CLIMATE CHANGE, HEAT WAVES, AND HUMAN HEALTH

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I. Abstract

The recent increases in global temperature have marked a critical milestone in the history of Earth. This has led to an intensification of weather patterns that have afflicted cities across the entire world and claimed the lives of thousands of individuals. The foci of this paper are three record-breaking heat wave events: Chicago, IL (1995), Lyon, France (2003), and Moscow, Russia (2010), where maximal temperatures reached unprecedented highs that increased heat-related mortality. The human body expends a wealth of energy to maintain ideal internal ranges, but prolonged exposure to extreme environmental conditions can tip organ systems into distress. This disruption is discussed in detail, along with the importance of public health preparedness as an adaptation strategy for the warmer future.

II. THE TWENTY-FIRST CENTURY HUMAN ISSUE

The world is changing.

This is evident from the overly congested highways we see, the non-stop sounds of traffic we hear, the chemically-treated produce we eat, the widespread odor of emissions, and the air we feel on our skin – air that, somehow, seems to feel a bit warmer than last year.

The research that aims to expand our understanding of these changes continues, but the argument of whether these changes are human-caused, is rightfully settled – in the scientific community, at least. The impact of our species has been so powerful in altering biological, climatic, and geochemical processes on Earth that the "Anthropocene" is now an entirely new geological time unit, with debates of it beginning in preindustrial centuries during early agriculture development or the mid-twentieth century (Ruddiman, 2013 & Waters et al., 2016). However, the most unsettling part is that these changes have become most noticeable within our lifetime.

In the six-or-so decades that have passed from the start of the proposed "Anthropocene," the 'change' that has arguably garnered the most attention is climate change. The media coverage of climate change is ceaseless, from fictional films, like 'The Day After Tomorrow,' to being the source of heated debates during the 2016 United States Presidential Election. The debate on the legitimacy of climate change continues, but irrespective of view, this phrase is now a topic of interest.

This is because even if the opinions about climate change differ across the globe, there are events happening that are revealing of what climate change might look like and how it is affecting the entire world, in real-time. The thing is, these are changes that are no longer taking thousands or millions of years to be reflected in future generations, but rather are changes that are harming the health of our own generation, right now.

This makes the fight against climate change an even more urgent issue as increasing global temperatures can disrupt the physiological functions of the entire human body and at times, lead to death, exacerbating an already present public health concern. The effort to reduce our global carbon footprint and cut the emissions that are contributing to rising temperatures are crucial for the future, but adaptation to the increased frequency of heat waves starting today is pivotal for human life.

III. THE REALITY OF CLIMATE CHANGE

The intensification of weather patterns is the feature of climate change that we have had the most interaction with. The latest assessment by the Intergovernmental Panel on Climate Change (Pachauri, 2014) reports an increase in extreme weather events starting, yet again, in the 1950s. This includes an increase in the frequency of heat waves and heavy precipitation events, posing a significant threat to living things, including humans that are left unprepared. It is a fact that the climate on Earth has changed throughout history, but there is a difference between weather trends and extreme, abrupt events.

The recent increases in global temperature have marked a critical milestone in the history of our changing planet, so much so that this was headlined in *The New York Times* on January 19, 2017. The article noted that for the past three consecutive years, the temperature on Earth has set a record-high; 2016 is now the hottest year on record. It is important to recognize that this record-high temperature has been influenced by El Niño, but the continual heat bursts are alarming considering that the warmest recorded temperatures to date have occurred within this century.

The consequences of increasing global temperatures are frankly, quite predictable. This rise has warmed the oceans and is melting the land ice that is responsible for increasing sea levels, and because the warming of the planet is caused by greenhouse gases, especially carbon dioxide, ocean acidification worsens. This is analogous to a chain reaction, which continues and begins to heavily disrupt all forms of life and the natural processes guided by them.

IV. THE EXTREMES OF CLIMATE CHANGE AND VULNERABILITY

If for a second, we disregard the damage that climate change is having on our non-human relatives, it could be argued that the human race is capable of adapting and surviving the challenges presented by climate change. The increase in global temperature is harmful to agriculture, but with the advancement of genetically-engineered crops and foods, this can be conquered. From the perspective of a more economically developed country, the argument can also be applied to heat discomfort; access to air conditioning and clean water has never been easier.

The least-developed countries are inherently among the most affected; their limited access to basic resources makes them most vulnerable to climate change. Their access to clean water is readily at stake and their shelter could be nonexistent, making access to air conditioning the least of concerns. If relying on their environment for sustenance, abrupt weather patterns can make it incredibly difficult to grow crops and without funds for genetically-modified seeds that are resistant to these conditions, under-developed countries are at greater risk of surviving climate change. However, even the most developed countries can be heavily afflicted.

In July 1995, Chicago, Illinois sustained a record-breaking heat wave. The average daily temperatures during this eight-day heat wave ranged from 33.9˚C (93.0˚F) to 40.0˚C (104.0˚F), with a daily maximum temperature of 48.3˚C (118.9˚F) on the second day (Dematte et al., 1998). This is truly exceptional considering that the typical

average daily maximum temperature for this month is 27.0˚C (80.6˚F) in Chicago; the deviation in temperature range led to thousands of emergency department visits and as reported in a study following this heat wave, 437 heat-related deaths (Dematte et al., 1998 & Naughton et al., 2002). This widespread eight-day event also heavily afflicted several states in the Midwest region of the United States.

Less than a decade later in August 2003, Lyon, France experienced a fifteen-day heat wave with an average daily maximum temperature of 37.0˚C (98.6˚F); the result was an estimated >14,800 heat-related deaths, including nearby and surrounding cities in the region, like Dijon, Paris, Bordeaux, and Le Mans, where temperatures were also exceptionally high (Misset et al., 2006 & Vandentorren et al., 2004). The typical average daily maximum temperature of August in Lyon, France is 22.0˚C (71.6˚F), clearly exceeded during this heat wave and particularly, in urban areas, which experienced temperatures markedly higher than normal (Argaud et al., 2007).

It is now quite evident that heat waves directly threaten the well-being of the public, but the damage can be much more extensive and inflict indirect threats to human health. In July 2010, Moscow, Russia suffered a prolonged heat wave that triggered wildfires and elevated the levels of carbon monoxide at street level (Shaposhnikov et al., 2014 & Bondur, 2011). The heat wave, a forty-four day event, lasted until August and had average daily temperatures ranging from 24.0˚C (75.2˚F) to 31.0˚C (87.8˚F), with an estimated >11,000 heat-related deaths that resulted, including nearby cities in the region (Shaposhnikov et al., 2014). This exceeds the number of deaths in Chicago 1995 and Lyon 2003, a true testament to the potential consequences of heat

waves, but more in general, extreme weather conditions.

The studies following each of these historical incidents have nearly identical conclusions: the interaction between high temperatures and high-risk populations increases the risk of mortality. It is also suggested that the risk increases in individuals with advanced age, but air conditioning is the most important protective factor against heat-related deaths. The studies were, for the most part, observational studies that gathered the records of patients and statistically analyzed the relationship between past health conditions, environmental conditions, and if applicable, death, in an effort to uncover possible causal relationships.

V. THE VIOLENCE THAT EXISTS IN THE HUMAN BODY

The heart is arguably the most important muscular organ in our body. For the hopeless romantic, the heart is the source of decision and thought; for the less-poetic individual, the heart is the circulatory pump that moves oxygen around the body, functions that are vital for human life.

The heart is located between the right and left lung, and has an intricate anatomy that allows for the efficient transport of oxygen. This begins when we inhale and allow air into our body and into our lungs, which by various transfers, extract oxygen and deliver it to the bloodstream for transport by the heart. While the mechanism of transport is much more complex than that and involves an incredible network of blood vessels, the end goal is simple: to deliver oxygen-rich blood to tissues, and after unloading, to return this oxygen-poor blood to the lungs for collection of more oxygen. The proper circulation of blood is critical as more than oxygen is being transported; blood transports nutrients, hormones, and waste products like carbon dioxide.

This regulatory mechanism is responsible for maintaining an ideal environment that is critical for proper functioning of cells and tissues for a plethora of reasons that include membrane fluidity and enzyme function, and disruption can tip the system into distress. The body maintains a fairly narrow temperature range, around 37.0˚C (98.6˚F), and invests a wealth of energy to regulate this regardless of surrounding temperature (Leon & Kenefick, 2012). The disturbance that elevated temperature

creates is enough to completely shut-down organ systems; a study that investigated the short and long-term outcomes of heatstroke following the heat wave incident in Lyon, France revealed that the majority of non-surviving patients exhibited cardiovascular, respiratory, and renal dysfunctions, all in association with neurological disorders (Argaud et al., 2007).

If body temperature increases from exposure to environmental temperatures, the heart increases heat loss by pushing warm blood towards the skin surface, but extreme elevations in body temperature cannot be sustained; the amount of blood pumped by the heart to further increase heat loss cannot be maintained, overheating the entire body. This results in heat exhaustion and can eventually lead to heatstroke, the most severe form of a heat-related illness, defined in the presented studies as an elevated body temperature of 40 C (104 F) and above. The condition of heat exhaustion is often associated with dehydration, which can be managed, but the case of heatstroke is a medical emergency that is much more complex and without treatment, can rapidly increase the chance of death.

The exact mechanism of the impact that heatstroke has on the body to cause multiple-organ dysfunction and death is heavily researched, but with incidents like heat waves, the reaction of the heart to increased body temperature is now foreseeable. As mentioned, the attempt to increase heat loss by convection leads to an increase in heart rate from increased cardiac output. This is more or less the same thing that happens during exercise, but this continual increase in the rate and strength of contraction can only last so long; a study that assessed the initial clinical

features and functional outcomes of patients after the heat wave in Chicago, IL revealed various type of tachycardia and atrial fibrillation, with 71% of patients showing sinus tachycardia (Dematte et al ., 1998). This means that these patients could no longer maintain adequate cardiac output, depriving organs and tissues in the body from oxygen, a possible explanation for multiple-organ dysfunction.

The fact that the distribution of all contents in the bloodstream to particular tissues is critical for the appropriate functioning of organs, makes entire organ systems incredibly vulnerable to heat stress. The disruption that initially happens at the heart leads to interruptions across the entire body; this affects the respiratory, digestive, and renal system by depriving organs of oxygen or hormones, or causing an imbalance in nutrients from attempts to rapidly increase heat loss or from organ failure (Leon & Kenefick, 2012). The damage ranges from liver damage to renal failure, compromising the function of unique systems that are critical for detoxification, digestion, and waste removal; all studies mentioned involved patients with at least one of these conditions, but most suffered from multiple.

The aftermath of near-fatal heat stroke in this Chicago, IL study was not so satisfying. The survivors made modest recoveries but disability persisted, and after a year, no functional improvements were seen; in addition, over a quarter of patients died (Dematte et al., 1998). In the mentioned studies, multi-organ dysfunction was the main reason for heat-related deaths, but it is important to consider that the majority of these patients also had neurological impairment; increasing body temperature includes the brain, and increased brain temperature often leads to poor judgment. In

the same study, findings revealed that on admission the majority of patients suffered from coma, lethargy, disorientation, or seizures.

The processes that occur in the brain are temperature-dependent and like the cardiovascular system, exposure to extreme temperature are consequential and can cause irreversible brain damage (Kiyatkin, 2010). The brain represents a small portion of the human body, it accounts for less than two-percent of total body mass, but it constitutes roughly twenty-percent of total oxygen consumption (Schmidt-Nielsen, 1997). This means that any disruption to the pathway that delivers oxygenated blood to the brain, inhibiting the delivery of oxygen, is a source of neural dysfunction. The body contains efficient mechanisms to "cool-off" if body temperature rises above particular boundaries, but if the source of this heat, like prolonged exposure to high temperatures continues, the body cannot "cool-off," and this mechanism of heat dissipation fails. The end result is accumulation of heat in the brain (Kiyatkin, 2010).

The knowledge of the effects that temperature has on the brain is limited and the potency that such conditions have on the brain, controversial; but case studies reveal that thirty-percent of heatstroke survivors have permanent neurological impairment despite aggressive treatment (Leon & Helwig, 2010). This is likely a consequence of reduced cerebral blood flow, caused by the inability of the heart to maintain cardiac output during heat stress, depleting brain cells from oxygen. It is estimated that brain cells can die in minutes if deprived from oxygen, causing irreversible damage and at

times, death (Lutz et al. 2003).

The likeliness of heatstroke is further complicated with the use of medications that treat conditions present before the heat-related incident. The largest risk factors for heatstroke and really, any heat-related illness for that matter, are age and pre-existing health conditions; healthy-young adults can be afflicted with heatstroke, but this is often not comparable to the amount of older individuals with chronic diseases that are afflicted (Leon & Helwig, 2010). This makes sense; after all, immunodeficiency refers to the inability of an immune system to fight disease, but medications that treat this or the condition responsible, can be equally, if not more damaging. In a study that characterized the clinical conditions of patients during the heat wave in Chicago, IL it was revealed that nearly half of patients were using medications, with some patients taking medications that predispose them to heatstroke (Dematte et al., 1998).

The shortcomings of the human body during heat stress are further highlighted in the particularly extraordinary heat wave that burdened Moscow, Russia in 2010; a study that quantified the effects of death during this event concluded that cardiovascular, respiratory, genitourinary, and nervous system diseases were the most pronounced effects for death (Shaposhnikov et al., 2014). The study also revealed additional information about the additive effect of air pollution on human health and mortality, and the interaction between high temperatures and wildfire air pollution, which contributed a substantial number of deaths as compared to events without air

pollution from wildfires.

The human body is clearly sensitive to changes and this includes the introduction of foreign substances into the body. This might sound like humans are vulnerable to nearly anything, but the evolution of life makes this hardly plausible. The respiratory tract is an example of this with defense mechanisms that filter thousands of liters of air each day for the average person; this is particularly impressive if considering the plethora of pathogens that invade the environment. However, air pollutants are remarkably successful in causing harm by disrupting cellular signals that inhibit vital cellular mechanisms. This includes the ability of air pollutants to mistakenly bind with proteins or to act like prooxidants, which induce oxidative stress (Kampa & Castanas, 2008).

The adverse effects that air pollutants have on human health are widespread and like the rest of the entire body, concentration is the main force that drives the body into distress. This means that we can withstand challenges, but this is dependent on the extremity of the challenge. The human body has tipping points and that is the exact issue with climate change; global temperatures are rising because of increasing greenhouse gases and this will continue if changes are not made. The estimated total number of heat-related deaths from the three events discussed is 26,237 – the problem is that this is only the beginning and we have already failed.

VI. HANDLING THE URGENT THREAT OF A CHANGING CLIMATE

With continued global warming events, heat waves are expected to increase in frequency, length, and in severity. The willingness of a few countries to mitigate climate change but not others is an issue. The fact is that extreme weather events like such are not limited to any particular region, making it crucial that nations cooperate to reduce greenhouse gas emissions and the consequent planetary warming. The best thing is to be proactive about mitigating climate change and finding the most effective way to adapt to the changing climate.

The truth is that we will likely be living in a warmer planet; even if the efforts to cut emissions and reduce the global carbon footprint are fulfilled, it is estimated that the global temperature will rise by 3.5 C at the end of this century (Schneider, 2009). This constitutes a significant public health threat, which reframes climate change as a public health issue and inquires on management strategies for improving human health. The nature of managing community health is not new, but public interventions to adapt to climate change are if the goal is to build human resilience from the devastating consequences that extreme weather conditions can elicit.

The ability to acclimate to weather events like heat waves is burdened by physiological limitations, but is of course, a process that biological organisms like plants can considerably take advantage of. This makes the built environment the most important artificial protective factor against climate change for humans. In the case of extreme heat, heat-related illnesses are best avoided by staying hydrated

and limiting heat exposure, but at a community level, public health preparedness is equally as important. It should now be quite clear that heatstroke is a medical emergency that requires immediate attention, but heatstroke is the last-state after prolonged exposure; this means that homeostasis can be re-reached by ending this exposure, which refers to access to air conditioning, or even shade.

The relationship between mortality and temperature is largely influenced by latitude and climate zones (McMichael et al., 2006). For example, regions in temperate latitudes are most vulnerable to heat waves and are anticipated to warm disproportionality with increasing global temperature; in addition, the effect of heat waves is exacerbated in urban areas (Patz et al., 2005). The modification of natural land to roads and buildings, and the high concentration of people and emissions, make urban areas significantly warmer than surrounding rural areas; this means that heat waves are an issue for all major cities and that housing improvements are not inclusive of the entire at-risk population.

The development of organized provisions for heat waves need to be developed by community health centers to reduce health impacts. This includes public cooling-facilities that expand past protecting oneself and instead recognize the vulnerability of the entire region; it requires a change from small-scale adaption to big-scale efforts. The effectiveness of this type of change is dependent on the willingness of regional health departments, but without the change, it is likely that heat-related deaths will increase with frequent heat waves. The research on climate change is robust and the effects that these abrupt changes will have are estimated

using various models, but the consensus is the same – the world will continue to change and this change will begin with human life.

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