Wearable sensors for predicting heat stroke risk with machine learning techniques

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Problem and objective

People uneducated about and at risk for non-exertional heat stroke in hot regions of India need a method to reduce the likelihood of experiencing heat stroke to decrease mortality.

The problem

- Heat stroke kills thousands of people annually across the world. Furthermore, the incidence is increasing due to heat waves that are becoming more frequent and intense as a result of climate change.
  - The 2015 Indian heat wave resulted in over 2,300 deaths over a two-month period [1].
- In heat stroke, core body temperature is over 40°C and is accompanied by neurological impairment [2].
  - Full-body immersion in an ice slurry is typically accepted as the most effective cooling method, but many resource-limited areas do not have this option readily available.

Unaddressed factors

- Access to proper and timely intervention is critical to successful recovery.
- Risk varies from individual to individual: factors such as age, sex, and weight can influence risk assessment.
  - No studies show which factors are most predictive of heat stroke.
  - No customized preventative technologies exist.

Our solution

Inexpensive wearable device measuring physiological and environmental parameters + **Machine learning** → **Real-time risk prediction**

Our risk prediction and notification would allow people to take preventative actions more intelligently, thereby reducing rates of heat stroke and mortality during heat waves. We also aim to reduce the number of parameters needed for accurate prediction to minimize costs for a product that would be mass-produced and distributed to low-resource areas.

Prototype design and testing

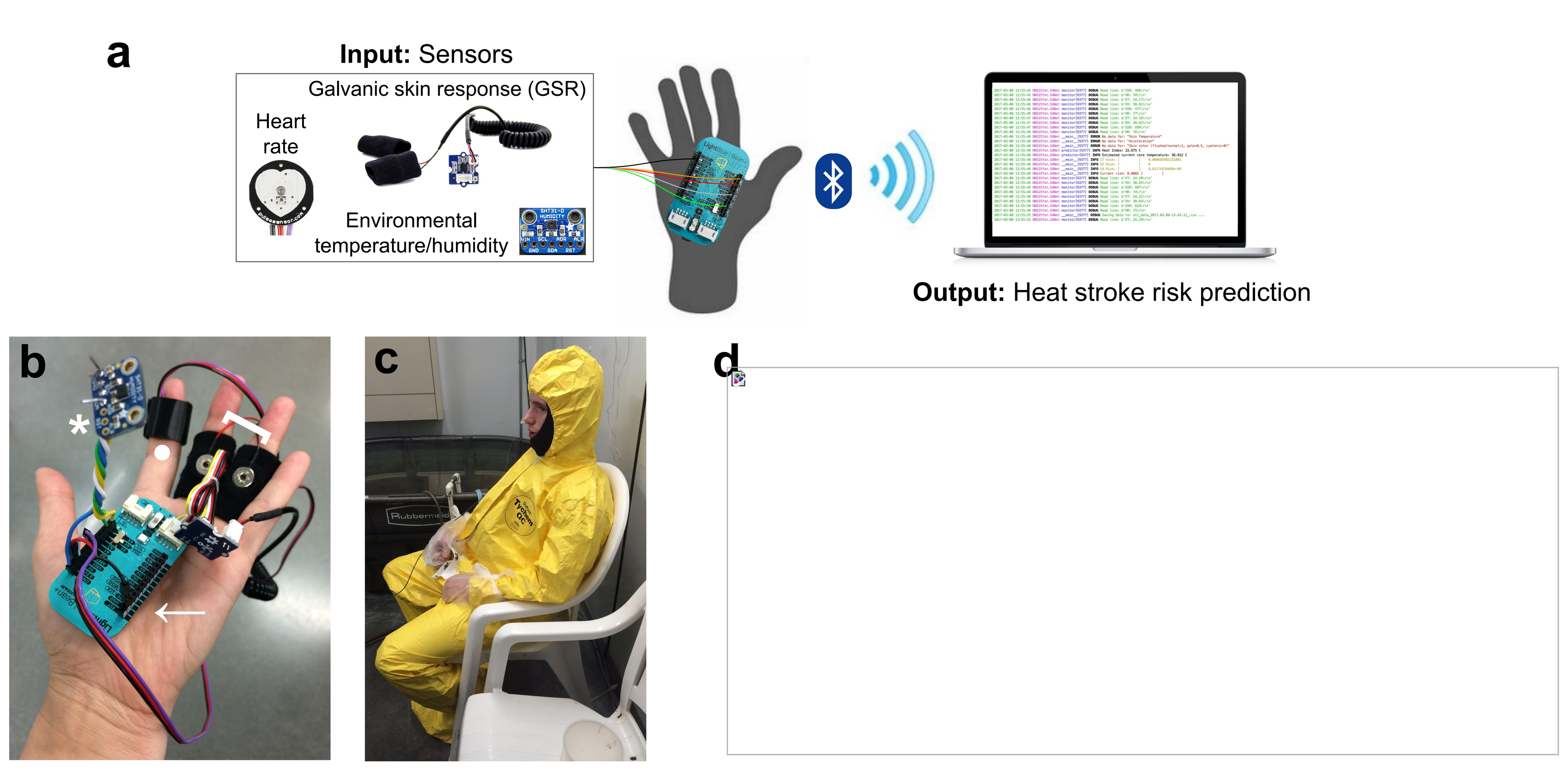

Fig. 1. Setup for testing feasibility of heat stroke risk prediction device prototype and algorithm. (**a**) **Systems-level concept of early-stage wearable device.** Data input comes from a series of sensors (i.e., pulse monitor, galvanic skin response, and environmental temperature/humidity) wired to a bluetooth microcontroller (LightBlue Bean+). Sensor data are then transmitted in real-time via bluetooth to a laptop, which contains an algorithm that processes these data and outputs heat stroke risk predictions at regular intervals. (**b**) **Device prototype (arrowhead).** Connected sensors indicated as follows: Adafruit SHT31 environmental temperature/humidity (asterisk), Pulse Sensor (bullet), and Grove galvanic skin response (bracket). (**c**) **Nonexertional heat stress experimental testing condition setup.** Room is held at 46°C (115°F). User wears a hazmat suit, balaclava to cover the face, plastic bags around hands, esophageal probe to monitor core temperature, and heart monitor strapped around the chest. Microcontroller is covered with saran wrap and the device is held in the user's hand. (**d**) **Block diagram of risk algorithm structure.** Overall aggregated risk is composed of an average of logistic regression risk, core temperature risk, heat index risk, and galvanic skin response risk, which take in current physiological and environmental data, core temperature as estimated from heart rate data, environmental temperature and humidity data, and galvanic skin response data, respectively.

Results and analysis

We tested our prototype in two conditions: *Control* - sitting inside at 24°C room temperature (dotted lines in all plots) and *Experimental* - sitting in 46°C controlled room (solid lines in all plots). We were able to successfully collect environmental and physiological data from the sensor device and calculate real-time risk predictions that were higher in the experimental condition than the control, which was essentially 0 risk. (Fig. 2a). Environmental temperature and humidity measurements in the control setting remain constant as expected; in the experimental setting, temperature and humidity increase over time and follow expected values, which is consistent with the sensor device being slightly insulated from the external environment (Fig. b-c). Heart rate remained constant in the control setting as expected, and in the experimental condition increased over time; this increase is consistent with higher cardiac demand as thermoregulation becomes increasingly more difficult (Fig. d). A model from literature [3] was used to estimate core temperature from heart rate measurements (Fig. 2e), providing a more accurate and accessible way of measuring core temperature than other proxies such as skin temperature. This model allows us to use core temperature as a component of our risk prediction, which is useful because elevated core temperature is a defining property of heat stroke. We have not yet incorporated galvanic skin response into the risk algorithm, but the experimental data changes with expected sweating behavior (indicated with arrows: perspiration initially decreases from 0-10 min, approximately plateaus from 10-35 min, and then decreases from 35-45 min; Fig. 2f) and may be a valuable parameter moving forward in predicting onset of heat stroke. Together, these data demonstrate that we have successfully developed a proof-of-concept device that collects environmental and physiological parameters and transmits them for further algorithmic processing, resulting in real-time outputs of heat stroke risk.

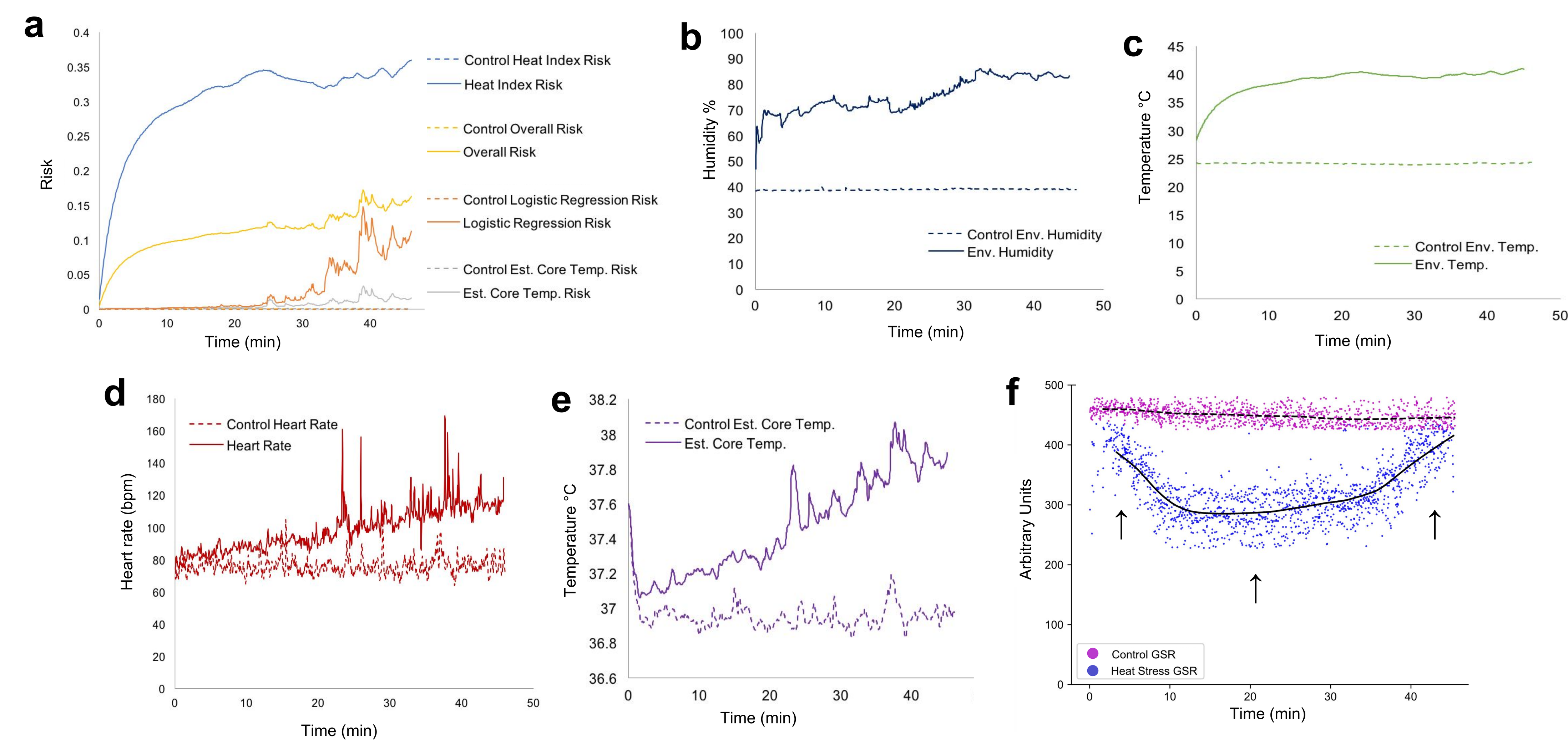

Fig. 2. Risk prediction results and individual contributing sensors (n = 1 per condition). **(a) Risk prediction.** Three risk components and total aggregate heat stroke risk in control and heat stress experimental conditions plotted over time. **(b) Environmental humidity.** Measured environmental humidity in control and heat stress experimental conditions over time. **(c) Environmental temperature.** Measured environmental temperature in control and heat stress experimental conditions over time. **(d) Heart rate.** Heart rate measured by pulse monitor in control and heat stress experimental conditions over time. **(e) Estimated core body temperature.** Core temperature estimation from heart rate (adapted from [3]) in control and heat stress experimental conditions over time. **(f) Galvanic skin response.** Measured galvanic skin response in control and heat stress experimental conditions over time.

Future directions

- Determining which parameters (sensors) are most predictive by:
  - Improving our logistic regression algorithm through obtaining and using experimental data and improving data imputation methods
  - Examining logistic regression weights and calculating correlations between sensor data and risk estimates
- Evaluating likelihood of use/compliance:
  - Rather than output risk as a probability, estimate the time remaining before heat stroke onset to provide more useful information to the user
- Optimizing device cost
  - Our current prototype cost $142.82, although we are confident that this price can be brought down significantly to tens of dollars
- Testing the predictive power of the combined device and algorithm on relevant test populations (e.g., India, hot regions of the United States, etc.)
- Developing a phone application-centered user interface to disseminate information about preventative action to take given heat stroke risk
- Additional applications:
  - Expanding the target population beyond India for greater impact in global health applications
  - Expanding the algorithm prediction beyond non-exertional heat stroke to encompass exertional heat stroke, heat stress, other heat stress-related conditions, and use as a general health monitor

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