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News & Highlights

Wearable Sweat Sensors

Elizabeth K. Wilson

Senior Technology Writer

Sweat, like blood, contains electrolytes and biomolecules that can reveal aspects of a person's physiology, from hydration to kidney function. Though scientists have long recognized sweat's potential use as a medical diagnostic tool, only recently have engineering advances allowed them to explore the possibility in earnest.

Now, the idea of sweat sensors is generating public interest, as technologies such as lab-on-a-chip and cellphone data transmission, as well as wearable devices that track heart rate or blood oxygen levels have become robust and commonplace. The number of peer-reviewed papers on sweat sensors has exploded since 2015, as engineers worldwide explore numerous different approaches to their design.

The new prototype sweat sensors are light, thin patches stuck to an arm or forehead, that can measure, for example, skin pH, or chloride levels, which can be important in the diagnosis of the genetic disease cystic fibrosis. Other potential devices include wristbands or headbands for athletes that keep track of hydration during exercise.

In more medically complex applications, wearable sweat sensors could take the place of invasive blood draws. They might analyze creatinine, to assess kidney function, or cortisol, to track the stress response. Wearable sweat sensing devices could potentially allow continuous biomonitoring, eliminating the need for bulky equipment, repeat visits to labs, or hospital stays.

Recently, an international team led by John A. Rogers, the director of the Center for Bio-Integrated Electronics at Northwestern University, unveiled what may be the most sophisticated prototype sweat sensor developed to date (Fig. 1). The device not only monitors lactate, glucose, chloride, and pH, but also sweat rate and loss [1]. The ability to measure these last two parameters is particularly novel, and crucial for understanding their effects on the composition of sweat samples.

The Rogers group's device features a flexible elastomeric system of microfluidic channels, valves, and chambers that are removable and can be swapped out for new ones, enabling reuse. The natural action of sweat glands pumps sweat through holes in the bottom of the device into the channels and analysis chambers, each containing a sensor for a different substance. While enzymes in biofuel cell-based, electrochemical sensors catalyze reactions that increase with concentration to assess lactate and glucose levels, the device measures chloride and pH colorimetrically by comparison to color calibration markings. The device transmits and receives data to and from the same cell phone that powers it via near-field communication (NFC) technology. Using this external power source makes the patch up to 20 times lighter and four times smaller than devices that rely on batteries.

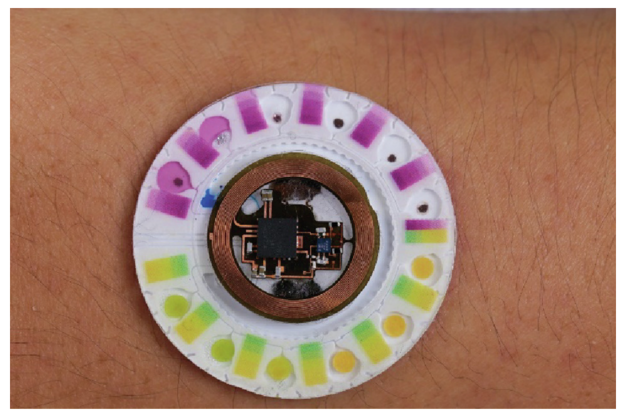

Fig. 1. Developed by an international team of collaborators, this prototype, battery-free sweat sensor can monitor lactate, glucose, chloride, pH, and sweat rate and loss. The sensor wirelessly transmits and receives data to and from the same cell phone that powers it by via near-field communication (NFC) technology. Credit: John A. Rogers, Northwestern University.

Other labs take different approaches. At the California Institute of Technology (Caltech), medical engineering assistant professor Wei Gao and his team believe sweat can be used for many complicated analyses involving substances such as heavy metals, drug molecules, and hormones and other proteins. Before moving to Caltech, Gao was a postdoctoral fellow in the laboratory of engineering professor Ali Javey at University of California, Berkeley (UC Berkeley), where he helped develop a wearable sensor for caffeine as a model for detecting methylxanthine drugs [2]. Unlike the devices powered via NFC, the Gao lab's prototypes use tiny batteries. For some continuous monitoring applications, Gao said, staying close to a cell phone may not be practical.

Yet another team, headed by Hong Liu at Southeast University in Nanjing, recently designed a wearable glucose sweat sensor that, unlike the Rogers' device, does not rely on enzymes [3]. These biomolecular components present a number of issues for sensor development. For example, enzymes are sensitive to pH, temperature, and ionic strength; they can degrade over time; and the

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process of attaching them to electrodes can affect their activity. The Liu group's sensor, using fluorocarbon-coated gold electrodes, measures current generated during the electrochemical oxidation of glucose.

Even though the field is nascent, the potential of wearable sweat sensors has already attracted the attention of companies such as Gatorade. The company's Sports Science Institute is collaborating with the Rogers' lab and the United States Air Force to test a wearable sweat sensor that measures hydration via electrolyte concentrations [4]. Through his company Epicore Biosystems, Rogers is also working with the skin care company L'Oreal to developing a wearable skin pH sensor that can detect unbalanced skin pH levels linked to conditions such as dryness and eczema. L'Oreal and its skincare brand La Roche-Posay unveiled the investigational device, called My Skin Track pH, at the huge annual Consumer Electronics Show in Las Vegas in January 2019. The company plans to have the prototype tested by dermatologists this year [5].

But commercial applications may take some time to be realized. In pursuing wearable sweat sensors, developers have taken on two inextricably linked challenges, of engineering and biology. Because the sophisticated technology needed to begin reliably analyzing sweat has only recently been achieved, the scientific study of sweat has just begun, said Gao's mentor UC Berkeley professor Javey, who co-directs the university's Sensor and Actuator Center. "Sweat is a highly under-explored class of biofluid," Rogers agreed.

Addressing the biology part of the challenge is not simple. Sweat rates affect biomarker concentrations, and biomarkers in sweat vary from person to person, changing daily or even hourly, all of which makes it difficult to correlate sweat-excreted biomolecules with health. In addition, not all biomolecule concentrations in sweat correlate well with those in blood. Much more research is needed, involving hundreds or even thousands of human subjects, before definitive claims can be made about sweat and health [6,7].

Key to these biological studies, however, will be continued advances in wearable sensor engineering. For example, Eccrine Systems, a company co-founded by Jason Heikenfeld, the head of the Novel Device Lab at the University of Cincinnati, is working with technology covered by the university's 2018 patent for sensors that can correlate measurements of substances in sweat with the time the substances were collected [8,9]. The invention enables researchers to generate sweat pharmacokinetic profiles, a critical step for ensuring sensor reliability.

All this research activity suggests that wearable sweat sensors have great promise to become important medical and consumer devices, although it is early and likely that different applications will require different types of sensors. "At this stage, we need to explore any and all of these techniques," Javey said.

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