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The relative overlooking of human behavioral temperature regulation

An issue worth resolving

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It has long been appreciated that behavior is the most powerful and diverse thermoregulatory mechanism. In animal-based studies a behavioral assay is typically the first assessment when investigating the effect of a perturbation on thermoregulation, highlighting its importance. Oddly however, such an approach has been largely ignored in human research.

As such, our understanding of the mechanisms and modulators of behavioral temperature regulation (or thermal behavior) in humans is minimal, especially when compared with the rather vast knowledge of the control of the autonomic thermoregulatory responses of skin blood flow, sweating, and shivering. Nevertheless, strides have begun to be made toward resolving this paradox. The purpose of this Discovery Article is to highlight one such study.[1] As a result of this Article, in place of hard conclusions or answers, it is hoped that the reader, like the author, is left with questions that, if investigated, will help to resolve the perplexing lack of knowledge regarding the mechanisms and modulators of thermal behavior in humans.

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Behavior—Our First Line of Thermal Defense?

The purpose of temperature regulation is to maintain a relatively constant core (or internal) body temperature. Historically this regulation has been presented as a classic feedback loop, whereby core temperature provides the "error" signal initiating thermoeffector responses to promote heat loss or conservation. Indeed, this is mostly true for autonomic responses such as sweating and shivering, which are typically initiated by core temperature "thresholds."[2] However, current evidence, mostly from animal-based studies, suggests it is unlikely that thermal behavior is controlled in this manner.[3] As such, we aimed to characterize the thermal input(s) in the control of human thermal behavior.[1] We utilized a traditional thermal behavioral model adapted for use in human subject research,[4] in which 'behaving' involved voluntarily moving between warm (~45 °C) and cool (~8 °C) environments when subjects deemed they felt "too warm" or "too cool." Based upon our previous work,[4] we hypothesized that, when given the opportunity to behaviorally thermoregulate, behavior would be initiated prior to measurable changes in core temperature. As expected, behavior (i.e., moving from cool to warm <u>or</u> from warm to cool) occurred prior to meaningful changes in core temperature, whether measured in the rectum or esophagus, but did occur at a point during which skin temperatures were drastically different (by ~8 °C, **Fig. 1A**). We interpreted such findings to indicate that skin temperature is an important and capable controller in the decision to behaviorally thermoregulate, and that skin temperature is dictating this behavior via its modulation of thermal discomfort, a pre-requisite in the initiation of thermal behavior.[5] These findings also indicate that behavior, in the current paradigm, acts to prevent changes in core temperature, supporting the notion that behavior is our "first line of defense" for regulating body temperature. Perhaps most importantly however, such findings also raise several intriguing questions. For instance, are these findings constrained to this population of young, healthy males? What if, in a given population, behavior is not initiated prior to a change in core temperature? Is this evidence for integrated thermoregulatory dysfunction? What is/are the thermal input(s) after core temperature has been displaced? Asking and, most importantly, answering fundamental questions such as these will undoubtedly improve our understanding of the thermal input(s) governing human thermal behavior in both function and dysfunction.

Co-Activation of Thermoeffectors—Coincidence or Causal?

A second, but related hypothesis in the highlighted article[1] was that the decision to move from the warm environment to the cool one would occur prior to evidence of sweating, while the decision to move from the cool environment to the warm one would occur prior to evidence of shivering. This hypothesis is based on the concept that behavior is preferentially elicited to prevent the activation of water and energy consuming thermoregulatory responses (i.e., sweating and shivering), as is typically observed in animal-based models.[6] To our surprise, the initiation of behavior in the cool was associated with

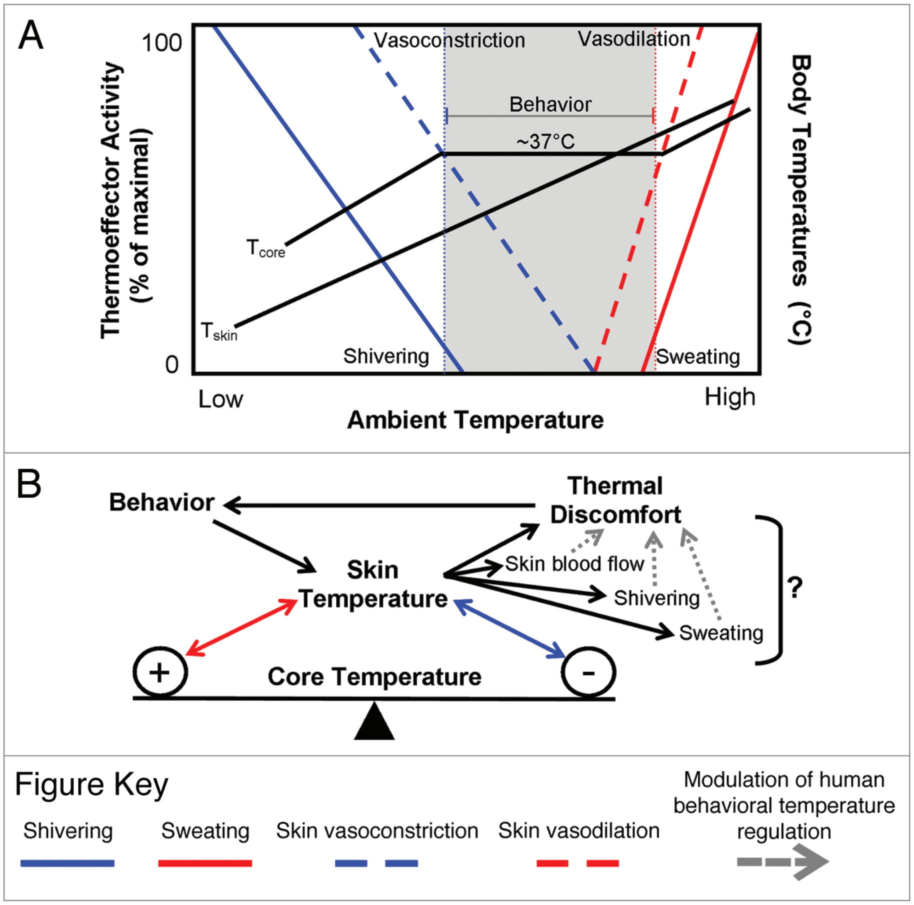

Figure 1. (**A**) Relationships between changes in body temperatures (skin temperature: T_{skin}, core temperature: T_{core}) and autonomic thermoeffector activity (shivering, sweating, skin vasoconstriction, and skin vasodilation) when humans are given the opportunity to behaviorally thermoregulate. Behavior acts to prevent changes in core temperature (as indicated by the gray box) and is accompanied by skin vasoconstriction and slight shivering during exposure to cool ambient temperatures and by skin vasodilation and slight sweating during exposure to warm ambient temperatures. (**B**) Known and potential modulators of human behavioral temperature regulation when humans are given the opportunity to behaviorally thermoregulate.

slight shivering, while the initiation of behavior in the warm was associated with slight sweating (**Fig. 1A**). Importantly however, the magnitudes of the observed changes were much smaller than those found to occur during 30 min of constant exposure to the same cool and warm environments. Such findings indicate that behavior does not *prevent* the activation of sweating and/or shivering, but rather it *minimizes* their activation. Notably, these findings raise the question as to whether sweating or shivering is "required" in the initiation of thermal behavior or whether this observation was just coincidence. If sweating or shivering is implicated in the initiation of thermal behavior, such findings would be important for people and/or circumstances that have known alterations in the control of sweating and/or shivering (e.g., dehydration, aging, burn survivors, etc.). We also found that skin blood flow was different upon the initiation of thermal behavior. Given the modulatory role of skin temperature on skin blood flow,[7] such a finding was not surprising. That said, it raises some interesting questions, with potentially meaningful ramifications. For instance, how is skin blood flow involved in the initiation of thermal behavior? And what does this mean for individuals and/or circumstances with impaired or altered skin blood flow responsiveness (e.g., heat acclimation, hypoxia, aging, diabetes, etc.)? Because of these rather unexpected findings, it has become apparent that we need to more fully understand the role of autonomic thermoregulation on human thermal behavior.

More Questions than Answers!

Clearly, we have only reached the "tip of the iceberg" regarding our understanding of behavioral temperature regulation in humans. Non-human, animal-based research has repeatedly demonstrated that behavior is the most preferred, powerful, and diverse thermoregulatory response. As highlighted in this Article, efforts are now being made to "catch up" and understand the mechanisms and modulators of human behavioral temperature regulation. As outlined in **Figure 1B**, rather fundamental questions regarding the control of this behavior remain to be answered. Striving to answer these questions is of vital importance in light of our ever-changing climate, as a breakdown or misunderstanding of our "first line of defense" against thermal insults could have lasting ramifications for human health and well-being.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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