Designing with Biosignals: Challenges, Opportunities, and Future Directions for Integrating Physiological Signals in Human-Computer Interaction

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Biosensing technologies are a rapidly increasing presence in our daily lives. These sensor-based technologies measure physiological processes including heart rate, breathing, skin conductance, brain activity and more. Researchers are exploring biosensing from perspectives including: engineering, human-computer interaction, medicine, mental health, consumer products, and interactive art. These technologies can enhance our interactions allowing connection to our bodies and others around us across diverse application areas. However, designing with biosignals in Human-Computer Interaction presents new challenges pertaining to User Experience, Input/Output, interpretation of signals, representation, and ethics. There is an urgent need to build a scholarly community that includes the diverse perspectives of researchers, designers, industry practitioners and policymakers. The goal of this workshop is to leverage the knowledge of this community aiming to map out the research landscape of emerging challenges and opportunities, and to build a research agenda for future directions.

CCS Concepts: • **Human-centered computing → Interaction techniques**; **Interaction design theory, concepts and paradigms**.

Additional Key Words and Phrases: biosignals, physiological signals, biofeedback, biodata, affective computing, ethics, wearables

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1 BACKGROUND

Physiological or **biosensors** measure our physiological processes (e.g., heart rate, breathing, skin conductance, brain activity, muscle tension), provide **biofeedback**, and allow us to externalize our **biodata** to perceive our internal bodily states. **Biosignals** provide useful insights about health, emotions, and cognition [8]. This can allow us to *connect* and better understand our own bodies, as well as other people. Along with the pervasive "quantified self" movement, we observe a rapid adoption of biosensing technology in the consumer market. Most consumer devices target individual health and self-improvement (e.g., fitness and health trackers and meditation apps). But, there are also growing opportunities for sharing biosignals within a social context, e.g., to understand others' emotions and support a

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sense of intimacy and connection. Finally, emerging research explores biodata as a design material to explore novel somatic experiences and extend understanding and somatic appreciation of our bodies [18].

Designing with biosignals in Human-Computer Interaction (HCI) is a rapidly evolving field that spans many domains including tangible and embodied interaction, affective computing, VR/AR, interactive art, health and well-being HCI, cooperative and social computing, game design, body-centric design, etc. A diverse range of applications is explored: emotion regulation [7], supporting intimacy in long-distance relationships [11], augmenting social interactions in social Virtual Reality (VR) entertainment [9], improving productivity in workplaces [20], inviting reflection in public spaces building "smart cities" [6], stimulating social exertion in sports [19], etc.

A recent emergence of review papers mapping out sections of the domain of design with biosensors reveals community's desire to structure and better understand this evolving design space. Moge et al. [13] reviewed the use of biosignals in social interaction, noting a growing rate of papers over the last five years. Prpa et al. [14] analyzed theoretical frameworks underlying breath-responsive systems. Yu et al. [21] reviewed biofeedback for stress management, identifying challenges of interpretation, scalability, and evaluation. Feijt et al. [3] analyzed systems for biofeedback-sharing in interpersonal communication, and Halbig et al. explored biosignal use in VR [4]. While these systematic reviews outline the range of existing opportunities presented by biosignals, what is missing is the practice-based overview of the many challenges observed when working with biosignals, often hidden in the design process.

More research and discussion is needed pertaining to how we *can* and *should* design bio-responsive systems. There is a particular need to stimulate cross-disciplinary conversations to synthesize common vocabulary, definitions, and strategies to address challenges of meaning-making, Input/Output (I/O) implementation, design of representations, and ethics. Despite the increasing prominence, there is little governance and established best practices for the use of biosensing outside of the medical field. Yet, careless designs and unregulated use of biodata has the potential to harm users and society. E.g., imbuing biosignals with rich objective interpretations about others' subjective hidden states may result in inaccurate judgments and discrimination. Neglecting to provide users with agency over sharing their biodata can result in issues of privacy and power inequality. This is not only a question of *ethics* and *policy* as to when biosignals can be shared, but also a **design question** of how we interpret and represent them. Thus, it is critical to bring together the community to share our diverse perspectives, and to synthesize knowledge emerging from practice in order to identify the emerging challenges and begin to formulate guidance for policy and future design developments.

The workshop will invite diverse attendees to share their experiences to identify and articulate common challenges and imagine opportunities. This communal effort will begin to map out future directions for the field of biosignals.

TOPIC 1—Meaning-Making and UX of biodata: The various biosignal applications reveal the plurality of effects that this technology can have on individuals, and our relationship to our own and others' bodies, including the long-term consequences of reshaping these relationships. For instance, the use of biofeedback can improve one's interoceptive awareness—the ability to empathize with others by learning about one's own or other's internal state. However, this enhanced access to others' states carries the risk of drawing too much attention towards an externalized representation of biodata and away from the human at the other end. Also, trusting too much in the accuracy of biodata could develop false confidence in knowing others' states, while, in reality, biodata might only provide a very limited insight into what others are experiencing [8], and is often ambiguous [5]. E.g., what does it mean if someone's heart rate is 10 beats faster than their partner's? There is a growing debate arising from the constructionist models of emotions [10] on how much can truly be inferred about users' emotions from physiological data alone given the lack of universal expressions. How can we design biofeedback systems to avoid over-interpretation and support reflective meaning-making? There is also a challenge in synthesizing knowledge across diverse applications of biosensing systems, as different fields come from

variant epistemological groundings resulting in divergent meaning-making [14]. The influence of diverse contexts of use presents another challenge. Naturally, our social relationships have a significant effect on our level of comfort with sharing our intimate biodata, as well as the meaning-making we engage in when seeing a representation of a biosignal depending on whether it comes from a computer, from ourselves, our loved one, our boss, or a stranger.

TOPIC 2—I/O of biosignals: Integration of biosensing in HCI presents many technical challenges. How can we design for robustness, scalability and adaptability of continuously sensing biosensors themselves [17], especially when used outside of a controlled lab setting with many sensors requiring calibration or being prone to noise from movement [12]? How can we couple biosensing with the appropriate body feedback modalities? Such body augmentation, can also bring to question our sense of bodily agency [2]. Lastly, while there is a growing trend in HCI to design for bodily engagement in interaction, the diversity of our bodies is often overlooked. Designs are often biased towards able-bodied white adult males that continue to dominate the design community [16]. As our bodies and physiological processes are not the same across different shapes, ages, ethnicities, and abilities, how can I/O of biosensing systems address such challenges of diversity?

TOPIC 3—Representing biosignals: Another challenge concerns deciding how to represent biosignals. Biosignals can be represented in a broad variety of ways ranging from direct display of raw data, skeuomorphic visualizations in social VR [9], heavily processed signals with embedded interpretations, to abstract and artistic forms such as varying the appearance of an avatar in VR [1]. While raw data can be difficult to interpret [15], processing biodata and presenting it in the form of discrete affective states often is met with skepticism about its accuracy [11]. Various streams of biodata can also be represented individually [19] or as an aggregate of signals from a group, potentially overcoming some privacy concerns [13]. Furthermore, while the biofeedback design landscape is dominated by visual representations, what benefits may other sensory modalities offer? This choice of modality and the design of the display will also have a considerable effect on meaning-making and how implicit or invasive the system can be. Having multiple users opens further options in how the signals can be represented for each user, and whether this representation needs to be symmetrical across users.

TOPIC 4—Ethics of sharing biosignals: Working with biosignals inevitably raises ethical considerations. Our physiology is inherently private and thus biodata can be considered sensitive information necessitating that users have the agency to make an informed decision to share or not. In many cases, biodata may reveal more about us than we realize making this consent to share a particularly challenging problem. We ourselves may be lacking awareness of and control over our physiological activity, thus not fully understanding the interpretive potential when making it accessible to others. When designing for biodata-sharing, how can we minimize immediate and future harm pertaining to privacy, agency over data, equity and power relationships, data use and storage? For instance, while neuromarketing provides useful insights for better understanding consumer preferences and behaviour, gaining access to this understanding of consumers' 'subconscious' inclinations by companies furthers the longstanding hegemony which companies already wield over consumers. and service providers. This issue is further amplified by the lack of consistent standards for data security across domains of health, academia and private business, where industry is often not bounded by the same standards as academic and medical fields. It is equally critical for developers to avoid overstating the interpretive potential of rather limited data collected by a given biosensor. Consumer-grade sensors are particularly prone to significant noise, but even with high-end technology, biosignals should always be interpreted with caution. Considering the immense ethical concerns raised by biodata-focused research, it is important to reflect on how we could work towards alternative and radical inclusive ways of living and knowing together with biodata and multiple bodies [18].

2 GOALS AND ANTICIPATED OUTCOMES

There are existing efforts to build a community discussing challenges pertaining to technological implementation of biosensing [12]. We are building on this discussion broadening the scope to challenges beyond I/O to incorporate the domains of design, ethics, psychology, and the social impacts. By bringing the broader biosignals in HCI community together, we aim to work towards a more holistic and multidisciplinary view of design for sharing biosignals centered around human and societal needs. In this one-day workshop we aim to bring together the interdisciplinary community of researchers, designers, artists, and policymakers to explore the challenges occurring in integrating biosignals in HCI to reconnect with oneself and one's body, as well as others and their bodies. We will discuss key topics, identify key challenges spanning different domains, and begin to articulate future directions for addressing these challenges.

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