Wearable devices

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Face masks as a platform for wearable sensors

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A flexible sensor interface integrated into different commercial face masks can be used to measure breathing patterns, skin temperature, physical activity and the fit of the mask itself.

Unlike conventional diagnostic testing, which takes place at a centralized clinical laboratory, wearable sensors can provide continuous physiological information about the health of an individual[1]. The sensors thus have the potential to personalize the diagnosis of diseases, that is, abnormal conditions could be identified – practically in real time – by measuring deviations (or patterns of deviations) from healthy baselines. This could lead to early diagnosis, which can improve health outcomes while reducing the overall costs associated with diagnosing and treating illnesses.

Today, wearable sensors come in many forms – including watches, tattoos and straps[2,3] – and can continuously measure biophysical (such as heart rate) and biochemical (such as glucose in sweat) signals. With the emergence of the COVID-19 pandemic, the general population has become accustomed to wearing low-cost face masks and these could provide a platform for the development of new classes of wearable sensors. Face masks have several advantages over other types of wearable sensor. In particular, they provide easy access to: respiratory airflows for measuring respiratory rates and patterns; exhaled breath for measuring volatile biomarkers of disease; respiratory droplets and (aerosol) particles originating from the wearer or present in the environment; and toxic gases in the environment. Because of the large area of face masks, they can also provide a medium for storing reagents and attaching the electronics needed to operate various biophysical and biochemical sensors.

Writing in *Nature Electronics*, Canan Dagdeviren and colleagues at the Massachusetts Institute of Technology now report a flexible sensor interface for face masks[4]. The system can measure breathing patterns, skin temperature, physical activity, coughing and the fit of the mask itself. It is based on a modular platform that contains a flexible printed circuit board that connects (primarily off-the-shelf) sensors and electronics together. The flexible circuit board is connected to an external printed circuit board for power (up to 60 hours), data acquisition and transmission over Bluetooth to a nearby mobile device. The use of a flexible, polyimide-based material in the flexible printed circuit board to connect the components together renders the mask lightweight and conformable to the face of the wearer. The sensor interface can be laminated and delaminated on various commercially available face masks (surgical, N95 and cotton masks) through a gecko-inspired thin adhesive layer.

A face mask is effective only when worn properly. Similarly, with wearable sensors of any form factor, the quality of the data produced is severely impacted by poor fitting. Previous work has tried to improve the fitting of wearable sensors using stretchable materials[5], but the approach of Dagdeviren and colleagues actually quantifies fitting using sensors. In particular, accelerometer and capacitance sensor pads integrated into the sensor interface were used to measure the quality of fitting across five male and five female participants. The position of the face mask was estimated using unsupervised machine learning, which yielded an accuracy of 92.8% for the male participants and 77.5% for the female participants. The users could thus be informed if the mask was not worn correctly. The mask-fit results from the sensory face mask were also correlated with conventional mask fit testers.

The work of Dagdeviren and colleagues is an important advance in the development of mask-based sensing, but further work is needed to improve the translational potential of the technology. One of the biggest challenges is the overall cost of the sensory system, which consists of many elements attached to a flexible printed circuit board (which are more costly than rigid printed circuits boards). The cost will be particularly important if the technology is intended for single-use (disposable) applications, or if it does not become a regulated medical device and is thus only used for wellness. More testing is also needed to evaluate the performance of the sensory face mask during extended outdoor and indoor usage, including in rain, at high temperatures and at high relative humidity. Although not particularly important if used as a disposable product, performance after cleaning should also be characterized.

In addition to physical and biophysical signals[6,7], mask-based wearable sensors are a potential platform for measuring chemical and biological analytical targets (Fig. 1). Such technology is only at an early stage of development and there are only a few examples of integrating biological and chemical sensors into face masks to detect pathogens or biomarkers associated with diseases[8–10]. In the future, optical, electrochemical and chemiresistive transducers could be integrated into

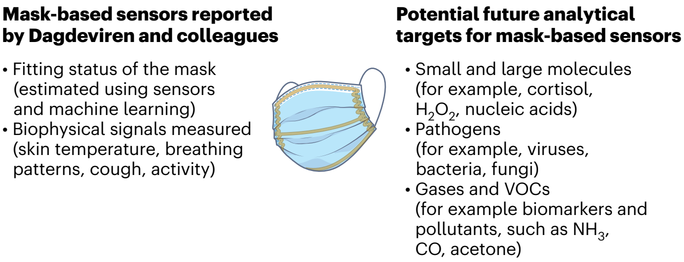

Fig. 1 | The present and future of face-mask-based sensors. The face-mask-based wearable sensing system developed by Dagdeviren and colleagues can measure a range of biophysical signals (including skin temperature, breathing patterns, coughing and activity) in a multiplexed fashion and estimate the quality of the fit of the mask itself. In the future, chemical and biological sensing technologies could also be integrated into face masks to enable the detection of small and large molecules (for example, cortisol, hydrogen peroxide (H_2O_2), nucleic acids and proteins), pathogens (for example, viruses, bacteria and fungi), gases and volatile organic compounds (VOCs; for example, ammonia (NH_3), carbon monoxide (CO) and acetone). These new technologies could pave the way for truly personalized diagnostics and the development of new classes of protective equipment that can detect environmental pollutants and hazardous biological and chemical agents in real time (such as biological and chemical weapons).

face masks to detect various molecules (expelled in the form of droplets), pathogens (such as bacteria or viruses), and gaseous and volatile biomarkers in exhaled breath. Because many methods of chemical and biological sensing require storage and sequential execution of multiple reagent handling steps, techniques such as microfluidics (or CRISPR/lateral-flow-type sensing) may also need to be integrated into the face masks to eliminate manual handling and improve usage. The use of chemical and biological sensors could also extend beyond applications in healthcare, and could be used to detect environmental (air) pollutants, and biological and chemical weapons — areas where masks are already used for protection.

The field of wearable devices has advanced rapidly in recent years, particularly in regard to watches and straps. However, early commercial activity with mask-based wearable sensors — which includes the Spyras smart mask (https://www.spyras.com/), the CLIU Pro mask (https://cliu.it/) and the AirPop Active+ mask (https://airpophealth.com/products/active-smart-mask-halo-sensor) — is a strong indicator that there is room for growth. And much remains to be explored by scientists and engineers across the globe. The work of Dagdeviren and colleagues is a valuable step in the development of mask-based wearable sensors and should help catalyse a range of new research activities.

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Competing interests

Y.C. formerly served as the chief technology officer at Spyras Ltd. F.G. is a non-operating co-founder of Spyras Ltd.