# BioSparks: Jewelry as Electrochemical Sweat Biosensors with Modular, Repurposing and Interchangeable Approaches

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**Figure 1: BioSparks: a. System components, b. Modularity, c. Interchangeable electrode, and d. Repurposing**

## ABSTRACT

This paper presents BioSparks, a wearable device that detects glucose levels in sweat through electrochemical biosensors crafted with traditional jewelry techniques. Unlike conventional biosensors that are disposed of after use, BioSparks employs a repurposing method, allowing for the reuse of discarded electrodes within the jewelry's chain, as pendants or earrings. It incorporates interchangeable electrodes that facilitates their replacement after timelife. The modular design enables the wearable to be placed on various body parts, including the neck, wrist and waist. The paper outlines our design considerations for Wearability Factors for Jewelry Biosensors, and the fabrication process combining traditional jewelry techniques and electromistry. Our technical evaluation shows the performance of our biosensor under ten different glucose concentrations.

## CCS CONCEPTS

• **Human-centered computing → Interface design prototyping**; • **Hardware** → *Emerging interfaces.*

## KEYWORDS

electrochemistry; electrodes; biosensor; wearable; jewelry

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## 1 INTRODUCTION

Electrochemical biosensors are devices that employ electrochemical reactions to detect and measure specific substances like glucose, pH, and sodium. These biosensors convert the concentration of the substance into an electrical signal, allowing for real-time monitoring and analysis. They consist of three key electrodes: the working electrode, which detects the target substance; the reference electrode, which provides a stable reference point; and the counter electrode, which completes the electrical circuit by conducting the necessary current. In recent years, the development of electrochemical biosensors in sweat [12, 18, 37] has emerged as a promising approach for health monitoring. Various form factors, like patches, wrist watches, transfer tattoos, stickers, or bandages, have been proposed [35].

This paper focuses on using electrochemical biosensors to measure glucose levels in sweat by placing the electrodes directly in contact with the skin. Traditional glucose monitoring methods, such as finger-prick testing [42], permanent tattoos [51] or microneedles attached to the skin [46], have limitations in terms of invasiveness, inconvenience, and potential skin damage. This project focuses in sweat analysis, offering non-invasive and continuous monitoring capabilities. Moreover, our design approach provides modularity to place the wearable in different body parts, interchangeable electrodes to facilitate replacements, and repurposes the electrodes into other jewelry pieces.

Numerous works have explored the intersection of wearable technology and jewelry design, paving the way for innovative applications [2, 7, 11, 29]. This research not just utilize jewelry techniques to design the form factor, but also the electrochemical biosensors that seamlessly blend with wearable jewelry pieces. In this way, a new realm of discreet and convenient glucose monitoring opens up, expanding the horizons of HCI-driven biosensor applications in the context of stylish and functional wearable accessories for sensing body fluids.

The paper presents BioSparks, the design of electrochemical biosensors as jewelry with a modular, repurposing and interchangeable approaches. Our contributions include:

1. Electrochemical Electrodes as Jewelry: Departing from conventional flat-shaped electrodes, we introduce a novel 3D design of jewelry-based electrochemical biosensors, created with common jewelry techniques. The wearability factors for designing jewelry in electrochemical biosensors are proposed, and their functionality was evaluated with ten glucose concentrations.

2. Repurposing Electrodes: In contrast to the typical practice of disposing of electrodes or other biosensors after use, our repurposing method promotes sustainability by reusing the electrodes within the jewelry's chain, as pendants or earrings.

3. Modular Jewelry Design: The modular design offers flexibility and adaptability to accommodate different body parts and sizes.

4. Interchangeable Electrodes: Electrodes can be easily replaced after their lifespan. While other devices offer this feature, our approach seamlessly integrates pressure rivets, a jewelry method for attaching and detaching pieces, into the biosensor design.

## 2 RELATED WORKS

The HCI and Wearables field much explored smart jewelry as a wearable technology form factor. Analytical studies identify design criteria, including functionality, form factor, interactivity, and aesthetics [15]. Jewelry design embraces an artistic approach [7, 29]. Many projects adopt a modular design approach, combining form factors. For example, BLInG project uses a beaded design with interchangeable electronic components [22]. Gehna explores sensor-based touch-based jewelry technology for different body areas [2]. Some modular smart jewelry studies focus on design principles, using modularity to shape the product's form factor and inform research nature [7, 24]. Similarly, BioSparks adopts a modular approach with interchangeable straps, allowing users to decide the device's placement based on clothing, sweat location, or style.

Jewelry's close proximity to the skin enables interaction with movement, heat, and touch. For instance, Gemini embeds sensors in face jewels to detect facial muscle movements [47]. ThermalRing uses a low-resolution thermal camera for gestures and ThermalTag to reflect heat [59]. The Empathy Amulet generates warmth using a Kapton heater [6]. Considering this proximity was a crucial design consideration for our project, as we aimed to collect sweat data through electrochemical biosensors. Other projects explore attaching electronics to the skin through beauty products [34, 48], fake nails [25, 50], and hair extensions [39, 49]. Additionally, iSkin and Duo Skin sense touch by a temporal tattoo as the form factor, similar to the most common form factor for sweat biosensors [26, 53]. While drawing inspiration from these works, we found that directly applying and reapplying electrochemical biosensors on the skin becomes impractical for everyday use due to the precision required by our sensors.

BioSparks focuses on using an electrochemical biosensor for glucose analysis in sweat, as sweat sampling offers a less invasive method of gathering biodata [23, 30]. Existing form factors for electrochemical biosensors include smartwatches [4], bandages [37], headbands [18], rings [27], and temporary tattoos [28]. Adhesive-style wearable sensors have been explored in previous works [20, 21, 52], including a wrist-worn multiplexed sensor array for sweat analysis [19]. Various form factors for glucose biosensors in sweat have been introduced, with an emphasis on skin-friendly sensors [5]. In the realm of jewelry biosensors, Sweatcessory presented a choker with a wearable potentiostat to collect sodium levels from sweat [56], while e-ring is a flexible 3D printed ring with gold electrodes capable of electrochemical glucose sensing [27]. Additionally, an electrochemical sensing ring was developed for detecting tetrahydrocannabinol and alcohol from saliva [38]. BioSparks employs electrochemistry techniques and evaluations from past studies of electrochemical wearables, specifically utilizing chronoamperometric data for glucose level measurements [1, 13, 17, 31, 62].

In the context of the production of biosensors, recent developments have primarily focused on making biosensors more sustainable and reducing production costs [8]. Some biosensors have attempted to use environmentally friendly materials for electrodes [10, 36] or substrates [57] to reduce waste resulting from disposal. However, it is worth noting that, the elements required for electrode fabrication are not easily recyclable [45]. For example, in the case of glucose test strips, research shows that diabetic users alone can go through 1.5 to 3 strips every day [14]. The frequent replacement of these strips is evident in the overall cost of glucose self-monitoring [55]. BioSparks proposes a different approach by repurposing biosensors as jewelry or accessories. By using electrochemical biosensors with longer lifespans, the frequency of replacements is reduced compared to traditional test strips. Sustainability is enhanced through the upcycling of otherwise discarded components, contributing to a more environmentally friendly and cost-effective solution.

## 3 DESIGN CONSIDERATIONS

We drew inspiration from the Wearability Factors for Skin Interfaces [33] and adapted them to propose our Wearability Factors for Designing Jewelry Biosensors, incorporating additional considerations such as modularity, interchangeability, and repurposing within our system.

- Modularity - The jewelry piece serves as a versatile module that can be worn on different parts of the body due to its curved design and the adjustable leather strap that secures it. By using different strap's lengths, the piece can be worn around the neck, waist, arm, wrist, or even as a ring on the finger.
- Interchangeable - The electrodes can be replaced from the case without the need to open thanks to a rivet system

that enables the attachment and detachment of electrodes through pressure. To facilitate their removal, the electrodes' holder features a raised border, providing a convenient grip. The heart shape of the holder allows for easy replacement in the correct orientation of the electrode.

- Repurposing - A repurposing feature is added to the system by creating a heart-shaped perforation in the leather strap which allows the user to insert the used electrode and reuse it as an multi functional accessory, instead of disposing it. The electrodes themselves are also unique, compared to industry electrodes, artistic designs that can serve as jewelry. This reduces waste of disposing used electrodes, which contain precious metal and hard to recycle materials [8, 36]. The replaceable silicone part has a perforation and notch so it can also be used as a pendant by inserting a chain.
- Location - Locations for the modular use of BioSparks are based on the body sweat map [3, 9, 58] which suggested the neck, arms, and torso as heat and sweat producing parts. The replaceable biosensor is strategically positioned at the center of the case, ensuring optimal contact with the body.
- Body characteristics - The case is designed following the curvature of the body, and the circuit and battery are flexible to follow the case shape. The leather straps can be fastened to the body shape and size.
- Body movements - The electrodes are embedded in a silicone insert to provide comfort to the user and are sticking out of the case to ensure contact with the skin.
- Weight and attachment method - Leather straps are used to ensure holding the jewelry and device firmly and secure.
- Aesthetics - Thanks to the jewelry-like case and electrodes in the inner side of it, electronics and electrodes are not visible when the device is worn.
- Interaction - Data visualization and interaction occur from and through the app.
- Conductors - Sterling silver alloy is used to create the jewelry electrodes that are part of the circuit design.
- Insulation - an inner silicone case ensure the insulation of the PCB to the silver case. The jewelry electrodes are also embedded in a silicone holder.
- Device care - case can be opened for cleaning purposes and battery recharging.
- Connectors - common wires to connect the electronic components, and silver parts are soldered with silver paste.
- Communication - The circuit includes a Bluetooth component to send data to the application.
- Battery Life - A rechargeable commercial battery is used.

## 4 BIOSPARKS IMPLEMENTATION

The implementation of BioSparks consist on the design of the electrochemical biosensor, the integration with the circuit, and the design of the case as a jewelry for embedding electronics.

**Traditional Jewelry Design for Electrode Fabrication.**

The replaceable electrode is comprised of three parts: pin electrodes, electrodes receivers and silicone holder. The pin electrodes were made using Sterling silver alloy (925 parts of silver, 75 parts of copper) due to its common use in jewelry making as well as conductivity properties. We carefully cut the heads of the pins from thin flat sheets of silver, shaping and polishing them into three distinct shapes to easily identify each electrode (moon, circle, star). These pin electrodes were then soldered to posts with a 0.9mm external diameter. The receivers utilize a rivet system that connects the pins through pressure, similar to a male-female attachment. They were made by soldering a silver tube of slightly wider inner diameter to flat pieces of silver that would become the connector to the PCB. The holder firmly secure and insulates the electrodes. It was 3D printed in a FormLabs STL printer using Flexible 80A V1 resin. The silicone holder was perforated on the top to receive and securely hold the pins in place. On the bottom, we used a thicker drill bit to create a fitting for the receivers. Finally, all the metal pieces were cleaned with Riogrande pickling solutions, then polished and finally rinsed again using neutral soap and de-ionized water.

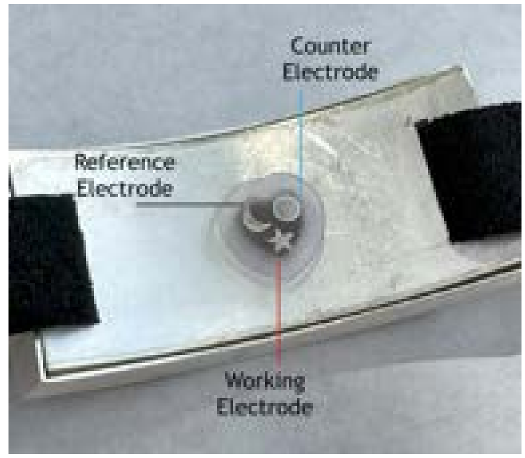


**Figure 2: Designing Electrodes with Traditional Jewelry**

Our biosensor comprises a three-electrode system. The working electrode reacts specifically with the analyte, glucose. It was activated using an enzyme solution and cross-linker solution to make it selective to glucose only, excluding other analytes [1]. The enzyme solution specifically target glucose, and the cross-linker is used as part of the activation process. The other two electrodes in the system include the reference electrode, which has a fixed potential for reference, and the counter electrode, acting as an auxiliary electrode that completes the circuit and enables the flow of current [16, 61]. Finally, an insulating barrier solution [2] is applied over the non-sensing portion of the electrodes for insulation.

The finished biosensor is connected to the ecFlex potentiostat[3]. Each of the three electrodes is connected to the corresponding pin on the electronics. The ecFlex potentiostat operates using chronoamperometry, continuously sending live data to the software via BLE communication. Chronoamperometry is an analytical electrochemistry technique where an electrical potential is applied and stepped

[1]https://www.zimmerpeacocktech.com/products/liquid-solutions/glucose-strip-active-formulation
[2]https://shop.zimmerpeacock.com/products/biosensor-barrier-layer-solution
[3]https://www.zimmerpeacocktech.com/products/electrochemical-sensors/wearable-biosensors/

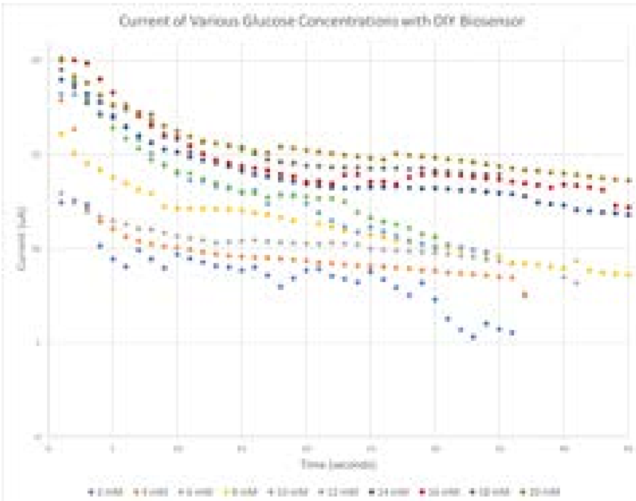


**Figure 3: Chronoamperometric measures for each glucose solution with our biosensor**

in the potentiostat system, and the resulting current is measured. This technique is the standard electrochemical technique used for glucose measurements [40, 43, 60]. The system is powered by a flexible 3V battery.

**Silver Case for Embedding Electronics.** Flat silver sheets were manually cut and curved using a bracelet mandrel. They were then soldered together using medium solder for silver (60 parts silver, 40 parts brass). Decorative gems were cast in silicone molds using epoxy colored resin and placed them after polishing the case. The gems were hold to the exterior case within boxes which were pre-formed in a finer sheet and soldered to the case. Additionally, an interior case was 3D printed using silicone material. This case served as an isolating agent between the conductive materials and held the inner electronic components securely in place.

## 5 TECHNICAL EVALUATION

To evaluate our jewelry biosensor, we conducted tests using 10 controlled glucose solutions within the typical range found in human sweat (2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 mM) [20, 21]. Each concentration was tested with the biosensor through wetting a sterile wipe with 1 microliter of solution to simulate sweat on skin. The potentiostat applies a preset and controlled potential. Test trials lasted for at least 30 seconds, varied due to rate of evaporation or absorption, during which sample data were collected. The resulting chronoamperometric data for each solution were graphed, showing curves following the Cottrell equation as expected for chronoamperometry, which describes current decay over time after initial exposure to a test solution [32, 44, 54].

The graphed results show noticeable trends where, after an initial spike when the electrodes come into contact with the testing solutions, each concentration stabilizes to a curve of unique amplitude. Higher concentrations yield higher currents. By mapping the values of each solution at any given time after the initial 10 seconds, it becomes possible to estimate the concentration from the current, as is typically done in biosensor chronoamperometry analysis [54].

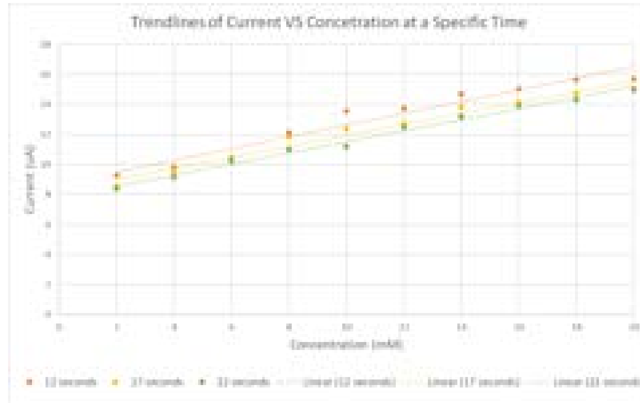


**Figure 4: Trendlines of current values for each concentration at exact times after application of solutions**

Figure 4 illustrates this, where the trendlines for times 12, 17, and 22 seconds have different vertical intercepts but share similar slopes due to exponential current decay, resulting in parallel lines.

Our jewelry biosensor's performance aligns with past research results that used industry-grade glucose biosensor electrodes [12, 30, 41, 44]. This validation further supports the effectiveness and reliability of our biosensor design for glucose detection in sweat.

## 6 CONCLUSION

BioSparks introduced a novel form factor of jewelry wearable design, incorporating electrochemical biosensors capable of detecting glucose in sweat. Our contributions lie in four key areas: introducing traditional jewelry design for electrochemical biosensors, adopting a modular design approach for flexible biosensor placement, implementing interchangeable jewelry electrodes for easy replacement, and repurposing used electrodes within the jewelry's chain, as a pendant or as earrings. This exploration of electrochemical sweat biosensors represents a burgeoning field within the HCI community, offering exciting opportunities for interacting with bodily fluids and developing health monitoring technologies.

Future works involve the use of multiple electrochemical biosensors to detects illnesses that require more than one analyte information, a cleaning process to prolong their lifetime, and experimenting with other jewelry materials that could be used for electrochemical biosensors such as platinum, gold or other sustainable materials. Technical evaluations will be done on oxidation, durability of our electrodes, and reliability of biosensors. We aim to conduct experiments with potential users in exploring 1) other applications for repurposing electrodes for continued support of sustainable biosensors and 2) incorporation of an app visualizer for support of user needs and feedback. This project was a collaboration with two jewelry designers, next iterations will include workshops and interviews with jewelry designers and biotechnologists.

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# REFERENCES


[1] Erman Akyol, Roberta Cabral Cabral Ramos Mota, and Sowmya Somanath. 2021. DiaFit: Designing Customizable Wearables for Type 1 Diabetes Monitoring. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–6. https://doi.org/10.1145/3411763.3451716

[2] Jatin Arora, Kartik Mathur, Aryan Saini, and Aman Parnami. 2019. Gehna: Exploring the Design Space of Jewelry as an Input Modality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300751

[3] Lindsay B Baker, Corey T Ungaro, Bridget C Sopeña, Ryan P Nuccio, Adam J Reimel, James M Carter, John R Stofan, and Kelly A Barnes. 2018. Body map of regional vs. whole body sweating rate and sweat electrolyte concentrations in men and women during moderate exercise-heat stress. *Journal of Applied Physiology* 124, 5 (2018), 1304–1318.

[4] Ananta Narayanan Balaji, Chen Yuan, Bo Wang, Li-Shiuan Peh, and Huilin Shao. 2019. pH Watch-Leveraging pulse oximeters in existing wearables for reusable, real-time monitoring of pH in sweat. In *Proceedings of the 17th Annual International Conference on Mobile Systems, Applications, and Services*. 262–274.

[5] Emanuel Bilbao, Octavio Garate, Theo Rodríguez Campos, Mariano Roberti, Mijal Mass, Alex Lozano, Gloria Longinotti, Leandro Monsalve, and Gabriel Ybarra. 2023. Electrochemical Sweat Sensors. *Chemosensors* 11, 4 (April 2023), 244. https://doi.org/10.3390/chemosensors11040244

[6] Sophia Brueckner. 2018. Empathy amulet: a wearable to connect with strangers. In *Proceedings of the 2018 ACM International Symposium on Wearable Computers (ISWC '18)*. Association for Computing Machinery, New York, NY, USA, 248–253. https://doi.org/10.1145/3267242.3267301

[7] Oğuz 'Oz' Buruk, Çağlar Genç, İhsan Ozan Yıldırım, Mehmet Cengiz Onbaşlı, and Oğuzhan Özcan. 2021. Snowflakes: A Prototyping Tool for Computational Jewelry. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3411764.3445173

[8] Estefanía Costa-Rama and María Teresa Fernández-Abedul. 2021. Paper-Based Screen-Printed Electrodes: A New Generation of Low-Cost Electroanalytical Platforms. *Biosensors* 11, 2 (2021). https://doi.org/10.3390/bios11020051

[9] Nicole A Coull, Anna M West, Simon G Hodder, Patrick Wheeler, and George Havenith. 2021. Body mapping of regional sweat distribution in young and older males. *European journal of applied physiology* 121 (2021), 109–125.

[10] Eric Crouch, David Cowell, Stephen Hoskins, Robin Pittson, and John Hart. 2005. A novel, disposable, screen-printed amperometric biosensor for glucose in serum fabricated using a water-based carbon ink. *Biosensors & bioelectronics* 21 (12 2005), 712–8. https://doi.org/10.1016/j.bios.2005.01.003

[11] Artem Dementyev, Hsin-Liu Kao, Inrak Choi, Deborah Ajilo, Maggie Xu, Joseph A Paradiso, Chris Schmandt, and Sean Follmer. 2016. Rovables: Miniature on-body robots as mobile wearables. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. 111–120.

[12] Sam Emaminejad, Wei Gao, Eric Wu, Zoe A Davies, Hnin Yin Yin Nyein, Samyuktha Challa, Sean P Ryan, Hossain M Fahad, Kevin Chen, Ziba Shahpar, et al. 2017. Autonomous sweat extraction and analysis applied to cystic fibrosis and glucose monitoring using a fully integrated wearable platform. *Proceedings of the National Academy of sciences* 114, 18 (2017), 4625–4630.

[13] Sam Emaminejad, Wei Gao, Eric Wu, Zoe A. Davies, Hnin Yin Yin Nyein, Samyuktha Challa, Sean P. Ryan, Hossain M. Fahad, Kevin Chen, Ziba Shahpar, Salmonn Talebi, Carlos Milla, Ali Javey, and Ronald W. Davis. 2017. Autonomous sweat extraction and analysis applied to cystic fibrosis and glucose monitoring using a fully integrated wearable platform. *Proceedings of the National Academy of Sciences* 114, 18 (May 2017), 4625–4630. https://doi.org/10.1073/pnas.1701740114 Publisher: Proceedings of the National Academy of Sciences.

[14] Jamie Falk, Kevin J. Friesen, Anuoluwapo Okunnu, and Shawn Bugden. 2017. Patterns, Policy and Appropriateness: A 12-Year Utilization Review of Blood Glucose Test Strip Use in Insulin Users. *Canadian Journal of Diabetes* 41, 4 (2017), 385–391. https://doi.org/10.1016/j.jcjd.2016.12.007

[15] Jutta Fortmann, Wilko Heuten, and Susanne Boll. 2015. User requirements for digital jewellery. In *Proceedings of the 2015 British HCI Conference (British HCI '15)*. Association for Computing Machinery, New York, NY, USA, 119–125. https://doi.org/10.1145/2783446.2783573

[16] Fupeng Gao, Chunxiu Liu, Lichao Zhang, Tiezhu Liu, Zheng Wang, Zixuan Song, Haoyuan Cai, Zhen Fang, Jiamin Chen, Junbo Wang, Mengdi Han, Jun Wang, Kai Lin, Ruoyong Wang, Mingxiao Li, Qian Mei, Xibo Ma, Shuli Liang, Guangyang Gou, and Ning Xue. 2023. Wearable and flexible electrochemical sensors for sweat analysis: a review. *Microsystems & Nanoengineering* 9, 1 (Jan. 2023), 1–21. https://doi.org/10.1038/s41378-022-00443-6 Number: 1 Publisher: Nature Publishing Group.

[17] Nan Gao, Zhiwei Cai, Gang Chang, and Yunbin He. 2023. Non-invasive and wearable glucose biosensor based on gel electrolyte for detection of human sweat. *Journal of Materials Science* 58, 2 (Jan. 2023), 890–901. https://doi.org/10.1007/s10853-022-08095-7

[18] Wei Gao, Sam Emaminejad, Hnin Yin Yin Nyein, Samyuktha Challa, Kevin Chen, Austin Peck, Hossain M Fahad, Hiroki Ota, Hiroshi Shiraki, Daisuke Kiriya, et al. 2016. Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis. *Nature* 529, 7587 (2016), 509–514.

[19] Wei Gao, Sam Emaminejad, Hnin Yin Yin Nyein, Samyuktha Challa, Kevin Chen, Austin Peck, Hossain M. Fahad, Hiroki Ota, Hiroshi Shiraki, Daisuke Kiriya, Der-Hsien Lien, George A. Brooks, Ronald W. Davis, and Ali Javey. 2016. Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis. *Nature* 529, 7587 (Jan. 2016), 509–514. https://doi.org/10.1038/nature16521 Number: 7587 Publisher: Nature Publishing Group.

[20] Wei Gao, Hnin Y. Y. Nyein, Ziba Shahpar, Li-Chia Tai, Eric Wu, Mallika Bariya, Hiroki Ota, Hossain M. Fahad, Kevin Chen, and Ali Javey. 2016. Wearable sweat biosensors. In *2016 IEEE International Electron Devices Meeting (IEDM)*. 6.6.1–6.6.4. https://doi.org/10.1109/IEDM.2016.7838363 ISSN: 2156-017X.

[21] Xuecheng He, Tailin Xu, Zhen Gu, Wei Gao, Li-Ping Xu, Tingrui Pan, and Xueji Zhang. 2019. Flexible and Superwettable Bands as a Platform toward Sweat Sampling and Sensing. *Analytical Chemistry* 91, 7 (April 2019), 4296–4300. https://doi.org/10.1021/acs.analchem.8b05875 Publisher: American Chemical Society.

[22] Jeyeon Jo, Doyeon Kong, and Huiju Park. 2021. BLInG: Beads-Laden Interactive Garment. In *Proceedings of the 2021 ACM International Symposium on Wearable Computers (ISWC '21)*. Association for Computing Machinery, New York, NY, USA, 189–193. https://doi.org/10.1145/3460421.3478827

[23] Seongbin Jo, Daeun Sung, Sungbong Kim, and Jahyun Koo. 2021. A review of wearable biosensors for sweat analysis. *Biomedical Engineering Letters* 11, 2 (May 2021), 117–129. https://doi.org/10.1007/s13534-021-00191-y

[24] Lee Jones, Sara Nabil, Amanda McLeod, and Audrey Girouard. 2020. Wearable Bits: Scaffolding Creativity with a Prototyping Toolkit for Wearable E-textiles. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20)*. Association for Computing Machinery, New York, NY, USA, 165–177. https://doi.org/10.1145/3374920.3374954

[25] Hsin-Liu Kao, Artem Dementyev, Joseph A Paradiso, and Chris Schmandt. 2015. NailO: fingernails as an input surface. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 3015–3018.

[26] Hsin-Liu Kao, Christian Holz, Asta Roseway, Andres Calvo, and Chris Schmandt. 2016. DuoSkin: rapidly prototyping on-skin user interfaces using skin-friendly materials. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*. 16–23.

[27] Vassiliki Katseli, Anastasios Economou, and Christos Kokkinos. 2021. Smartphone-addressable 3D-printed electrochemical ring for nonenzymatic self-monitoring of glucose in human sweat. *Analytical Chemistry* 93, 7 (2021), 3331–3336.

[28] Jayoung Kim, William R de Araujo, Izabela A Samek, Amay J Bandodkar, Wenzhao Jia, Barbara Brunetti, Thiago RLC Paixao, and Joseph Wang. 2015. Wearable temporary tattoo sensor for real-time trace metal monitoring in human sweat. *Electrochemistry Communications* 51 (2015), 41–45.

[29] Nantia Koulidou and Robb Mitchell. 2021. Art Digital Jewellery: Practitioners' Perspectives. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*. 1–11.

[30] Yongjiu Lei, Wenli Zhao, Yizhou Zhang, Qiu Jiang, Jr-Hau He, Antje J. Baeumner, Otto S. Wolfbeis, Zhong Lin Wang, Khaled N. Salama, and Husam N. Alshareef. 2019. A MXene-Based Wearable Biosensor System for High-Performance In Vitro Perspiration Analysis. *Small* 15, 19 (2019), 1901190. https://doi.org/10.1002/smll.201901190 _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/smll.201901190.

[31] Pei-Heng Lin, Sian-Chen Sheu, Chien-Wei Chen, Sheng-Cih Huang, and Bor-Ran Li. 2022. Wearable hydrogel patch with noninvasive, electrochemical glucose sensor for natural sweat detection. *Talanta* 241 (May 2022), 123187. https://doi.org/10.1016/j.talanta.2021.123187

[32] Yuanjing Lin, Mallika Bariya, Hnin Yin Yin Nyein, Liisa Kivimäki, Sanna Uusitalo, Elina Jansson, Wenbo Ji, Zhen Yuan, Tuomas Happonen, Christina Liedert, Jussi Hiltunen, Zhiyong Fan, and Ali Javey. 2019. Porous Enzymatic Membrane for Nanotextured Glucose Sweat Sensors with High Stability toward Reliable Noninvasive Health Monitoring. *Advanced Functional Materials* 29, 33 (2019), 1902521. https://doi.org/10.1002/adfm.201902521 _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/adfm.201902521.

[33] Xin Liu, Katia Vega, Pattie Maes, and Joe A Paradiso. 2016. Wearability factors for skin interfaces. In *Proceedings of the 7th Augmented Human International Conference 2016*. 1–8.

[34] Elle Luo, Ruixuan Fu, Alicia Chu, Katia Vega, and Hsin-Liu Kao. 2020. Eslucent: an eyelid interface for detecting eye blinking. In *Proceedings of the 2020 ACM International Symposium on Wearable Computers*. 58–62.

[35] Kuldeep Mahato and Joseph Wang. 2021. Electrochemical sensors: From the bench to the skin. *Sensors and Actuators B: Chemical* 344 (2021), 130178.

[36] Emiliano Martínez-Periñán, Cristina Gutiérrez-Sánchez, Tania García-Mendiola, and Encarnación Lorenzo. 2020. Electrochemiluminescence Biosensors Using Screen-Printed Electrodes. *Biosensors* 10, 9 (2020). https://doi.org/10.3390/bios10090118

[37] Jihong Min, Juliane R Sempionatto, Hazhir Teymourian, Joseph Wang, and Wei Gao. 2021. Wearable electrochemical biosensors in North America. *Biosensors and Bioelectronics* 172 (2021), 112750.

[38] Rupesh K. Mishra, Juliane R. Sempionatto, Zhanhong Li, Christopher Brown, Nathalia M. Galdino, Rushabh Shah, Shuyang Liu, Lee J. Hubble, Kara Bagot, Susan Tapert, and Joseph Wang. 2020. Simultaneous detection of salivary 9-tetrahydrocannabinol and alcohol using a Wearable Electrochemical Ring Sensor. *Talanta* 211 (May 2020), 120757. https://doi.org/10.1016/j.talanta.2020.120757

[39] Marie Muehlhaus, Jürgen Steimle, and Marion Koelle. 2022. Feather Hair: Interacting with Sensorized Hair in Public Settings. In *Designing Interactive Systems Conference (DIS '22)*. Association for Computing Machinery, New York, NY, USA, 1228–1242. https://doi.org/10.1145/3532106.3533527

[40] Zouaghi Noura, Imran Shah, Shahid Aziz, Aamouche Ahmed, Dong-Won Jung, Lakssir Brahim, and Ressami ElMostafa. 2022. Wearable Healthcare Monitoring Based on a Microfluidic Electrochemical Integrated Device for Sensing Glucose in Natural Sweat. *Sensors* 22, 22 (Jan. 2022), 8971. https://doi.org/10.3390/s22228971

[41] Hnin Yin Yin Nyein, Mallika Bariya, Liisa Kivimäki, Sanna Uusitalo, Tiffany Sun Liaw, Elina Jansson, Christine Heera Ahn, John A. Hangasky, Jiangqi Zhao, Yuanjing Lin, Tuomas Happonen, Minghan Chao, Christina Liedert, Yingbo Zhao, Li-Chia Tai, Jussi Hiltunen, and Ali Javey. 2019. Regional and correlative sweat analysis using high-throughput microfluidic sensing patches toward decoding sweat. *Science Advances* 5, 8 (Aug. 2019), eaaw9906. https://doi.org/10.1126/sciadv.aaw9906 Publisher: American Association for the Advancement of Science.

[42] Zhiqing Peng, Xiangyu Xie, Qilong Tan, Hu Kang, Ji Cui, Xia Zhang, Wang Li, and Guoying Feng. 2022. Blood glucose sensors and recent advances: A review. *Journal of Innovative Optical Health Sciences* 15, 02 (2022), 2230003.

[43] Anjum Qureshi and Javed H. Niazi. 2023. Graphene-interfaced flexible and stretchable micro–nano electrodes: from fabrication to sweat glucose detection. *Materials Horizons* (Feb. 2023). https://doi.org/10.1039/D2MH01517J

[44] Aditi R. Naik, Yiliang Zhou, Anita A. Dey, D. Leonardo González Arellano, Uzodinma Okoroanyanwu, Ethan B. Secor, Mark C. Hersam, Jeffrey Morse, Jonathan P. Rothstein, Kenneth R. Carter, and James J. Watkins. 2022. Printed microfluidic sweat sensing platform for cortisol and glucose detection. *Lab on a Chip* 22, 1 (2022), 156–169. https://doi.org/10.1039/D1LC00633A Publisher: Royal Society of Chemistry.

[45] Apichart Saenchoopa, Supannika Klangphukhiew, Rachata Somsub, Chanon Talodthaisong, Rina Patramanon, Jureerut Daduang, Sakda Daduang, and Sirinan Kulchat. 2021. A Disposable Electrochemical Biosensor Based on Screen-Printed Carbon Electrodes Modified with Silver Nanowires/HPMC/Chitosan/Urease for the Detection of Mercury (II) in Water. *Biosensors* 11, 10 (2021). https://doi.org/10.3390/bios11100351

[46] Wilson H Smart and Kumar Subramanian. 2000. The use of silicon microfabrication technology in painless blood glucose monitoring. *Diabetes technology & therapeutics* 2, 4 (2000), 549–559.

[47] Shuyi Sun, Neha Deshmukh, Xin Chen, Hao-Chuan Wang, and Katia Vega. 2021. GemiN' I: Seamless Skin Interfaces Aiding Communication through Unconscious Behaviors. In *Proceedings of the Augmented Humans International Conference 2021 (AHs '21)*. Association for Computing Machinery, New York, NY, USA, 277–279. https://doi.org/10.1145/3458709.3458997

[48] Katia Vega, Abel Arrieta, Felipe Esteves, and Hugo Fuks. 2014. FX e-Makeup for Muscle Based Interaction. In *Design, User Experience, and Usability. User Experience Design for Everyday Life Applications and Services (Lecture Notes in Computer Science)*, Aaron Marcus (Ed.). Springer International Publishing, Cham, 643–652. https://doi.org/10.1007/978-3-319-07635-5_61

[49] Katia Vega and Hugo Fuks. 2016. Hair Interfaces. In *Beauty Technology: Designing Seamless Interfaces for Wearable Computing*, Katia Vega and Hugo Fuks (Eds.). Springer International Publishing, Cham, 17–41. https://doi.org/10.1007/978-3-319-15762-7_3

[50] Katia Vega and Hugo Fuks. 2016. Nail Interfaces. In *Beauty Technology: Designing Seamless Interfaces for Wearable Computing*, Katia Vega and Hugo Fuks (Eds.). Springer International Publishing, Cham, 57–68. https://doi.org/10.1007/978-3-319-15762-7_5

[51] Katia Vega, Nan Jiang, Xin Liu, Viirj Kan, Nick Barry, Pattie Maes, Ali Yetisen, and Joe Paradiso. 2017. The dermal abyss: Interfacing with the skin by tattooing biosensors. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers*. 138–145.

[52] Minqiang Wang, Yiran Yang, Jihong Min, Yu Song, Jiaobing Tu, Daniel Mukasa, Cui Ye, Changhao Xu, Nicole Heflin, Jeannine S. McCune, Tzung K. Hsiai, Zhaoping Li, and Wei Gao. 2022. A wearable electrochemical biosensor for the monitoring of metabolites and nutrients. *Nature Biomedical Engineering* 6, 11 (Nov. 2022), 1225–1235. https://doi.org/10.1038/s41551-022-00916-z

[53] Martin Weigel, Tong Lu, Gilles Bailly, Antti Oulasvirta, Carmel Majidi, and Jürgen Steimle. 2015. iSkin: Flexible, Stretchable and Visually Customizable On-Body Touch Sensors for Mobile Computing. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (2015).

[54] So Yamamoto and Shigeyasu Uno. 2018. Redox Cycling Realized in Paper-Based Biochemical Sensor for Selective Detection of Reversible Redox Molecules Without Micro/Nano Fabrication Process. *Sensors* 18 (02 2018), 730. https://doi.org/10.3390/s18030730

[55] Jason Yeaw, Won Lee, Mark Aagren, and Torsten Christensen. 2012. Cost of Self-Monitoring of Blood Glucose in the United States Among Patients on an Insulin Regimen for Diabetes. *Journal of managed care pharmacy : JMCP* 18 (01 2012), 21–32. https://doi.org/10.18553/jmcp.2012.18.1.21

[56] Meredith Young-Ng, Grace Chen, Danielle Kiyama, Anna-Sofia Giannicola, Erkin Şeker, and Katia Vega. 2023. Sweatcessory: a Wearable Necklace for Sensing Biological Data in Sweat. In *Adjunct Proceedings of the 2022 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the 2022 ACM International Symposium on Wearable Computers (UbiComp/ISWC '22 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 141–143. https://doi.org/10.1145/3544793.3560342

[57] Paloma Yáñez-Sedeño, Susana Campuzano, and José Pingarrón. 2020. Screen-Printed Electrodes: Promising Paper and Wearable Transducers for (Bio)Sensing. *Biosensors* 10 (07 2020), 76. https://doi.org/10.3390/bios10070076

[58] Clint Zeagler. 2017. Where to wear it: functional, technical, and social considerations in on-body location for wearable technology 20 years of designing for wearability. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers*. 150–157.

[59] Tengxiang Zhang, Xin Zeng, Yinshuai Zhang, Ke Sun, Yuntao Wang, and Yiqiang Chen. 2020. ThermalRing: Gesture and Tag Inputs Enabled by a Thermal Imaging Smart Ring. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376323

[60] Jiangqi Zhao, Yuanjing Lin, Jingbo Wu, Hnin Yin Yin Nyein, Mallika Bariya, Li-Chia Tai, Minghan Chao, Wenbo Ji, George Zhang, Zhiyong Fan, and Ali Javey. 2019. A Fully Integrated and Self-Powered Smartwatch for Continuous Sweat Glucose Monitoring. *ACS Sensors* 4, 7 (July 2019), 1925–1933. https://doi.org/10.1021/acssensors.9b00891 Publisher: American Chemical Society.

[61] Yunmeng Zhao, Qingfeng Zhai, Dashen Dong, Tiance An, Shu Gong, Qianqian Shi, and Wenlong Cheng. 2019. Highly Stretchable and Strain-Insensitive Fiber-Based Wearable Electrochemical Biosensor to Monitor Glucose in the Sweat. *Analytical Chemistry* 91, 10 (May 2019), 6569–6576. https://doi.org/10.1021/acs.analchem.9b00152 Publisher: American Chemical Society.

[62] Wenbin Zhou, Qian He, Haifeng Ye, Changqing Ye, Xing Wu, and Junhao Chu. 2021. Recent advances in flexible sweat glucose biosensors. *Journal of Physics D: Applied Physics* 54, 42 (Aug. 2021), 423001. https://doi.org/10.1088/1361-6463/ac14ef