

The science of sweating still holds surprises

An overlooked factor can limit sweat's cooling effect, ASU researchers discover

By Joe Rojas-Burke, ASU News
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The purpose of perspiration was a mystery in 1775, when English physician Charles Brian Blagden and a few inquisitive friends experimented on themselves by spending time in rooms heated to over 230 degrees Fahrenheit.

Although the temperatures were hot enough to cook raw meat placed in those rooms, Blagden noted how human bodies resisted the heat. Their core body temperatures remained nearly constant as the sweat poured out and evaporated.

The science of sweating has come a long way in 250 years. Yet a surprising amount remains unexplored, according to [Konrad Rykaczewski](#), an associate professor of engineering at Arizona State University.

In a new study, Rykaczewski and colleagues have uncovered an unrecognized physical process that can dramatically change how effectively sweat cools the body in hot, dry and windless weather.

"It turns out that the impact is huge," Rykaczewski said. "It can change how much sweat evaporates from your skin by over 50%."

Why this research matters

Research is the invisible hand that powers America's progress. It unlocks discoveries and creates opportunity. It develops new technologies and new ways of doing things.

Learn more about ASU discoveries that are contributing

Understanding the mechanics of sweating is vital to accurately predict heat strain and cooling efficiency in different situations. Scientists use this knowledge to guide recommendations for heat-stressed workers and to design cooling clothing and heat-management systems for first responders, soldiers and athletes.

Unlike Blagden's crew in 1775, the ASU researchers didn't subject anyone to oven-like conditions in their experiments. Instead, they used ANDI, a customized manikin rigged throughout its body with sensors to measure heat loss and heat gain and covered with pores that drip simulated sweat in response to rising heat.

The evaporation of sweat into water vapor is what cools the body. Air movement speeds evaporation and enhances cooling. The ASU researchers focused on an overlooked aspect of the cooling process: how temperature and humidity change the buoyancy of air near the skin.

When the outside temperature is hotter than a person's skin, the air very close to the skin cools, becomes denser and drifts downward. But when the weather is hot and dry, humidity from evaporating sweat creates an opposing upward flow because humid air is lighter than dry air.

Experiments showed that at temperatures around 105 F with low humidity and no wind, the opposing currents near the skin can completely cancel each other, stopping airflow that could help sweat evaporate. In the absence of wind, this phenomenon leads to increased body heat storage and significantly elevated skin and core temperatures. Commonly used human heat-balance models don't take this into account and will underestimate how hot the body becomes in hot, arid environments with little airflow.

The researchers measured the impact using models of sweat evaporation combined with simulations of the human body working to control its temperature. Neglecting humidity-driven buoyancy effects led to an underprediction of core body temperature rise by nearly 2 F for a person at rest in still air after two hours of heat exposure.

"This is really important for indoor settings or places with very little air movement," Rykaczewski said. "Think about a tent, or a partially enclosed worksite or an unfinished building."

Rykaczewski published [the findings](#) in Science Advances on Aug. 19 with first author Shri Viswanathan, who completed his PhD at ASU in May, and eight others at the university.

The competing buoyancy effect is familiar to engineers working on heat exchange problems in electronics, "but it's been overlooked in terms of the human body," Rykaczewski said. "I think the reason is that most people working in this area don't come from an engineering background. It really shows the benefit of having engineers and physiologists working together in interdisciplinary research."

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[The heat is on: Researchers aim to find more effective ways of coping with overexposure to extreme high temperatures](#)

[When it comes to sweat, second time's the charm](#)

Breaking a sweat for research

Proving how the effect applies to sweating human bodies was no easy task. The ASU researchers performed dozens of experiments using ANDI. They developed a computer model and ran about 100 sweating simulations representing a wide range of conditions.

“There are multiple heat-transfer pathways involved, so isolating each one, making sure we could replicate it computationally and then combining them all into one model took a tremendous amount of effort,” Rykaczewski said.

Last year, the ASU researchers [uncovered hidden details](#) about how sweat rises and spreads over the skin. Those experiments required volunteers to don a bodysuit lined with tubes that circulate hot or cold water to warm or cool the wearer. The researchers observed how sweat first saturated the skin’s outermost layer, then collected in shallow pools around pores and spread into a thin, connected film. After a first round of sweat evaporated, it left a light salt residue. When the volunteers were heated again, that residue helped new sweat wick across the surface more rapidly, allowing a film to form without the earlier pooling stage.

A thin film can expose more sweat to the air, potentially making evaporation more efficient. The findings also suggest that sweating may behave differently across the body, where hair, sweat-gland density and skin structure vary.

Plenty of perspiration questions remain unanswered. The ASU team is exploring how sweat can either cling to the body and evaporate or run and drip off before it can evaporate and how that effects body cooling. The researchers are planning studies of the interactions between skin, sweat and clothing textiles. They see opportunities to improve clothing design so that it cools people more effectively by improving sweat evaporation.

“The bigger question is how you manage that sweat and what kinds of materials you can put next to the skin to optimize cooling,” Rykaczewski said.

In field studies across Arizona, the researchers are measuring how different populations experience and respond to extreme heat using advanced environmental sensing platforms combined with their improved models of sweat evaporation and thermoregulation. Their insights are supporting the design of heat adaptation measures and safer buildings and outdoor spaces.

The science of sweating was not a specialty Rykaczewski envisioned when he began his research career.

“It’s funny because it’s kind of an icky topic, but it’s also fascinating. You can spend your entire career doing highly specialized research that only 20 experts care about. But not sweating, because everybody sweats.”

Built to sweat — but make sure to hydrate

Humans are champions of perspiration. Along with horses, we’re among the animals most specialized for cooling by sweat evaporation.

About 2 million sweat glands cover the skin surface. During extreme exertion, sweat rates can exceed 2 liters per hour.

Adapting to repeated heat exposure, people begin sweating at a lower core temperature, produce more sweat and conserve more sodium.

Sweating may have helped early humans forage and travel long distances in hot environments. But sweating only works if it can evaporate and the body has enough fluid to keep it flowing. With dehydration, sweating and skin blood flow can't keep up — and body temperature rises dangerously fast.

This story originally appeared on [ASU News](#).

Main image



ANDI the sweating manikin helps ASU researchers discover the secrets of sweating. Photo by Samantha Chow/Arizona State University

Text image(s)



Konrad Rykaczewski wears the thermal suit used to raise body temperature and induce sweating in his lab. Photo by Samantha Chow/Arizona State University