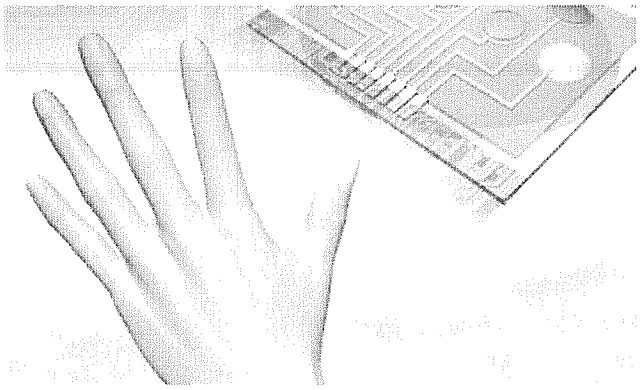
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Let them see you sweat: What new wearable sensors can reveal from perspiration

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Wearable sensors measure skin temperature in addition to glucose, lactate, sodium and potassium in sweat. Integrated circuits analyze the data and transmit the information wirelessly to a mobile phone. Credit: Der-Hsien Lien and Hiroki Ota, UC Berkeley

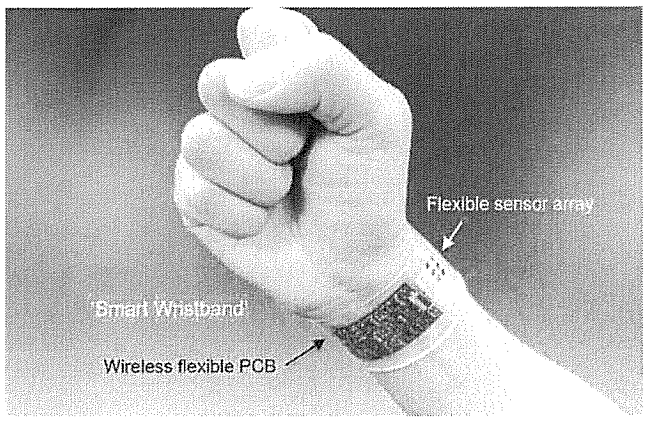
When engineers at the University of California, Berkeley, say they are going to make you sweat, it is all in the name of science.

Specifically, it is for a flexible sensor system that can measure metabolites and electrolytes in sweat, calibrate the data based upon skin temperature and sync the results in real time to a smartphone.

While health monitors have exploded onto the consumer electronics scene over the past decade, researchers say this device, reported in the Jan. 28 issue of the journal *Nature*, is the first fully integrated electronic system that can provide continuous, non-invasive monitoring of multiple biochemicals in sweat.

The advance opens doors to wearable devices that alert users to health problems such as fatigue, dehydration and dangerously high body temperatures.

"Human sweat contains physiologically rich information, thus making it an attractive body fluid for non-invasive wearable sensors," said study principal investigator Ali Javey, a UC Berkeley professor of electrical engineering and computer sciences. "However, sweat is complex and it is necessary to measure multiple targets to extract meaningful information about your state of health. In this regard, we have developed a fully integrated system that simultaneously and selectively measures multiple sweat analytes, and wirelessly transmits the processed data to a smartphone. Our work presents a technology platform for sweat-based health monitors."



The flexible sensor developed at UC Berkeley can be made into "smart" wristbands or headbands that provide continuous, real-time analysis of the chemicals in sweat. Credit: Wei Gao, UC Berkeley

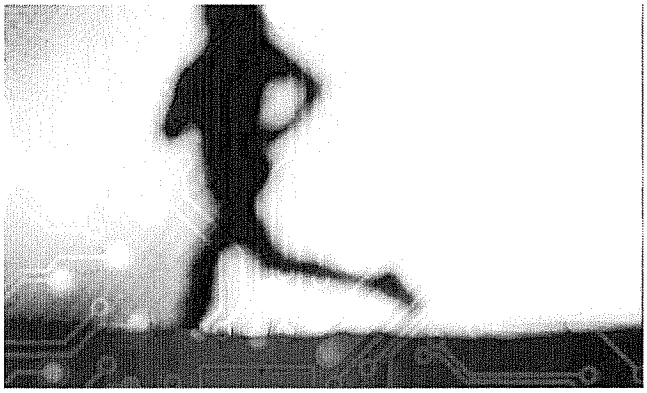
Javey worked with study co-lead authors Wei Gao and Sam Emaminejad, both of whom are postdoctoral fellows in his lab. Emaminejad also has a joint appointment at the Stanford School of Medicine, and all three have affiliations with the Berkeley Sensor and Actuator Center and the Materials Sciences Division at Lawrence Berkeley

National Laboratory.

Chemical clues to a person's physical condition

To help design the sweat sensor system, Javey and his team consulted exercise physiologist George Brooks, a UC Berkeley professor of integrative biology. Brooks said he was impressed when Javey and his team first approached him about the sensor.

"Having a wearable sweat sensor is really incredible because the metabolites and electrolytes measured by the Javey device are vitally important for the health and well-being of an individual," said Brooks, a co-author on the study. "When studying the effects of exercise on human physiology, we typically take blood samples. With this non-invasive technology, someday it may be possible to know what's going on physiologically without needle sticks or attaching little, disposable cups on you."



Users wearing the flexible sensor array can run and move freely while the chemicals in their sweat are measured and analyzed. The resulting data, which is transmitted wirelessly to a mobile device, can be used to help assess and monitor a user's state of health. Credit: Der-Hsien Lien and Hiroki Ota, UC Berkeley

The prototype developed by Javey and his research team packs five sensors onto a flexible circuit board. The sensors measure the metabolites glucose and lactate, the electrolytes sodium and potassium, and skin temperature.

"The integrated system allows us to use the measured skin temperature to calibrate and adjust the readings of other sensors in real time," said Gao. "This is important because the response of glucose and lactate sensors can be greatly influenced by temperature."

Developing smart wristbands and headbands

Adjacent to the sensor array is the wireless printed circuit board with off-the-shelf silicon components. The researchers used more than 10 integrated circuit chips responsible for taking the measurements from the sensors, amplifying the signals, adjusting for temperature changes and wirelessly transmitting the data. The researchers developed an app to sync the data from the sensors to mobile phones, and fitted the device onto "smart" wristbands and headbands.

They put the device - and dozens of volunteers - through various indoor and outdoor exercises. Study subjects cycled on stationary bikes or ran outdoors on tracks and trails from a few minutes to more than an hour.

"We can easily shrink this device by integrating all the circuit functionalities into a single chip," said Emaminejad. "The number of biochemicals we target can also be ramped up so we can measure a lot of things at once. That makes large-scale clinical studies possible, which will help us better understand athletic performance and physiological responses to exercise."

Javey noted that a long-term goal would be to use this device for population-level studies for medical applications.

Brooks also noted the potential for the device to be used to measure more than perspiration.

"While Professor Javey's wearable, non-invasive technology works well on sweating athletes, there are likely to be many other applications of the technology for measuring vital metabolite and electrolyte levels of healthy persons in daily life," said Brooks. "It can also be adapted to monitor other body fluids for those suffering from illness and injury."

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More information: *Nature*, nature.com/articles/doi:10.1038/nature16521

Provided by University of California - Berkeley

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