Can the human body cope with extreme heat in a changing climate?

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The scorching summer of 2022 left a devastating trail of 61,000 lives lost across Europe,[1] illustrating the human body's vulnerability to extreme heat. But amidst this tragedy arises a compelling question: how does the human body defy incineration under the assault of a 40°C summer sun? What arsenal of defences does it wield to brave such extreme conditions? Let's discover an incredible journey through the body and its perfectionated physiology to safeguard our survival regardless of the temperature's merciless whims. It is a breathtaking showcase of nature's ingenuity.

Yet, even the most formidable defences have their breaking points. When does this finely tuned orchestra falter, and how does the scorching heat transform from a mere discomfort to a lethal threat? In the light of climate change, these questions loom large. With record-breaking temperatures signalling the onslaught of more frequent and severe heatwaves, one cannot help but wonder: can our bodies endure the relentless march towards a hotter world? And how can we best anticipate to protect ourselves and our peers?

INTRODUCTION

Climate change is a stark, undeniable reality. The seemingly modest rise of 1.5°C in global temperatures has already wrought significant changes, such as the intense heatwaves that have hit the European main lands over the last years. In France, for example, out of 47 heatwaves experienced since 1947, 22 have occurred since 2010.

These events highlight the profound impact of extreme heat on human health. The 2003 heatwave that swept across Europe and caused over 70,000 additional deaths, remains vividly remembered.[2] A global analysis attributes 37% of heat-related fatalities between 1991 and 2018 to climate change.[3] Future projections suggest even more extreme heatwaves and increased heat-related illnesses and mortality, particularly if global temperatures were to climb above the 2°C threshold.

Beyond the death tolls, heat exposure affects everyone. Symptoms of heat distress range from minor discomforts to more serious illnesses. How does the human body endure extreme heat? Let's delve into the mechanisms through which our body deals with intense warmth, and discover at what point things take a turn for the worse.

1 Ballester, J.,et al. (2023). *Heat-related mortality in Europe during the summer of 2022.* Nature Medicine, 29(7), 1249-1259. https://doi.org/10.1038/s41591-023-02419-z.

2 Robine, J. M., et al. (2008). *Death toll exceeded 70,000 in Europe during the summer of 2003.* Comptes Rendus Biologies, 331(2), 171–178. https://doi.org/10.1016/j.crvi.2007.12.001.

3 Vicedo-Cabrera, A. M., et al. (2021). *The burden of heat-related mortality attributable to recent human-induced climate change.* Nature Climate Change, 11(6), 492-500. https://doi.org/10.1038/s41558-021-01058-x.

THE PERFECT TEMPERATURE

The human body stands as a masterpiece of nature's design. Within its confines, billions of cells work in harmony tirelessly, ensuring our seamless journey through each day, allowing us to focus on life's more significant endeavours. Yet, this intricate choreography is contingent upon optimal conditions for cells and their enzymes to function. One critical parameter for our mental and physical well-being, and fundamental to survival, is a core temperature of precisely 36.8°C. There is no margin for error. Recall the discomfort experienced when even a slight increase of 1 or 2 degrees is displayed on the thermometer during your body's battle against an unwelcome viral or bacterial intruder.

That however, is a temperature increase governed by the body, called fever. It is for our own good. During prolonged periods of extreme heat or strenuous physical activity on the other hand, there is a risk of the temperature escalating uncontrollably, above levels that are tolerable for cells, threatening the proper functioning of vital organs. If our core temperature were to exceed about 43°C, mere minutes would stand between life and death due to the incineration of cells and proteins on a microscopic scale.

Fortunately, over millions of years of evolution, our bodies have developed sophisticated physiological defence mechanisms to keep their internal temperature stable, regardless of external conditions. This inherent ability, known as thermoregulation,[4] is indispensable for our daily survival, and it is our physiological armour to resist violent heatwaves.

OUR BODIES REACTING TO HEAT - SWEATY FOREHEADS AND RED CHEEKS

The primary mechanism for cooling is sweating. When the core temperature increases, the hypothalamus, a specialized brain centre overseeing the body's vital functions, jumps into action. It controls the activation of somewhat 2-4 million sweat glands distributed throughout our skin, producing the salty substance. As sweat evaporates, it absorbs heat from the skin, thus aiding in the body's cooling process. Covering an expansive two square meters, heat dissipation by sweating via the skin is the principal way of keeping our core temperature at its precise equilibrium of 36.8°C. Sweating profusely can result in a significant loss of fluids, up to a liter per hour, causing the typical sweaty foreheads and armpits, the body locations where sweat glands are densely present.

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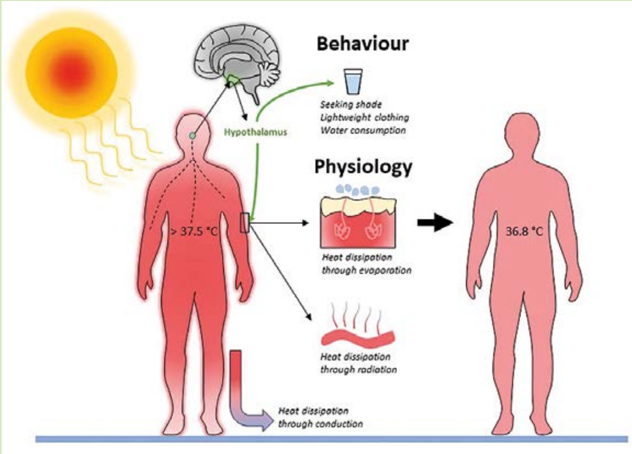
Fluid loss also triggers a response in the kidneys with as primary goal to reduce unnecessary water loss. This is partly governed by the hypothalamus sending a special hormone called *anti-diuretic hormone*, stimulating the kidneys to recuperate water from urine being produced. As a consequence, the urine gets more concentrated, and turns from lightly yellow into dark yellow, an important sign your body needs a water refill! Alcohol consumption inhibits the production of this hormone, and therefore aggravates fluid loss in hot conditions. Hence the advice to reduce consumption at the warmest hours of the day.

Figure 1*: Principal mechanisms by which the human body maintains a core temperature of 36.8°C when exposed to intense heat*



Source: Pieter Vancamp.

In tandem with sweating, vasodilation occurs, wherein blood vessels near the skin's surface expand, facilitating the release of heat to the surrounding environment through radiation. There is another sign of the body fighting to keep our inside at the magical 36.8°C: red cheeks and flushed foreheads. Some hormones such as adrenaline, released when you're nervous, also expand blood vessels, and give you red cheeks as well. Additionally, a shallower and more rapid breathing pattern enables the exchange of heat for cooler external air.

Lastly, our brain also prompts us, often subconsciously, to help cooling down the body and minimize exposure to heat. Fluid loss triggers a behavioral reflex to drink more. Other adaptations comprise actions such as seeking shade and donning lightweight clothing. Molecules produced in our bodies' extremities during intense heat travel through the bloodstream and function as messengers to inform the hypothalamus it's time to refrain from strenuous physical exertion. That's why we have a feeling of general fatigue when it is hot outside. Taking a lukewarm shower or lying on a chilled surface, behaviours also often observed in animals, are other ways of efficiently guiding heat

4 Cramer, M. N., et al. (2022). *Human temperature regulation under heat stress in health, disease, and injury.* Physiological Reviews, 102(4), 1907-1989. https://doi.org/10.1152/physrev.00047.2021.

away from the body. Additionally, modern technology offers us some welcomed assistance: air conditioning, for example, accelerates the evaporation of sweat, enhancing our comfort in high temperature environments.

THE BODY'S LIMITS TO WITHSTAND HEAT

During a heatwave, these highly efficient physiological mechanisms (we can tolerate virtually every climate and live anywhere on planet Earth!) may become overwhelmed or less effective due to the prolonged and intense heat exposure. In the face of extreme hot conditions, the body's resilience is tested, with particular strain placed on two vital organs: the heart and the brain.[4]

The demand for sweating to cool the body may exceed the body's capacity to produce sweat or evaporate it efficiently. Loss of fluids and salts can lead to dehydration and electrolyte imbalances. The latter can precipitate painful muscle cramps. Fluid loss combined with prolonged dilation of blood vessels can lead to a drop in blood pressure, compromising blood flow to vital organs. This loss prompts the heart to intensify its efforts, beating faster and more forcefully to maintain circulation. But it can only work with what it has in hand, and if fluid levels do not return to normal, the strain on the heart can worsen, and its functioning deteriorate.

> *"In a 2016 study, researchers found that young, healthy students were more than 10% slower and less accurate on cognition tests when they were exposed to a warmer indoor environment during a heatwave."*

Consequently, reduced oxygen delivery to the brain ensues, manifesting in symptoms such as dizziness, weakness, fainting, and cognitive impairment. Before we hover into the danger zone, however, heat can already negatively affect our mental performance. Even moderate heat exposure during prolonged periods can reduce work efficiency, and increase the rate for errors. In a 2016 study, researchers found that young, healthy students were more than 10% slower and less accurate on cognition tests when they were exposed to a warmer indoor environment during a heatwave.[5] That is because nerve cells, the cells in the brain that help us to think and act, consume enormous amounts of energy and oxygen. In too warm conditions, they have difficulties regulating this energy expenditure, and start to misfire signals to their neighboring cells, resulting in unclear communication to our bodies.

More severe neurological manifestations such as confusion and fainting, coupled with an accelerated heart rate, dark urine, red cheeks and sweating, are hallmark indicators of heat exhaustion, a condition that increases the risk of heat-related illnesses and raises warning sign for worse to come if not acted upon.

The situation can deteriorate swiftly. When someone experiences heat exhaustion, immediate action is imperative. The person must be escorted to a cool, shaded area, encouraged to hydrate, take up electrolytes (often abundantly found in sport drinks), and provided with methods to lower body temperature, such as cool water or ice packs – most efficient in places where large blood vessels pass, such as in the armpits and inner legs.[4] Vigilant monitoring for escalating symptoms – such as a changed personality or vomiting – is essential. Without intervention, the body's core temperature may escalate to perilous levels, compromising vital organs' functionality. In extreme cases, the fluid reservoirs being empty, the person typically ends up not sweating anymore, despite the extreme heat.

Eventually, the body reaches a tipping point where it can no longer withstand the stress, resulting in organs shutting down, one after another. This progression marks the onset of a heat stroke, demanding urgent medical attention for any hope of recovery. It is not surprising that, during heatwaves, a surge in hospital admissions for heat-related illnesses can be observed. For instance, on hot days when the temperature exceeded 31°C, the Royal Hobart Hospital in Australia noticed a threefold increase in the relative risk of hospital admissions (study conducted for the years 2003-2010).[6]

WHY WE ARE NOT ALL AFFECTED IN THE SAME WAY

Heat can place significant stress on the body's innate ability to regulate temperature, heightening the risk of heat-related health complications. However, susceptibility varies among individuals; some people seem unaffected by the heat and seem like they could run a marathon, while others can hardly leave their home to face the burning sun. In addition, geography matters: sun and heat exposure are not the same in southern Spain or on the cool Belgian coast. Hence, what determines an individual's susceptibility?

Broadly, two factors dictate one's tolerance to heat.[4] Firstly, environmental conditions play a pivotal role. Elevated humidity, for instance, hinders the evaporation of sweat, which is crucial for cooling the body. Canadian researchers in 1965 have devised the Humidex,[7] an informative table that gives an idea of the perceived temperature by integrating both outside temperature and humidity levels. For example, at outdoor temperatures of 30°C and 70% humidity, the humidex equals 41, a dimensionless number indicating

5 Cedeño Laurent, J. G., Williams, A., Oulhote, Y., Zanobetti, A., Allen, J. G., & Spengler, J. D. (2018). Reduced cognitive function during a heat wave among residents of non-air-conditioned buildings: An observational study of young adults in the summer of 2016. *PLoS medicine, 15*(7), e1002605.

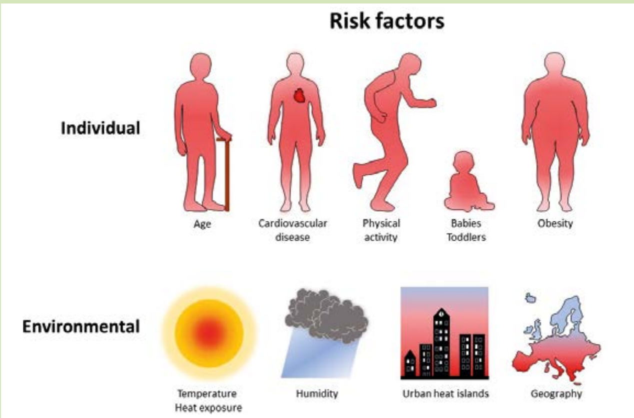
6 Watson, K. E., Gardiner, K. M., & Singleton, J. A. (2020). The impact of extreme heat events on hospital admissions to the Royal Hobart Hospital. *Journal of public health (Oxford, England)*, 42(2), 333–339.

7 Centre canadien d'hygiène et de sécurité au travail (CCHST), *Indice humidex et le travail.*

'great discomfort, avoid exertion'. Looking at the table, that level of discomfort corresponds to a temperature of 39°C in dry conditions (20% humidity).

Other environmental factors include the way we are exposed to heat based on our living environment: urban areas with high levels of concrete and asphalt, the so-called *urban heat islands*, can cause nighttime temperatures to remain elevated due to the retained heat from buildings and pavement. This reduces the body's ability to dissipate heat during the cooler nighttime hours, prolonging exposure to heat stress.

Figure 2: Individual and environmental risk factors dictating one's tolerance to heat



Source: Pieter Vancamp.

Individual factors inherent to each person's physiology also play a crucial role. Age, in particular, is a significant determinant. Statistics consistently reveal that more than two-thirds of the heat-related fatalities occur among individuals aged 65 years or older. Due to the global aging population, researchers expect an even sharper rise in heat-related fatalities in the future.[8] Particularly vulnerable as well are toddlers and infants. They share a common trait with the elderly: their thermoregulatory systems are not as efficient as those of healthy adults. They may need reminders to stay hydrated, as their cognitive functions, including awareness of thirst, may not be responsive. However, a significant number of people under the age of 75 are victims, signifying no one is completely exempt from any risk.

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Heat-related mortality is also higher among women. Data collected during the 2022 summer heatwave in Europe shows 56% more heated-related deaths victims among women than men, but this is probably due to women's life expectancy being longer than men's.

Engaging in strenuous physical labor or vigorous activity is strongly advised against during the hottest hours of the day. Such activities can elevate internal metabolism by up to 10-fold, resulting in the generation of excessive heat—an outcome particularly undesirable in hot conditions. In recognition of this risk, Spain has recently amended its legislation, banning individuals from performing heavy-load work in the afternoon whenever the national weather institute AEMET issues an alert for extreme high temperatures.[9]

Additionally, individuals diagnosed with cardiovascular conditions, often the elderly, are particularly vulnerable. Their capacity to compensate for fluid loss is markedly reduced compared to healthy adults, resulting in diminished resilience to heat stress.[4] Moreover, those with metabolic diseases, notably obesity, are at heightened risk from heat exposure. Increased corporal mass augments heat storage capacity, while the presence of more fat tissue in the skin acts as insulation, hindering heat dissipation to the surroundings.

ANTICIPATING WHAT IS TO COME

It is clear, heat can strain the body's natural thermoregulatory mechanisms, leading to increased risks of heat-related health issues, particularly among vulnerable populations such as the elderly, infants, and individuals with pre-existing health conditions. Hence it is no surprise that models predict an increase in heat-related mortality worldwide due to more intense heat waves coupled to climate change.[10] Even typical behavioral adaptations such as seeking shade or wearing lightweight clothing may provide inadequate relief from the heat. Southern countries are particularly affected, rendering some regions uninhabitable. Climate models based on empirical data predict that a 2°C increase in global temperatures above pre-industrial levels could frequently create conditions that surpass human heat tolerance for billions of residents in the Middle East, India, eastern China, and sub-Saharan Africa.[11] Already now India faces a 30-fold higher risk of experiencing extreme heat waves. Considering humidity as an aggravating factor, by 2050, the country is expected to be one of the first where weather conditions become incompatible with human survival. Such evolutions are also likely in several countries of the European continent.

8 Falchetta, G., et al. (2024). Global projections of heat exposure of older adults. *Nature Communications*, 15(1), Article 47197. https://doi.org/10.1038/s41467-024-47197-5.

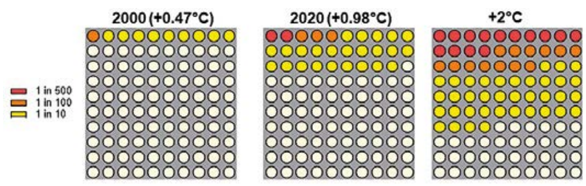
9 20minutos. (2023, May 10). El Gobierno prohibirá este jueves trabajar al aire libre cuando haya olas de calor extremo [The government will ban outdoor work during extreme heat waves this Thursday]. *20minutos*. https://www.20minutos.es.

10 Gasparrini, A., et al. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health*, 1(9), e360-e367. https://doi.org/10.1016/S2542-5196(17)30156-0.

11 Vecellio, D. J., et al. (2023). Greatly enhanced risk to humans as a consequence of empirically determined lower moist heat stress tolerance. *Proceedings of the National Academy of Sciences*, 120(42), e2305427120. https://doi.org/10.1073/pnas.2305427120.

As an example, if climate change persists at its current pace, alarming reports warn that numerous regions of the Southern Spanish mainland may transform into arid deserts, potentially inflicting irreversible damage on the local ecosystem.[12]

Figure 3: Expected occurrence of extreme heat-related events in a warmer climate as exemplified for Paris, France[13]



Source: Pieter Vancamp, based on data from Lüthi *et al.*, 2023 - *Nature Communications* - Rapid increase in the risk of heat-related mortality.

Although native people residing in warmer climates for generations may possess physiological adaptations and are thus more protected, they too become increasingly vulnerable the more weather events get extreme. Adaptive physiology has its limits, even to the fittest individuals. To escape life-threatening weather conditions, human populations, like other large mammals, often migrate to cooler regions, leading to significant political consequences. For example, the increased frequency of extreme heat, hurricanes, droughts and crops losses in Latin American countries is driving more people towards the United States than ever before.[14] As a consequence, in addition to standard measures like reducing greenhouse gas emissions to mitigate climate change, proactive steps must be taken at the international level to anticipate and safeguard populations over the coming years. Fortunately, there is no need for panic, as collective efforts have demonstrated a swift ability to innovate and implement solutions aimed at protecting our communities.

CONCLUSION

The last years have given us a foretaste of how extreme heatwaves take their toll on human life. Future projections suggest climate change will make these even more severe and frequent, posing a significant threat to public health. Amidst these challenges, it is crucial to recognize the remarkable adaptability of the human body. When not pushed beyond its limits, it can endure prolonged periods of intense heat.

A key takeaway is the importance of listening to our body's physiological signals (e.g., thirst, reddening skin). By heeding these cues, we can better care for vulnerable individuals (e.g., the elderly, pregnant women, pets). Adopting simple strategies, such as scheduling running sessions during cooler morning hours, can help mitigate individual risks associated with heat exposure.

In the meanwhile, only an international collaborative and coordinated effort can put the brakes on global warming and curb associated risks. Scientists and policymakers are actively engaged in raising public awareness, devising prevention plans, and implementing educational initiatives to prepare for anticipated challenges. Past experiences provide valuable lessons. For instance, since 2006, France has implemented heat warning systems to proactively address heat-related health issues.[15] Thoughtful urban design can also play a key role in combating extreme heat. Initiatives such as integrating green spaces to absorb heat and installing water fountains – as seen in preparation for the Olympic Games in Paris – provide accessible means to support the body's thermoregulation. These simple yet effective measures safeguard human physiology during future heatwaves, minimizing unnecessary loss of life.

12 Guiot, J., & Cramer, W. (2016). Climate change: The 2015 Paris Agreement thresholds and Mediterranean basin ecosystems. *Science*, 354(6311), 465-468. https://doi.org/10.1126/science.aah5015.

13 This figure represents the expected evolution in the occurrence of extreme heat-related events-in terms of mortality-for Paris, France in 2000 and 2020 (with average temperatures respectively up +0.47 and +0.98°C compared to the pre-industrial period (1850-1899)) and compares it to a potential +2°C increase in temperatures above pre-industrial average (limit set by the 2015 Paris Agreement). Extreme heat-related events that occurred once every 500 years in in the year 2000 would on average occur 14 times per 100 year in a world that is 2°C warmer.

14 Lakhani, N. (2021, November 1). "'So many have gone': Storms and drought drive Guatemalans to the US border." *The Guardian*. https://www.theguardian.com/world/2021/nov/01/guatemala-storms-drought-climate-migrants.

15 Pascal, M., et al. (2006). France's heat health watch warning system. *International Journal of Biometeorology*, 50(3), 144–153. https://doi.org/10.1007/s00484-005-0003-x.

**Dhaka Bangladesh 30 April 2024,
40 degrees Celsius. In such a situation,
at-risk drivers take a rest in the shade to relieve the heat.**