NOAA]) is greater than 35 °C and is largely due to high humidity, the evaporative heat loss is virtually nonexistent. Thus, even if an individual is exercising in an ambient "dry" temperature within a comfortable range (e.g., 21–23 °C), the high humidity (>90% relative humidity [RH]) can still inhibit sweat evaporation and could result in an "apparent temperature" or heat index high enough to create heat stress that is potentially great enough to result in heat injury. Indeed, it has been reported that several football player deaths occurred when the absolute temperature was below 23 °C but the RH was >95% [3]. However, this situation may have been aggravated by the football player's protective gear blocking the normal routes of heat exchange with the environment.

Work to Rest Ratio

The control of heat stress is not limited to the physiological mechanisms discussed previously. There are several other means of controlling heat stress, which do not rely on biophysical or physiological mechanisms. Some of these means are in a category usually known as "administrative" controls according to OSHA-NIOSH. These controls usually involve limiting exposure to heat using work/rest cycles, which allow the individual to exit the hot area for a time. When the individual moves away from the source of heat, the physiological processes of heat transfer to the (presumably) cooler environment can occur. In addition to the removal from heat, the individual may be allowed to physically rest, thus reducing the metabolic heat production that is added to the environmental heat source. In addition, the individual may be able to rehydrate in order to avoid the effects of dehydration discusses previously. Depending on the severity of the heat exposure, administrative controls can be adjusted to allow for a greater percent of rest per work as part of limiting the exposure to the heat.

Other work/rest cycles may take the form of timing the work during a cooler part of the day or evening to limit the exposure to heat. Work/rest may also take the form of putting additional workers on the job in order to reduce the workload for any given individual (thus reducing the amount of metabolically generated heat) [30]. In addition to these strategies, workers should be provided with an area that is cool in order to obtain respite from the heat. The individual must be provided with plenty of opportunity to drink fluids (even require workers to drink a specified amount of fluid per hour to maintain proper hydration). The administrative policy must also allow for self-paced work (i.e., workers can reduce work intensity or rest when they feel the need).

Finally, an administrative policy may use the Thermal Work Limit guide to define the maximum sustainable work (metabolic) rate that a well-hydrated and acclimatized individual can maintain in a particular thermal environment [30]. This may involve some monitoring of T_{core} and sweat rates to assure that the T_{core} does not exceed 38 °C ("industrial" and "hyperthermia") and the fluid loss from sweating does not exceed 1.2 kg·h^{-1}. In a hot environment, the thermal work limit may only be maintained with appropriate work/rest cycles and adequate hydration. However, monitoring of T_{core} and hydration in the field can be a challenge. Strictly speaking, it would require a designated person (supervisor, industrial hygienist, etc.) to periodically measure the workers T_{core} and body weight (to determine fluid loss from sweating) and this may be logistically challenging in the field.

Cooling Strategies and Devices

Several strategies for mitigating the effects of heat stress, including those involving the physiological response to heat (physiological heat strain), and the biophysical and physiological mechanisms for removing heat from the body have been discussed. Non-physiological administrative strategies to reduce heat exposure through work/rest cycles, as well as fluid-replacement strategies, have also been described previously. The following discussion will focus on the strategies for limiting the physiological response to heat exposure through the application of cooling devices that prevent increased T_{core} during exposure to environmental and internally generated heat.

Numerous studies have addressed a multiplicity of cooling garments, ice vests, and phase change materials used to keep the wearer cool. Each of these strategies has its advantages and disadvantages. The most effective cooling systems appear to be Spandex™ body suits impregnated with flexible plastic tubing in contact with the skin and through which fluid is continuously circulated thus allowing heat to be removed away from the wearer through convection (Fig. 7.1) [31, 32]. The temperature and flow rate of the fluid may be controlled with a water bath and pump system such that the rate of heat transfer may be adjusted to the heat output of the person wearing the system. The advantage of this system is that the rate of heat transfer can be controlled [31, 32].

From a physiological standpoint, optimal heat transfer occurs during exposure to an *optimal* temperature not a *maximal* temperature. The reason for this involves the physiology of heat transfer from the skin to the environment. Under normal circumstances, heat moves from the core regions of the body to the skin (shell) for heat transfer by both mass transfer and through the circulation of warm blood from central regions to the skin via the cutaneous circulation [4]. The redistribution of blood to the cutaneous circulation involves complex cardiovascular adjustments including a vasodilation of cutaneous blood vessels near the surface of the skin. The greater the mobilization of warm blood to the skin, the greater the heat transfer. However, the magnitude of the vasodilation of the cutaneous blood vessel is influenced by cold receptors in the skin. Should the skin become cold enough, the cutaneous vasculature will constrict thus limiting blood flow to the skin. This reduction in blood flow reduces the opportunity for heat transfer to the environment thus conserving

Fig. 7.1 Liquid cooling garment. (NPPTL/NIOSH photo archive)

body heat in a cold environment [1]. Therefore, should the circulating water temperature in the cooling garment be too low, the wearer will experience a cutaneous vasoconstriction, which will actually reduce the heat transfer from the skin to the circulating water tubing [31, 32]. Fortunately, studies have shown that a water temperature of 18 °C is an optimal temperature for maximal heat transfer, since that water temperature does not induce cutaneous vasoconstriction [31]. However, in certain therapeutic settings, there is a desire to induce body temperature to below normal (hypothermia: T_{core} ~ 32–34 °C) using a water-cooled system or a convective spray cooling strategy [33, 34]. However, these strategies are for special medical applications and are not performed outside of a modern clinic.

The cooling garment described above has some significant disadvantages for use in the field. First of all, the garment is tethered to a water bath and temperature controller that is too bulky to be taken into the field [31, 32, 35]. Secondly, the garment cooling system requires a power source to operate the water circulating bath and temperature controller. This is also not practical for field use at this time. Currently, these types of liquid cooling systems are used either for research purposes or in specialized settings such as military aircraft [36, 37].

As of this writing, cooling systems used occupationally are essentially a fabric vest with a series of pockets into which are inserted plastic bags containing ice or some kind of phase change material. The advantage of using a cooling vest employing ice or phase change material packs is that they allow complete mobility by not being connected to a motorized circulating water bath. However, the disadvantages are that the ice melts or the phase change material warms such that no cooling is provided and there are no means to control the temperature against the skin. Other significant issues include imposing too cold a temperature against the skin resulting in vasoconstriction of the cutaneous vasculature and a reduction of the flow of warm blood to the periphery limiting the potential for heat exchange. Finally, the melting of ice or warming of the phase change material occurring within 30–45 min limits the cooling advantage to heat exposures of less than an hour, thus requiring that the ice pack/phase change material must be frequently replaced and refrigeration must be available to store ice/phase change materials for use which requires electricity.

Some cooling systems rely on a vapor compression system for cooling that can be used in conjunction with a self-contained breathing apparatus (SCBA). This application has, thus far, been tested in our lab at the National Personal Protective Technology Laboratory, NIOSH/CDC, in conjunction with the SCBAs with HAZMAT suits [38]. A wearable vapor compression cooling system has also been developed by Aspen Systems, Inc. This system is belt worn and can force compressed cool air into a garment capable of providing 120–300 W of cooling to the wearer. The advantage is portability, but the disadvantage is limited battery life (2 h) and weight.

A novel approach to personal cooling is being investigated using anisotropic materials constructed of carbon nanotubes. This material allows transfer of heat in only one direction (e.g., body heat is permitted to cross the material, but environmental heat is prevented from crossing the material in the opposite direction) [39]. Clearly, these new materials may revolutionize the construction of protective garments which will provide passive cooling and solve many of the difficulties described in previous paragraphs in this section.

Physiological Monitoring Systems

Physiological monitoring has been performed in one form or another for more than 2500 years. The ancient Indian physician, Sage Kanada (~600 BCE), was the first to describe the pulse and relate the pulse to various physiological and pathological states [40]. Body temperature (i.e., fever) and its relationship to illness were noted by the ancient physicians Hippocrates (fifth century BCE) and Galen (second century CE) [41], but the ability to measure body temperature had to wait until the invention of the first crude mouth thermometer by Santorio in 1625 [42]. Arterial blood pressure was first measured in a horse by the English clergyman Stephen Hales [43], but the auscultative technique using a stethoscope and cuff sphygmomanometer was not developed until the nineteenth century. The first noninvasive sphygmomanometer was invented by von Basch ~1881 but was not introduced into clinical medicine until the development of modern auscultative techniques by Riva-Rocci in 1896 [44]. The electrical activity of the heart was first measured by Marey [45], but the first "electrocardiogram" (ECG) was recorded by Waller [46]. Finally, the "modern" ECG was recorded by Einthoven [47], who was also the first to recognize its clinical significance.

The twentieth century witnessed the rapid expansion of technologies allowing for the measurement of physiological variables with ever-increasing accuracy and rapidity. As human physiological research moved from the laboratory to the field, the ability to measure physiological variables without being "tethered" to the laboratory became increasingly important. This necessity fostered the development of several types of "remote" or wireless physiological monitoring systems that eventually became commercially available. Metabolic measurements (breath by breath analysis of O_2 consumption and CO_2 production) using a wearable "metabolic cart" became possible with the development of devices like the COSMED™ devices (e.g., K4b2) beginning in 1980. A wearable heart rate monitor that included a chest strap and a wristwatch-type receiver (Polar™ Heart Watch) was first introduced in 1982. NASA, in collaboration with the Johns Hopkins University, developed an ingestible "core" temperature pill for use by astronauts [48]. The technology has since been commercialized under the name of the CorTemp (HQ Inc.). A similar technology is commercially available under the Minimitter™ brand. In-helmet temperature monitors have also been developed and compared favorably to core body temperatures measured by rectal thermistors [49]. An attempt to measure several physiological variables simultaneously has also been developed by Zephyr™ Technology, Inc. (Fig. 7.2) [50]. Founded in 2003, this system utilizes a chest strap with sensors that monitor heart rate, heart rate variability, respiration, skin temperature, activity level, and 3D axis accelerometry. The sensor vest known as the LifeShirt® had the capability of monitoring heart and respiratory rate, tidal volume,

Fig. 7.2 Zephyr Technology™ Bioharness. (Photo courtesy of Zephyr™ Performance Systems with permission)

ECG, and skin temperatures [51]. Although the LifeShirt is no longer available, the technology provided a platform for physiological monitoring that became a model for other technologies. Recently, a synchronous wearable wireless body sensor network has been developed using novel textile technologies, which may prove invaluable when worn by emergency first responders [52]. In fact, these technologies continue to undergo development with the aim of adding more monitored variables, providing the most accurate measurements of those variables, and increasing the robustness for use in the field under a variety of environmental conditions.

These technologies are used by both athletes and patients in hospital settings, but interest has been shown in several occupational categories (e.g., firefighters, first responders) and the military in continual monitoring of physiological variables for safety reasons [50, 51]. Therefore, any device used for physiological monitoring must not only provide accurate measurements of the physiological variables but must be extremely robust to allow use in harsh environment.

In addition, the device itself must have a limited impact on the physiological burden of the wearer [53]. In sum, it seems safe to say that the rapid development of wearable physiological monitoring systems for use by athletes, first responders, and military personnel will continue. Advances in technology are expected to include a greater array of measurable physiological variables, smaller less ergonomically burdensome devices, and increased robustness thus allowing the use of wearable physiological monitors under the most harsh of environmental conditions.

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Chapter 8
A Road Map for Interdisciplinary Collaborations

Rachel K. Katch, Christopher W. Myers, Francis G. O'Connor, and Douglas J. Casa

Abstract When it comes to protecting athletes, warfighters, and laborers from exertional heat stroke (EHS), an interdisciplinary collaboration between different entities is of the upmost importance, especially when those entities share many common goals. Currently, organizations such as the Korey Stringer Institute, Uniformed Services University of the Health Sciences, Occupational Safety and Health Administration, and additional organizations discussed in this section do not have an effective framework in place to share their research and EHS knowledge, leading to a potential lack in appropriate EHS care. By providing a road map for effective interdisciplinary collaboration, organizations can facilitate advancement in each entity's ability to prevent, recognize, treat, and recover/return to activity from EHS.

Introduction

On October 27, 2016, a meeting, titled "Heat Risks in the Realm of Military and Occupational Safety," was organized by the Korey Stringer Institute (KSI) and held at the Uniformed Services University of the Health Sciences (USUHS) in Bethesda, MD. Representatives from the Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), National Oceanic and Atmospheric Administration (NOAA), USUHS, and KSI attended the

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R. K. Katch (✉) · C. W. Myers · D. J. Casa
Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, CT, USA
e-mail: rachel.katch@uconn.edu

F. G. O'Connor
Consortium for Health and Military Performance, Uniformed Services University of the Health Sciences, Bethesda, MD, USA

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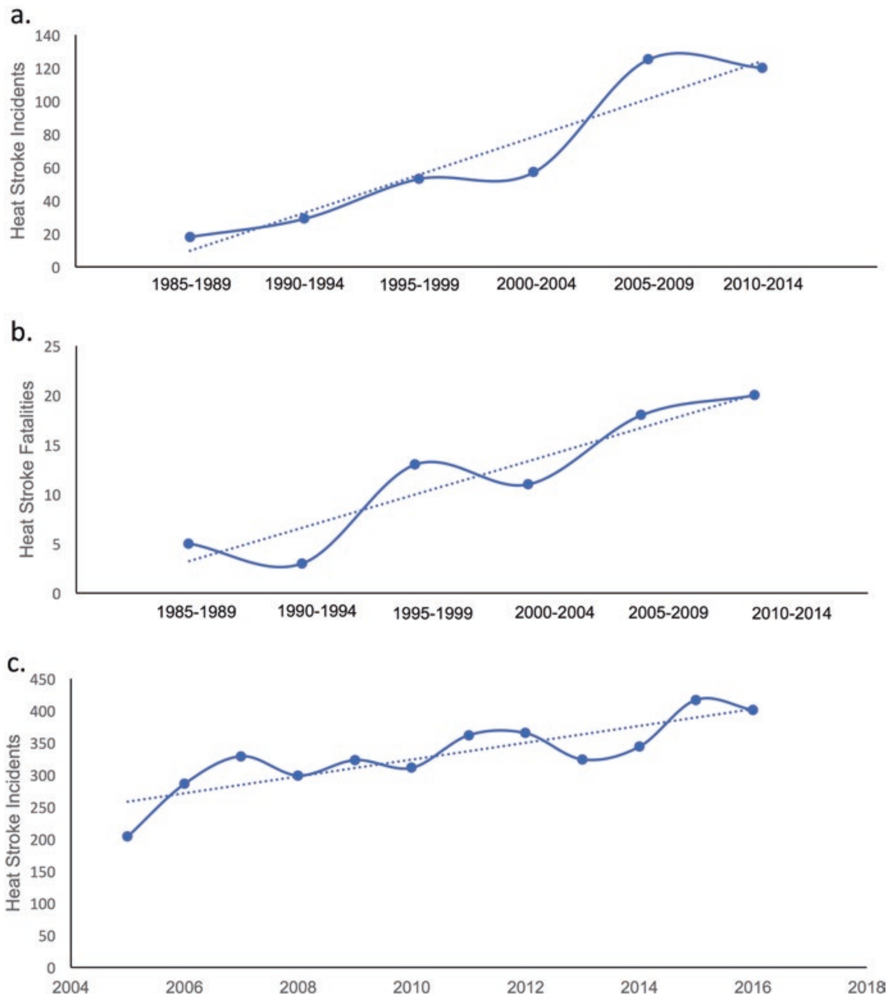

Fig. 8.1 (**a**) Represents EHS incidents in the occupational setting utilizing 5-year reporting periods [1]. (**b**) Represents EHS fatalities in the high school athletic settings utilizing 5-year reporting periods [2]. (**c**) Represents EHS incidents in the military setting utilizing annual reporting periods [3]

meeting. It was a historic moment for many reasons, as this was the first time governmental organizations and academic institutions assembled and discussed heat risk across their respective populations – athletes, warfighters, and laborers.

Every year, athletes, warfighters, and laborers are exposed to physiological demands and environmental stresses, and collaboration across representative organizations can improve safety and performance in extreme heat (Fig. 8.1). Overlapping concerns regarding prevention, recognition, treatment, and return to sport/duty/work of heat-related illnesses allow cooperation to greatly enhance quality of services and products by pooling resources and minds. For example, the central principle of exertional heat stroke (EHS) treatment is to cool the athlete, warfighter, or laborer as fast as possible. However, there is no standardized consensus for EHS treatment across these settings. Similarly, heat acclimatization, work-to-rest ratios based on environmental conditions, individualized hydration practices, and many other guidelines for activity in the heat are universally important across populations. The physiological response to heat is a biological response, not a work setting response. While the circumstances of each setting dictate the manner in which prevention and emergency action plans for exertional heat illness are implemented, the underlying principles to maximize safety and performance remain the same and should be addressed at the organizational level. While the context and unique pressures of each setting may limit the treatment options that are readily available, the basic premise of rapid evaluation, immediate onset of cooling, cooling with the most effective modality for the circumstance, and transporting to advanced care, as clinically indicated, should not change based on the population.

Review of Organizations

There are many organizations in the athletic, warfighter, and occupational settings that have recommendations and policies regarding the prevention, recognition, treatment, and return to activity from EHS (Table 8.1). In the athletic settings, the National Collegiate Athletic Association (NCAA) is on the forefront. The NCAA is in charge of Division I, II, and III colleges/universities, with 1123 institutions under its regulation [4]. As part of that regulation, the NCAA provides information and guidelines regarding the health and safety of the athletes under their control, including injuries/illnesses related to exercising in the heat [4]. In occupational settings, there are many organizations responsible for health and safety policy-making; in this chapter, we will focus our review on the OSHA and the NIOSH due to widespread public awareness of these organizations. The mission of OSHA is to assure safe and healthful working conditions for working men and women by setting and enforcing standards, providing training, outreach, education, and assistance [5]. NIOSH's mission is very similar, with the goal of developing new knowledge in the field of occupational safety and health and transferring that knowledge into practice [6]. For the military, currently the individual services (e.g., Army, Navy, Air Force, and Coast Guard) each develop service-specific guidance for their warfighters; however, a leading organization involved in clinical EHS research and the facilitation of joint policy-making is the Consortium for Health and Military Performance (CHAMP) at USUHS, a Defense Center of Excellence. Their mission is to educate, train, and comprehensively prepare uniformed services health professionals, scientists, and leaders to support the Military and Public Health Systems, the National Security and National Defense Strategies of the United States, and the readiness of our Uniformed Services [7]. In regard to all three settings (i.e., athletics, warfighting, and occupational settings), the KSI works to integrate and disseminate knowledge and practice to best service these constituents. While KSI does not set policies in these settings, it provides research, recommendations, education, advocacy, and

Table 8.1 Current organizational recommendations for exertional heat stroke [10–19]

	Prevention	Recognition	Treatment	Return to activity
KSI[10]	• Gradual heat acclimatization over a 10–14 day period • Ensure hydration (e.g., urine color, measure athlete's weight pre/post activity, encourage drinking throughout activity and the day, calculate sweat rate) • Wear loose-fitting, absorbent, or moisture wicking clothing • Minimize the amount of equipment worn during hot/ humid conditions • Minimize warm-up time, and practice in the shade when possible • Sleep at least 6–8 h and eat a well-balanced diet • Practice and perform conditioning drills avoiding the hottest parts of the day • Slowly progress the amount of time and intensity of conditioning practices throughout the season • Have pre-participation exam identifying high-risk individuals • Make sure emergency action plan is consistent with the most recent guidelines regarding EHS • Educate other medical staff, athletes, coaches, emergency personnel, and parents about EHS and proper hydration • Ensure proper body cooling methods are available (e.g., cold water immersion tub, ice towels, access to water, ice) and that equipment is prepared before activity begins • Establish hydration policies according to WBGT readings, time of activity, intensity/duration, equipment issues, rest/water breaks • Identify both intrinsic and extrinsic risk factors of EHS	• Athletes and coaches be trained in the recognition of EHS • Ensure proper medical coverage is provided that is familiar with EHS *Signs & Symptoms:* • Rectal temperature >40 °C • Irrational behavior, irritability, emotional instability • Altered consciousness, coma • Disorientation or dizziness • Headache • Confusion or just look "out of it" • Nausea, vomiting, diarrhea • Muscle cramps, loss of muscle function/balance, inability to walk • Collapse, staggering, or sluggish feeling • Profuse sweating • Decreasing performance or weakness • Dehydration, dry mouth, thirst • Rapid pulse, low blood pressure, rapid breathing	• Activation of emergency action plan • Remove all equipment and excess clothing • Cool the athlete as quickly as possible within 30 min via whole body ice water immersion (place them in a tub/ stock tank with ice and water approximately 1.7–14.4 °C) • Stir water and add ice throughout the cooling process • If cold-water immersion is not possible, take athlete to a shaded, cool area and use rotating cold, wet towels to cover as much of the body surface as possible • Maintain airway, breathing, and circulation • After cooling has been initiated, call 911 • Monitor vital signs such as rectal temperature, heart rate, respiratory rate, blood pressure, monitor central nervous system status • Cease cooling when rectal temperature reaches 38.3–38.9 °C • Cool first, transport second	• A specific return to play strategy should be implemented • The following guidelines should be implemented: – Physician clearance prior to return to physical activity (e.g., asymptomatic, lab tests normal) – Avoid exercise for at least one week after incident – Begin gradual return to play protocol under the direct supervision of an appropriate health-care professional such as an athletic trainer or physician – Heat tolerance testing may be indicated prior to return to play • Type and length of return to play program may vary individually, but a general outline includes: – Easy-to-moderate exercise in a climate-controlled environment for several days, followed by strenuous exercise in a climate-controlled environment for several days – If applicable to the individuals in sport: easy-to-moderate exercise in the heat with equipment for several days, followed by strenuous exercise in the heat with equipment for several days

NCAA[11]	• Initial complete medical history and physical evaluation, followed by yearly health status updates • Gradual heat acclimatization over a minimum of 10–14 days • Hold competitions during cooler parts of the day • Hydration should be maintained during training and heat acclimatization (drink two cups or more of water and/or sports drink in the hour before practice or competition, and continue drinking during activity every 15-20 min) • Athletes should replace fluid lost during training/ competition prior to any further activity • Frequent rest periods, especially for equipment laden sports • Wear moisture wicking clothing • Regular monitoring of WBGT and activity modifications • Limiting two-a-day practices • Weight athletes pre-and post-exercise • Addressing intrinsic risk factors	• Athletes and coaches be trained in the recognition of EHS • All training should be conducted under the supervision of a coach or athletic trainer *Signs & Symptoms:* • Rectal temperature >40 °C • Weakness, cramping, rapid and weak pulse, pale or flushed skin • Excessive fatigue, nausea, unsteadiness, vision disturbance, mental confusion, incoherency • Sweating profusely, but may have hot, dry skin • Central nervous system dysfunction	• Activation of emergency action plan, including calling 911 • Assessment of core body temperature/ vital signs • Immediate cooling via cold-water immersion • Alternate methods include rotating cold, wet ice towels • Cool first, transport second	• No recommendations can be found
NIOSH[12]	• Heat acclimation • Calculating metabolic heat load and proper clothing for heat dissipation • Assessing WBGT for work modifications • Medical monitoring of workers • Designating a work-site as, “Dangerous Heat Stress Area,” and providing work modifications • Addressing intrinsic risk factors • Proper work-to-rest ratios • Proper access to water (drinking 237ml of water or other fluids every 15–20 min)	• Training workers/ supervisors in the signs and symptoms of EHS *Signs & Symptoms:* • Rectal temperature >41 °C • Confusion, altered mental status, slurred speech • Loss of consciousness (coma) • Hot, dry skin or profuse sweating • Seizures	• Calling 911 • Someone should monitor the worker until emergency care arrives • Move worker to a shaded, cool area and remove outer clothing • Cool the worker quickly with a cold-water ice bath if possible; wet the skin, place cold wet cloth on skin, or soak clothing with cool water • Circulate the air around the worker to speed cooling • Place cold, wet cloth or ice on head, neck, armpits, and groin; or soak the clothing with cool water	• Recognizes that there could be long-term effects of suffering EHS • Recommends more research be conducted on how to properly return an individual to work after suffering an EHS

(continued)

Table 8.1 (continued)

	Prevention	Recognition	Treatment	Return to activity
NOAA[13, 14]	• Block out direct sun or other heat sources • Use cooling fans/air-conditioning • Proper work-to-rest cycles • Drink lots of water (i.e., about 1 cup every 15 min) • Wear lightweight, light colored, loose-fitting clothing • Avoiding alcohol, caffeinated drinks, or heavy meals • Addressing intrinsic risk factors	*Signs & Symptoms:* • Temperature 39.4 °C or higher • No sweating • Rapid pulse • Fast and shallow breathing • Hot, red, dry skin • Nausea, dizziness, headache, confusion • Dry, pale skin • Unconsciousness, seizures, mood changes	• Calling 911 • Move the victim to a cooler, shaded environment • Use cool baths or sponging to reduce body temperature • Don't leave the person alone • Lay individual on their back and remove any close objects if they are seizing • Lay on side if individual is sick • Remove any heavy outer clothing • Have person drink cool water (small cup every 15 min) if they are alert enough and not sick to their stomach • Cool the person by fanning, or misting with cold water, wet cloth, or wet sheets • If ice is available, place ice packs under arm pits and groin area	• No recommendations can be found
OSHA[15–18]	• Work modifications based on heat index • Heat acclimation of new and returning workers performing strenuous work • Checking weather forecast regularly • Sunscreen and other protections from direct sunlight • Potable water on work sites • Medical services are available • Providing workers with cooling modalities • Providing workers with shaded/air-conditioned rest areas • Addressing intrinsic risk factors	• Training workers/ supervisors in the signs and symptoms of EHS *Signs & Symptoms:* • Confusion, irrational behavior, loss of consciousness, convulsions • Lack of sweating (usually), hot, dry skin • Rectal temperature >41 °C	• Calling 911 • The worker should be placed in a shady, cool area and their outer clothing should be removed • Worker's skin should be wetted and air movement around the worker should be increased to improve evaporative cooling until professional methods of cooling are initiated and the seriousness of the condition can be assessed • Fluids should be replaced as soon as possible • The medical outcome of an episode of EHS depends on the victim's physical fitness and the timing and effectiveness of first aid treatment	• No recommendations can be found

	Prevention	Recognition	Treatment	Return to activity
U.S. Military[19]	• Gradual heat acclimatization over about two weeks • Temperature monitoring via WBGT measurements • Proper work-to-rest ratios • Monitoring duration of activity • Wear clothing appropriate for environment • Addressing intrinsic and extrinsic risk factors • Proper fluid replacement during exercise that is dependent on the work being conducted • Proper medical attention readily available • Deploy microclimate cooling systems and air-cooled garments • Electrolyte and salt replacement	• Leadership personnel be trained in the recognition of EHS • Ensure proper medical coverage is provided *Signs & Symptoms:* • Elevated core temperature >40 °C • Central nervous system dysfunction • Delirium, convulsions, coma • Headache, dizziness, drowsiness, restlessness, ataxia, confusion • Irrational or aggressive behavior • Profuse sweating	• Cool the individual as quickly as possible • Remove victim to a cool shady place • Remove clothing • Keep skin moist • Rectal temperature continuously monitored • Cool the individual until rectal temperature reaches 38.3 °C • Immersion in cool or iced water with skin massage is preferred; ice sheets and ice packs are also effective	• Referral to a medical evaluation board • After full clinical recovery, the medical evaluation board will give a 3-month profile – Restricts soldier from heat exposure and vigorous physical exercise for periods longer than 15 min – No maximal effort testing • If after 3-months the soldier has not shown heat intolerance, normal work will be permitted – Maximal exertion and significant heat exposure are still restricted • If the soldier doesn't manifest heat intolerance, normal activities are resumed and the soldier may be returned to full unrestricted duty without a physical evaluation board • Lack of full recovery or any evidence of significant heat intolerance during the profile, the soldier is referred to a physical evaluation board

consultation to help athletes, warfighters, and laborers perform and stay safe in the heat [8]. Lastly, the NOAA's missions are: (1) to understand and predict changes in climate, weather, oceans, and coasts; (2) to share that knowledge and information with others; and (3) to conserve and manage coastal and marine ecosystems and resources [9]. Although NOAA does not represent any specific population, its climatological focus can benefit everyone.

Altogether, these organizations provide a comprehensive view of the prevention, recognition, treatment, and return to activity of EHS in all settings. However, collaboration and open communication between these organizations in an effort to mitigate morbidity and mortality of EHS have not been fully explored until recently. Thus, combining the efforts of these organizations is an imperative next step in improving EHS policies and guidelines.

How Can We Improve Collaboration?

There are many ways in which collaborations among the aforementioned organizations can facilitate advancement in each organization's ability to prevent, recognize, treat, and recover/return to activity from EHS (Fig. 8.2). First, each organization can designate a point of contact whose job is to maintain contact with the other entities. This would safeguard a streamlined process of communication and allow the organizations to efficiently access each other and provide live updates of their information. Second, it is imperative to have a clear understanding of each organization's means. For example, OSHA is focused on occupational settings, whereas USUHS is strictly established in the military setting. Consequently, their resources available to execute effective EHS prevention, recognition, treatment, and recovery/return to activity are inherently different.

Third, each organization should actively share current evidence-based EHS information so that recommendations remain up-to-date. Currently, each organization has its own website with individual information regarding EHS and participating safely in the heat. However, some of the information is not updated with the current medical best practices, disseminating information that may have deadly consequences (Table 8.2). Therefore, it becomes imperative that proper and current evidence-based EHS information is shared uniformly across disciplines.

Dissemination of the material is the fourth method of collaboration. Currently, there are many formats of communication (e.g., quick tips, fact sheets, etc.) between and within organizations, making it difficult for the layperson to truly understand what is the best practice due to conflicting material being presented. By collaborating to create one easy-to-read dissemination format, any confusion regarding proper EHS prevention, recognition, treatment, and recovery/return to activity would be avoided. One potential outlet to provide a foothold for the dissemination of agreed upon, evidence-based information regarding EHS is the National Integrated Heat Health Information System (NIHHIS). NIHHIS was developed by the Centers for Disease Control and Prevention (CDC), NOAA, and domestic and international

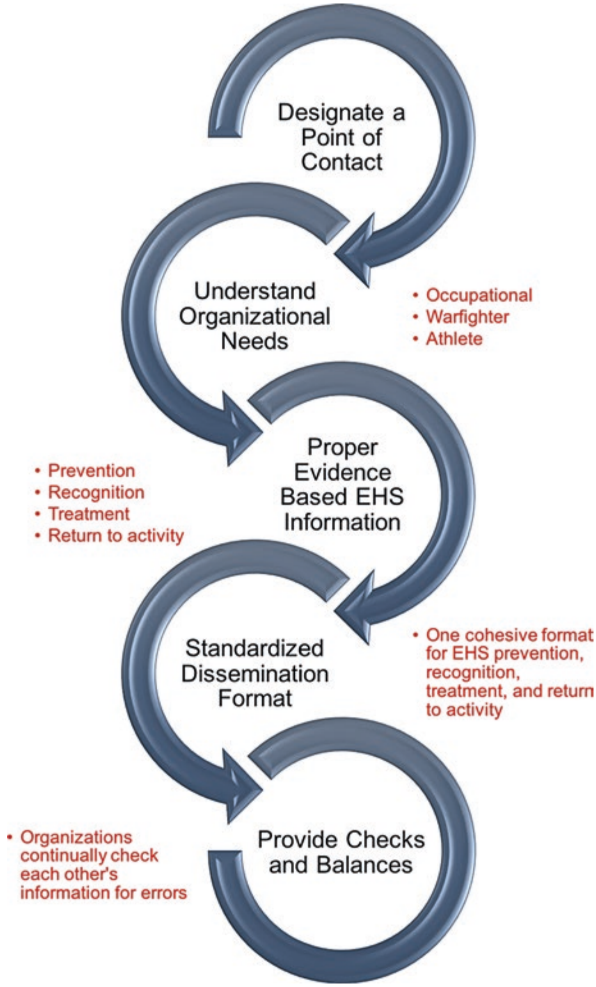

Fig. 8.2 Theoretical framework for organizations to work together ensuring EHS evidence-based best practice recommendations are implemented

partners to understand the threat of rising global temperatures, develop a robust and science-informed response, and build capacity and communication networks between organizations. Although NIHHIS does not create the health standards for participating organizations, it is currently working to expand their partnership to nonfederal entities so that they may broaden their outreach, creating an opportune platform for the dissemination of information once evidence-based information regarding EHS is organizationally agreed upon.

The final step of our proposed framework recommends that organizations reevaluate existing guidelines and consensus to ensure shared information remains current. This provides essential checks and balances between the organizations, so that information can be modified in accordance with evolving medicine and science regarding EHS prevention, recognition, treatment, and recovery/return to activity.

Table 8.2 Steps to ensure best practice recommendations are being followed [20]

Category	Steps to ensure best practices

Prevention	• Work-to-rest ratios
	  – WBGT guidelines
	  – Specific to environment where activity is taking place
	• Heat acclimation process
	  – Gradually over 10–14 days
	• Fluid replacement procedures
	  – Educate leadership on proper hydration
	  – Encourage drinking both water and fluids containing sodium
	• Wear loose-fitting, absorbent, or moisture wicking clothing
	• Minimize the amount of equipment worn during hot/humid conditions
	• Slowly progress the amount of time and intensity of work
	• Have a medical professional trained in the prevention, recognition, and treatment of EHS on-site
	• Identification of intrinsic and extrinsic EHS risk factors
	• Ensure proper cooling methods are available and that equipment is prepared prior to activity
	• Have an emergency action plan in place
	  – Review at least annually
	• Ensure a medical examination prior to activity is conducted to identify high risk individuals

Recognition	• Ensure proper medical coverage is provided • Ensure all parties are trained in the recognition and treatment of EHS *Signs & Symptoms:* • Rectal temperature >40.5 °C • Irrational behavior, irritability, emotional instability • Altered consciousness, coma • Disorientation, headache, or dizziness • Confusion or just look “out of it” • Nausea, vomiting, diarrhea • Muscle cramps, loss of muscle function/balance, inability to walk • Collapse, staggering, or sluggish feeling • Profuse sweating • Decreasing performance or weakness • Dehydration, dry mouth, thirst • Rapid pulse, low blood pressure, rapid breathing
Treatment	• Activation of emergency action plan • Remove all equipment and excess clothing • Cool the individual as quickly as possible within 30 min via whole body ice water immersion (place them in a tub/stock tank with ice and water approximately 1.7–15 °C) • Stir water and add ice throughout the cooling process • If cold-water immersion is not possible, take individual to a shaded, cool area and use rotating cold, wet towels to cover as much of the body surface as possible • Maintain airway, breathing, and circulation • After cooling has been initiated, call 911 • Monitor vital signs such as rectal temperature, heart rate, respiratory rate, blood pressure, and central nervous system status • Cease cooling when rectal temperature reaches 38.9 °C to prevent over cooling • Cool first, transport second

Table 8.2 (continued)

Category	Steps to ensure best practices
Return to activity	• Medical professional should monitor patient's condition until signs and symptoms are no longer present • Same day return to activity is not recommended and should be avoided • If treated effectively, individuals may be able to resume modified activity within one month with a physician's clearance • If treatment was delayed (i.e., not provided within 30 min), individuals may experience residual complications for months or years after the event • Recommendations suggest that an individual should be asymptomatic with normal blood-work results (renal and hepatic panels, electrolytes, and muscle enzyme levels) before a gradual return to activity is initiated

Framework for Success/Conclusion

The ability of the aforementioned organizations to successfully collaborate to maximize the delivery of knowledge and services related to EHS is of critical importance. Traditionally these organizations have functioned independently, even though they each serve constituents affected by the same science and medical best practices related to the prevention, recognition, treatment, and return to sport/duty/work of exertional heat illnesses. The efforts with the interassociation meetings and this book are a concerted effort to enhance efficiency, quality of services, and advancement of our knowledge base. Figure 8.2 is a diagram outlining the process to constantly collaborate and innovate to allow each individual entity to better serve its constituents. It takes more effort to function together at first, but the reward of improving knowledge and saving lives is well worth the time and energy to improve.

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Erratum to: Human Health and Physical Activity During Heat Exposure

Yuri Hosokawa

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The original version of the book had a typographical error that resulted in 'Heath' appearing instead of 'Health' and these changes have been updated in the Front matter and in the Title of Chapter 3 and Affiliation Detail in Chapter 4.

A. L. Williams
Occupational Health Clinic, Directorate of Public Health,
Walter Reed National Military Medical Center, Bethesda, MD, USA

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Index

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