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Author

Howell, Noura

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Noura Howell

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Committee in charge:

Associate Professor Kimiko Ryokai, Chair
Professor John Chuang
Associate Professor Greg Niemeyer
Associate Professor Abigail De Kosnik

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Abstract

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Doctor of Philosophy in Information Management and Systems in School of Information
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University of California, Berkeley

Associate Professor Kimiko Ryokai, Chair

How many steps did you take today? Counting steps may seem like a clear-cut number, but this number is embroiled in bigger goals around health, broadly conceived, how we feel about our bodies, behavior, and lifestyle. We engage these issues on a personal level while also influenced by social relationships and societal narratives. Technologies such as step-counters influence what "counts", or what seems important, valid, or worthwhile. In addition to step counts, other physiological sensors are increasingly embedded in wearables, walls, and furniture, producing data–implicitly deciding what "counts"–about people's bodies, behaviors, and even claiming to measure thoughts and feelings.

My work in this space starts from the simple yet often-overlooked observation that these are *embodied social and emotional* issues. Considerations of whether people feel OK about their bodies, behavior, lifestyle, and/or health are emotional, social, and embodied, and it would be too limited to only use analytical techniques with data for these considerations. Self-tracking is often touted as leveraging the seeming objectivity and neutrality of data for self-improvement and productivity, but it is important to also consider processes of embodied social and emotional meaning-making tied up in these practices.

Furthermore, data-driven categorizations about human bodies and behavior are caught up in problematic biopolitics of dehumanization. Categorization creates 'others' [41], margins outside the main categories. Categories are not neutral. They can embed implications around who is normal or abnormal, productive or unproductive, sane or crazy, safe or criminal. At its worst this can contribute to broader historical projects of otherization that treat some people as less than fully human, such as racism, sexism, ableism, or colonialism. My dissertation does not engage a particular axis of marginalization, although I draw from scholars who apply critical race, feminist, disability, and colonial studies to technology and data science (e.g., [29, 255, 62, 274, 157]). My designs explore tactics for reconceptualizing sensors and data in ways that try to avoid otherization, with some surprisingly positive and negative results.

Emotional biosensing is how I refer to a myriad of emergent sensing technologies that measure human bodies and behavior. Emotional biosensing can include counting steps, video, heart rate, skin conductance, brainwaves, breathing, etc., but it does not stop there. Companies (e.g., [5, 328, 94, 239, 266]) use this data to make claims about how people are feeling. Sometimes the goal is to help people manage their own stress or promote wellbeing. Other times the goal is to report drivers' road rage to automotive manufacturers [4], 'detect' hostile intent threats at airports [68, 67], or algorithmically determine job applicants' suitability for a role [154]. Prevalent approaches in the recent years 2014-2018 have been far too limited, with an emphasis on isolated individuals, discrete emotional states, and never-ending self-improvement. Newer research in the field of Human-Computer Interaction is starting to broaden this space, and my dissertation is part of that change.

We need more emotional ways of making meaning with the amassing biosensory data about our behavior, bodies, thoughts, feelings, etc. I explore questions such as,

What if designs gave people the agency and authority to make their own meaning based on emotional biosensing?

How might data displays support emotional, social, and embodied ways of knowing with emotional biosensing?

My work sits at the intersection of human-computer interaction, new media interactive art, and tangible data displays. By leveraging different material qualities and sociocultural associations of dynamic data displays, I design artifacts that invite social, embodied, emotional forms of meaning making with biosensory data. These designs offer critical alternatives to the limited prevalent approaches with emotional biosensing. With my designs, people feel the data on their skin, see it imbue the hues of their clothing, hear data as sound, feel data as vibration. Rather than claiming to 'detect' and 'improve' how people feel, I set up situations where people form open-ended, social, emotional interpretations about their own and others' data. The earlier work of my dissertation studies how pairs of friends interpreted color-changing garments they were wearing that responded to their skin conductance. The later work of the dissertation studies how pairs of strangers interpreted the live unfiltered sounds of their hearts emanating from the bench on which they were sitting.

My work contributes design tactics for alternative forms of meaning-making with biosensory data. Going beyond a sketch or gallery installation, these speculative designs are explored with real people experiencing fully functional prototypes. Their emotional experiences with and around the technology are not staged. Rather than trying to only imagine what these futures might be like, or what problems might arise, people experiencing my designs have emotional reactions that are often surprising. These experientially grounded speculative designs probe just around the corner to near-future possibilities with biosensing technology. They probe biopolitical issues of seemingly authoritative ways of knowing and suggest radically different visions for living with data.


الحمد لله

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Chapter 1

Reframing Emotional Biosensing

Biosensing is rising in daily life: Data and categories claim to know how people feel and suggest what they should do about it. Prevalent approaches to emotional biosensing are too limited, focusing on the individual, optimization, and normative categorization. This chapter introduces key conceptual shifts to help explore alternatives. These shifts move toward materiality, from representation toward performativity, inter-action to intra-action, shifting biopolitics, and shifting affect/desire. As a design researcher, from these conceptual shifts I draw out suggestions for designers and design researchers: humility in knowledge claims with emotional biosensing, prioritizing care and affirmation over self-improvement, and exploring alternative desires. These suggestions are themselves contributions to human-computer interaction, and they also motivate and inform my own design research as elaborated in later chapters. There is a need to critically question and generatively re-imagine the role of data in configuring sensing, feeling, 'the good life', and everyday experience. My dissertation explores these conceptual shifts and design suggestions through design research. This chapter draws from my lead-author paper [167].

Biosensing technologies track many aspects of daily life, including emotions, in sometimes unexpected ways. For example, video surveillance can be used to 'detect' percentages of joy, contempt, or anger [5], 'hostile intent' threats at airports [68], or heartrate [263]. Heartrate can be linked to stress [225] or future involvement in violent crime [202]. Mobile phone and Instagram data can be linked to depression diagnoses [285, 50]. Abilify, a medication for depression, bipolar, and schizophrenia, tracks whether patients ingest it to ensure compliance [265, 282]. It is difficult to know or manage how one might be categorized from the seemingly innocuous data one gives off by appearing on surveillance cameras or using a mobile phone, or how these correlative categorizations might masquerade as authoritative predictive insights.

For those of us not (yet) categorized as 'crazy' or 'criminal,' or those deemed 'healthy,' consumer products urge self-improvement via algorithmically generated behavioral adjustments [306]. Microsoft Band promises, "This device can know me better than I know myself, and can help me be a better human" [234, 233], with "actionable insights" to help "live healthier and achieve more" [232]. Wristband sensor Feel claims to be the "world's first emotion sensor and well-being advisor" [94]. Clip-on breath monitor Spire offers to help

Figure 1.1: (Left) Bellabeat Instagram post from February 24, 2019 [26]: "Are you ready for the new week? Let's get it! [muscle arm emoticon, winky face emoticon] The downside of being a busy bee is that you can get so wrapped up in all your obligations that you end up forgetting about your well-being. [bumblebee emoticon] That's where our wellness accessories come in! Leaf will track your activity, sleep, reproductive health, and mindfulness, while Spring tracks your hydration and reminds you to drink more. Our wellness tracker Leaf will also help you manage stress sensitivity by providing helpful insights into how all your wellness data correlates [twinkle star emoticon] and the best part is, all you have to do is wear it! [branching green leaf emoticon] #wellness #bellabeat" The leaf shaped pendant necklace and water bottle are both embedded with sensors to "sync your body and mind" [27]. (Middle) Spire offers, "Give the gift of calm" for Valentine's Day [148]. (Right) Microsoft Band promotes, "Live healthier and achieve more" [233]. These advertisements shape our desires toward a particular normative vision of the good life. How can emotional biosensing support alternative ways of living and feeling?

"gift wrap peace of mind this Christmas", [149], reducing stress and improving mindfulness [328]. Everyone might need help emotionally sometimes, and these technologies may help some people. Yet, these devices illustrate a prevalent approach to emotional biosensing that is far too limited.

In "Fitter, Happier, More Productive: What to Ask of a Data-Driven Life," Elsden et al. question the normative values of helping individuals be fitter, happier, and more productive. They argue that prevalent approaches to self-tracking are too limited. They call for broadening the design space to explore, "moving beyond an individual, trajectories and temporalities, and alternative representations of data" [137, 86]. Focusing on emotional biosensing, this dissertation builds on these questions and helps broaden the design space by locating emotion beyond the individual, exploring alternative material data displays, and highlighting epistemic tensions.

A growing body of design research, art, and human-computer interaction research already explores such directions. Sharing and interpreting biosensory data, Slovák et al. studied social connection [321, 323], Snyder et al. combined pair's data into a single display [324], Elsden et al. explored social performance [87] and memorabilia [85], Merrill and Cheshire investigated trust [229], and Kaziunas et al. [191] and Pina et al. [278] studied emotional aspects of family health tracking. Unfit Bits challenge step counts [43], plenty of work supports personal and social reflection [168, 236, 292, 296, 329] or social sharing in video

or fashion [91, 1, 347, 366], and somaesthetic design attunes bodies to sensing themselves [163]. Still more work explores immersive meditation [348], emotional meaning making and performativity [205, 206, 356], privacy [370], mindfulness [9], design fictions of BCI APIs and labor [368], or relationality [218, 244] with biosensing.

This chapter reflects on industry zeitgeist and draws from ongoing alternative explorations to outline how prevalent approaches with emotional biosensing are too limited: Prevalent approaches promote individuality and optimization, and claim data can capture and represent emotion extracted from context. Leveraging strands of critique from design research, feminist new materialisms, and (post-) biopolitics suggests generative alternative approaches for design researchers.

How designers approach emotional biosensing has intrinsic consequences for vital ethical and political questions and shifts [289]. What are or will be "the actors and authority involved in the production of 'self'-knowledge" [160, p. 2], who is granted the authority to speak what truth, and what ways of knowing the self are considered valid? With self-tracking, "At stake are the very lenses we use to see ourselves and others" [250, p. 10]. With emotional biosensing in particular, at stake are ways of feeling and the emotional experience of everyday life.

This chapter prioritizes open-ended generativity. It does not propose a new research agenda or ethical guidelines for emotional biosensing. Instead, this chapter (1) curates and synthesize a set of wide-ranging conceptual lenses, and unpacks how these can shift design research with emotional biosensing. (2) It selects and analyzes design exemplars to concretize concepts. (3) Throughout it offers reflections and recommendations for emotional biosensing design. In particular it calls for humility in emotional knowledge claims, prioritizing care and affirmation over self-improvement, and exploring alternative desires. In the spirit of Law's reflections on method and messiness [203], I put these lenses into conversation without flattening messiness to acknowledge the complexity of affect, feeling, and emotion, and reflect on how each lens crafts reality slightly differently. Rather than providing answers, this chapter wends pathways for asking:

How can emotional biosensing be reconfigured away from commodity lifestyle and self-optimization toward alternative ways of feeling and living?

1.1 Prevalent Current Approaches Are Too Limited

Emotional biosensing consumer products are too limited in their emphasis on the decontextualized individual, workplace productivity, and data as an authoritative way of knowing. These limitations are opportunities to explore alternatives.

1.1.1 Prevalent Current Approaches

Affective Computing quantifies emotion into discrete categories based on patterns of participants' physiological signals. As an overly simplistic example, if most participants respond

Figure 1.2: Consumer products Feel [94], Moodmetric [268], and Spire [327] (from left) provide categorical, quantitative, and comparative representations of emotion and suggest behavioral adjustments. They emphasize particular ways of knowing emotion and the self, locating emotion at the level of the individual and valuing scientific objectivity as a means of knowing the self. Feel's discrete emotional categories (e.g., joyful, sad, content, distressed) flatten richness and complexity of feeling while ignoring context, and its Mood Booster exercises suggest one should desire an 'upward' trajectory. Moodmetric's scale from 0 to 100 also flattens mood along a single axis. Considering context, how might Spire's suggestion of a "quick breathing exercise" be received during a hectic morning vs. a family emergency?

to a calming experimental stimulus like gentle ocean waves with a particular pattern of physiological signals, then this pattern is associated with calm. Experiments often include participant self-report of emotion as a kind of 'ground truth' to validate results, but the eventual goal is often framed as 'accurately' 'detecting' or 'predicting' emotions in daily life without needing self-report. Some claim this can provide more 'natural' experiences with technology or even detect deception. The goal is often to find generalizable categories of emotion that are universal and transcend sociocultural context [49]. Yet, methods not only describe but also help craft reality [203]. Affective Computing creates the categories it seeks and reifies particular approaches to emotion that influence industry and enthusiast emotional biosensing.

Drawing from Affective Computing, consumer and enterprise products quantify emotion into standardized categories used to offer behavioral suggestions for self-improvement and workplace productivity. Feel, Spire, Oura, Moodmetric, and Leaf Urban track physiological signals (e.g., skin conductance, breath, EEG) to produce quantitative or categorical representations of emotion, and suggest behavioral adjustments for emotional wellness like reducing stress and improving productivity [204, 328, 96, 266, 239]. Affectiva uses facial video analysis to produce percentage representations of discrete categories like anger, fear, and joy, to help advertisers and developers make products more appealing [5]. Humanyze offers workplace tracking of "objective, complete data" like employee chat messages and meeting durations to "improve productivity, cost-savings, and employee satisfaction using the proven science of our people analytics platform" [170]. Muse Lowdown Focus uses EEG to help improve cognitive performance [215]. These products put Affective Computing into practice, claiming scientific authority for their insights and suggestions about everyday emotional experience.

Enthusiast practices also use quantification and behavior change for self-improvement and productivity, but with more individual flexibility on what to measure, what it means, and what to do about it. Self-described 'biohackers' track mood, heartrate, steps, etc. They seek behavioral adjustments in diet, lifestyle, and medication to improve professional performance, health, and wellbeing (e.g., [372, 371]). Quantified Self enthusiasts also self-track mood in often creative and reflective ways (e.g., [238]). They often manually record data, offering flexibility and reflexivity in measurement and meaning making. Quantified Self may be a form of "soft resistance" against "dominant practices of firms and institutionalized scientific production" [248, p. 1784], and a way to resist social norms [313]. Broadly, these practices emphasize self-knowledge and self-improvement via individual data tracking, data analysis, and behavior change. While commercial products provide an intended use case or kind of desirable behavior change, biohackers and Quantified Selfers usually decide for themselves what to track and what to do about it.

Of course, there are many practices of emotional biosensing not discussed here. I focus especially on these practices because they align with a prevalent cultural imagination around data, where data is framed as having the authority to deliver promising insights. Reflexively, I am particularly attuned to Silicon Valley cultural imagination due to my location in Berkeley, California.

1.1.2 Potential and Limitations

There is positive potential in these approaches. For example, Feel executives hope their product will destigmatize mental health issues and make therapy more affordable [342]. For some, Spire does help manage stress throughout daily life as an alternative to medication [328]. Bio-hackers and Quantified Self enthusiasts share stories of how their practices have greatly helped them (e.g., [372, 371, 238]). Yet, the critique of this chapter is to call out what these approaches normalize or promote, outlining those as limitations to seek alternative approaches. While acknowledging that users may adapt products to their own purposes, this critique focuses on the approaches put forth by product companies, because these marketing materials influence our social and cultural imagination about what emotional biosensing can and should do.

These devices and practices focus on the individual as the site of sensing and behavior change. An individual focus on wellness can distract from and normalize structural issues, like stress due to race, poverty, or gender discrimination, as outlined by Lupton and others [13, 130, 132, 132, 217]. These devices and practices join a broader biomedical move around risk and responsibility: Health is framed as constantly at risk, and it is the individual's responsibility to mitigate risk. One should seek a normative 'good life' via informed decisions and individual behavior changes relying on data [80, 81, 288, 291, 306, 305, 334]. Self-tracking products frame wellness as never-ending self-optimization, promote the "commodification of daily living," and "give far too much power to those who decide what is worth measuring and who measures up" [250, pp. 6–7].

A focus on workplace productivity, and health for the sake of work, is prevalent. Employers are beginning to push for tracking workplace and fitness activities with the aim of increasing productivity and reducing insurance costs. Some insurance programs reward 'healthy' behavior as determined by Fitbit [30]. In the U.S., West Virginia teachers went on strike partly in response to insurance changes requiring fitness activities as tracked by Fitbit and other means [39, 106]. Big Health offers sleep tracking and apps for improving mental health; while acknowledging potential benefits, this is marketed as a way employers can reduce health insurance costs [31]. Even mindfulness gets framed as a tool for improved productivity and reduced stress [9].

These devices emphasize particular ways of knowing emotion and the self. Many devices treat emotion as something that can be put into discrete categories that transcend context, neglecting the socioculturally situated nature of emotion [36]. Cultural and new media scholar Hong describes how these technologies promote particular ways of knowing: "the idea that machines will know us better than we know ourselves, a kind of 'knowing' that embraces modernity's epistemic virtues of accuracy and objectivity" [160, p. 2]. This points to opportunities for emotional biosensing to support other ways of knowing and other values.

1.2 Seeking Alternatives via Theory

Theory can help explore alternatives, not by presenting explicit design directives, but rather by helping see things through different lenses and suggesting different areas of focus. Critically oriented work seeks to question and reimagine our everyday interactions, often drawing from theory. These approaches may not lead to solutions immediately, but they offer better understanding of the problem space. These approaches embrace critique as opportunity for further research [115, 277]. Our strategy for critique draws from Nafus quoting Latour in her introduction to Quantified: Biosensing Technologies in Everyday Life [246]: The critic can be "not the one who lifts the rug from under the feet of the naive believers, but the one who offers the participants arenas in which to gather" [201, p. 246]. This chapter offers 'arenas' by grouping together different theories and projects and putting them in conversation with one another. The selection of theories and projects stems from my own design research with emotional biosensing. These are the lenses that are especially generative for my own work. These are the design exemplars I find useful for discussing these lenses with interdisciplinary groups of biosensing researchers.

The theories presented here speak to one another but do not reach perfect consensus. They are presented as separate, but different boundaries could be drawn. Instead of a cohesive summary of relevant theories, this chapter sketches an (artificially linear) series of conceptual moves that suggest generative directions for a growing, dynamic design space. Reflecting on how these theories have informed particular design exemplars makes this engagement with theory more concrete. Reflexively acknowledging shortcomings or enduring tensions of these designs generates opportunities for further exploration. Methods and theoretical lenses are intertwined, and as Law argues they not only describe reality but

also help craft reality [203]. With alternative lenses design researchers can craft alternative realities for emotional biosensing, ways of feeling, and ways of knowing and configuring the self and social relationships.

1.2.1 Affect, Feeling, and Emotion

How are affect, feeling, and emotion defined in the first place? These definitions influence emotional biosensing designs. For example, distinguishing affect, feeling, and emotion suggests designing for more affective embodied experience, personal interpretation of feelings, or social interpretation of emotions. Affect, feelings, and emotion have been distinguished differently in different fields (e.g., [24, 192, 198, 267]).

One view from media and cultural studies outlines a progression: Affect is seen as precognitive or more embodied, before conscious identification by the person experiencing it. These can become feelings when consciously recognized by the person. These can become emotions when mapped to words or concepts that are culturally recognizable by others [315].

Psychology takes various approaches to understanding affect, feeling, and emotion: For instance, while social appraisal theory emphasizes the role of interpretation in orienting ourselves toward the world, processes like mimicry, contagion, and empathy focus more on "direct embodied" transfer without interpretation [267, p. 6]. Design could draw inspiration from processes of mimicry or social synchronization of physiological signals (e.g., [323]). Drawing from psychology, Affective Computing "hope[s] to build computer systems that can automatically recognize emotion by recognizing patterns in these sensor signals" [146, p. 1].

In sum, different distinctions rely on different framings of self, embodiment, and consciousness. Not taking a hard stance on these distinctions in this chapter acknowledges the variety of distinctions at play in the variety of work related to biosensing, mood, feeling, affect, and emotion. This variety indicates not a lack of rigor, but rather is an expected outcome of drawing from a variety of disciplinary approaches to the complexity of human experience.

1.2.2 From Digital to Material Data Representations

One way of exploring alternatives with emotional biosensing is to reconsider the way this data is represented (e.g., [102, 235, 292, 321, 324]). Material displays of data invite particular engagements in particular sociocultural contexts, and can evoke different associations that can influence interpretation. Most emotional biosensory data displays show time series graphs, or logs of emotional states over time, on digital light-emitting screens (e.g., [94, 3, 328, 84]). Sometimes a more abstract animation is displayed on a screen such as a growing tree [374]. A digital time series graph supports seeking patterns over time, while material representations offer other kinds of interpretations. For example, Miller's Conflict Sculptures represent family shouting incidents with playdough balls [235]; playdough could support kids rearranging, comparing, and analyzing the data. Showcase fashion uses LEDs, actuation, and fiber optics for expressive, dramatic biosensing garments (e.g., [19, 92, 107, 142, 1, 2, 366, 365, 172]). Data physicalization can support embodied interpretation [183].

Figure 1.3: Material representations can invite different meaning-making associations and engagements with data. (from left) Devendorf et al.'s slow, subtle color-changing fabric data displays evoke personal style associations [70]. Ryokai et al.'s chocolate bar graphs represent moments of laughter as biosensory data, inviting celebration and cherishing [293, 292]. Fox's bioluminescent algae displays the viewer's real time heartrate, creating an experience of cross-species connection [102]. How else can material representations invite different ways of engaging and knowing with biosensory data?

Data is often treated as intangible, yet as human bodies we only ever encounter it in material form, whether as a graph on a light-emitting screen or on paper. Digital 0s and 1s are fuzzy abstractions used to describe physical electrical properties. Vallgårda et al. introduce computational composites and material strategies for combining computational and material properties for interaction design [344, 343]. Latour frames data not as a given but rather as an achievement, something actively constructed and transformed from each material representation to the next [200]. Dourish and Mazmanian [79] describe how the materials used to present data—whether as a log of discrete emotional categories on a light-emitting mobile phone screen [94], or playdough balls [235]— "shape the questions that can be easily asked of it, the kinds of manipulations and analyses it supports, and how it can be used to understand the world" [79, p. 8].

For design researchers engaging materials with emotional biosensing, Giaccardi and Karana's framework of materials experience has relevance. They outline sensorial, interpretive, affective, and performative levels of experience with materials [122]. This lens can be applied to analyze Ryokai et al.'s chocolate laughter representations (Figure 1.3) [293, 292]. Sensorially chocolate can evoke pleasure, representing the pleasure of (most) laughter. Interpretively the chocolate shapes enable counts and comparisons of moments of laughter. Affectively the box of chocolates culturally suggests a special gift, commemorating moments of shared laughter. Performatively it suggests giving the gift and sharing the memories. On multiple levels, then, chocolate is a sensible choice for designing with the emotional biosensory data of laughter.

1.2.2.1 Recommendations

At a higher level, design researchers working with emotional biosensing should engage materials because doing so invites attunement to specificity and embodiment. Affect, feeling,

and emotion are embodied and situated in particular social and cultural contexts. This makes data physicalization a sensible choice because it can support embodied interpretation. Materials can make themselves present in a specific context, encouraging contextually situated interpretation. Physical artifacts are laden with social and cultural meanings that designers can leverage to craft particular avenues of open-ended interpretation. Materials can refer back to the context and process of their creation. In experiencing a crafted artifact one might wonder whose stories and whose bodies are wrapped up in its creation leading up to one's own embodied engagement. Yet, already this chapter is breaking its own categories and pointing to how materials have agency (Section 1.2.5) and become part of social performances (Section 1.2.3, 1.2.4).

1.2.3 From Representation to Performativity

Figure 1.4: Beyond representing biosensory data, biosensing technology, garments in these cases, can both sense and help enact performances of emotion. (From left) Farahi's Opale uses video-based emotional facial analysis to expressively alter the garment, in this case sensing and expressing strength or aggression [92]. Gadani's Porcupine Dress senses the emotionally pertinent movement of hunching over in fear or self-defense, extending quills in response [107]. Hartman et al.'s Monarch uses EMG sensors on the arm to create an expressive gesture of flexing and taking up more space [142, 283]. What might more everyday expressions of and performances with emotional biosensory data look like?

In tandem with materiality, CSCW has seen a broad shift from representation toward performativity. Instead of claiming that data capture reality and data displays represent or mirror reality, an alternative is to frame data and data displays as material responses to reality. These responses are shaped by data, humans, and materials and in turn they also shape reality [33]. For example, Leahu et al.'s Freaky performs fear instead of just representing it. It senses heartrate to predict fear in the person carrying it, then responds by 'freaking out' with noise and vibration that are clearly visible to others. Rather than attempting to represent the human's state, Freaky enacts an empathetic response, creating a shared human-machine performance of fear [206]. Flex-N-Feel senses and re-enacts emotionally pertinent data about hand flexing for long distance couples [319]. Performative engagements with biosensory data call attention to different aspects of data and context, such as

the performative, embodied, and socially emergent nature of emotion. Similarly, AI and Ubicomp have discussed moving away from attempts to completely represent reality toward ad-hoc, situated representations and actions [207, 333].

Sensing and display are not passive, neutral, or removed acts of observation; rather, they actively re-shape the world and experience. Verbeek describes this as technological mediation: "When a technological artifact is used, it facilitates people's involvement with reality, and in doing so it co-shapes how humans can be present in their world and their world for them... Technological artifacts are not neutral intermediaries, but actively co-shape people's being in the world: their perceptions and actions, experience and existence" [346, p. 6].

Somaesthetic design leverages sensing and feedback as technological mediators to attune bodies to sensing themselves and help people articulate nuances of their ongoing experience [163]. The somatic connoisseur is an important human mediator who facilitates sessions in paying attention and bringing insights out of that into daily life [301]. Wilde, Schiphorst, and Klooster describe applying somatic principles throughout the design process of participatory biosensing installations [301, 360, 361]. These practices are just a few of many ways of knowing the self and emotion through the body, through movement, and with expert guidance, all in contrast to the current moment favoring 'objective' data-driven insight.

For designers of more everyday experiences, performativity calls attention to ongoing practices rather than static states of context or emotion. Kuijer and Giaccardi describe how human and artificial agents combine in practice to shift what is seen as appropriate practice. Rather than designing 'smart' agents that try to replicate human capabilities and replace human decisions, they call for nonhuman agents that complement the unique capabilities of humans in collaborative co-performance [195].

1.2.3.1 Recommendations

Applying co-performance to emotional biosensing, designers should embrace and leverage capabilities of many humans to interpret their own and others' feelings and emotion in context. Instead of training algorithms to categorize emotion, emotional biosensing can provide resources for reflection, prompts for social sharing, or guides that leave space open for human adaptation, as many cited examples already do. More broadly, synthesizing these rich strands of research, this chapter argues that designs with emotional biosensing should treat affect, feeling, and emotion as embodied, dynamic, and fluid rather than abstract, static, discrete categories. Emotional biosensing designs do not represent emotion, they respond to and influence ongoing performances of emotion.

1.2.3.2 In relation to other lenses

With performativity, materiality is no less important, as performances unfold through bodies, materials, time, and space. Post-anthropocentric moves in design research emphasize the agency of materials, collaborating with humans in creating forms, such as with 3D printing

[71, 69]. Performativity and materiality can attune us as design researchers to similar aspects of biosensory data and display, but with a slightly different focus. For example, revisiting the chocolate laughter representations [293, 292] (Section 1.2.2, Figure 1.3), materiality as a lens emphasizes the tangible qualities of the chocolates. One can compare the heights of different pieces of chocolate or associate the pleasurable taste of chocolate with the pleasurable memory of the laughter. Performativity as a lens emphasizes the practices surrounding the chocolate, such as gift-giving. Of course there is overlap here. Both materials and performances can evoke meaning-making associations or invite particular kinds of engagement or practices. Material or artificial agencies can shape the development of appropriate ways of feeling and expressing emotion, individually and as part of social performance (Section 1.2.3). Designers working with emotional biosensing should leverage sensing and display to enact active, adaptable choices that reshape emotional experience.

1.2.4 From Machines Knowing to Humans Interpreting, Individually and Socially

Figure 1.5: Boehner et al. describe how affect-as-information treats emotion like any other kind of computational state or variable. Sensors and algorithms are used to 'detect' discrete categorical emotions like "happy" or "stressed," locating emotion in the individual. Context can be flattened here, where "happy" in one context is modeled the same way as happy in any other context. As an alternative, they propose affect-as-interaction, which treats emotions as emergent from interactions between people and contextually situated in interaction. Rather than teaching machines to detect and categorize feelings, the goal shifts to supporting emotional reflection and interpretation by humans [36]. Diagram is our own.

Reflective design calls for foregrounding the role of human interpretation in meaning making [310, 308]. Rather than emotional biosensing devices that try to tell people how they are feeling in terms of discrete emotional categories extracted from context, emotional biosensing devices can invite people to reflect on their own feelings. Rather than seeking to build computational systems that provide unambiguous machine-driven interpretations of emotional states, ambiguity is leveraged as a resource that encourages people to take a more active role in interpretation [116]. Self-tracking technologies can in some sense delegate

responsibility for self-knowledge away from the self to devices, as machines claim to 'know' more and more aspects of our daily lives [306]. Alternatively, there is an opportunity for emotional biosensing to encourage humans to take a more active role in emotional meaning making and self-knowledge.

In a performative move, Boehner et al. critique Affective Computing's representationalist approach to emotion [35]. They argue that much Affective Computing research treats affect-as-information, something that can be measured by sensors and algorithmically interpreted into discrete categorical representations of emotion. Sensors and algorithms are used to detect and categorize emotions into discrete symbolic categories like "happy," "angry," "sad," etc. They measure emotion on the level of the individual. "Happy" in one context is modeled as equivalent to "happy" in any other context. This approach treats emotions as pre-existing in individuals and able to be algorithmically detected independent of context [36]. For example, present day self-trackers Feel [94] and Spire [328] arguably treat affect-as-information: Both encode the user's internal state into discrete individual categories regardless of sociocultural context, displaying states such as "happiness" (Feel) or "calm" (Spire). Boehner et al. critique such approaches for reinforcing older models of cognition and ignoring the socioculturally constructed and performative nature of emotion [36].

They propose an alternative lens which treats affect-as-interaction, emphasizing how emotion is situated in and arises from sociocultural context. This lens shifts the goal of affective systems away from algorithmic interpretation toward supporting human interpretation of (their own and others') emotion in context. With affect-as-interaction, sensors, algorithms, and displays provide open-ended resources for emotional reflection and enactment. Emotion is not directly represented 'in' the machine but emerges through interaction [36].

Affect-as-interaction has already seen uptake in design. Affector used abstract distortions of video feed to prompt open ended emotional interpretation [309]. Sanches et al. intentionally avoided 'detecting' stress, instead using abstract visuals to prompt interpretation [296]. Slovák et al. studied couples' interpretations of a laptop heartrate display, finding the display was seen to provide a sense of social connection [321]. Howell et al. studied how pairs of friends, having a conversation while wearing thermochromic t-shirt displays of their skin conductance, enrolled the display in social meaning-making and self-presentation [166]. At a speed dating event, participants introduced themselves using hand-drawn graphs of their data [87]. These projects mark a shift away from attempts by machines to 'know' emotions as discrete categories, toward re-introducing biosensory data into social contexts for human interpretation.

Höök et al. extend affect-as-interaction into affective loop experiences with considerations for embodiment, privacy, and autonomy. They emphasize the embodied nature of perception, mind, and emotion, and call for affective loops that not only present emotionally pertinent displays but also invite user reflection and active feedback into the system. For example, Affective Diary combined personal notes and sensor data into a resource for personal reflection with visualizations that suggest affective bodily expressions [329]. EMoto used expressive gestural input to add emotional yet abstract visual cues to text messages [90]. Relying on humans rather than machines to form emotional meaning gives users more autonomy and

more privacy in deciding how they feel, and how or what to share with others.

Affect-as-interaction also informs social science. Merrill and Cheshire studied social interpretations of heartrate in vignette [228] and trust game [229] experiments. Combining quantitative and qualitative results, the interactional lens supports both rigor and common sense in their analysis, as they discuss how people formed emotional interpretations around heartrate while drawing on social context. Liu et al.'s studies, of people interpreting another's brainwaves or of socially sharing heartrate, also consider how biosensory data displays can take on social meaning [212, 211]. For social science as well as design research, an interactional lens for emotional biosensing shifts attention to social context and human interpretation.

1.2.4.1 Recommendations

More humility is needed in the emotional knowledge claims made by machines with emotional biosensing, leaving more open to contextual interpretation, adaptation, and contestation by humans. This is easier said than done, as even a highly ambiguous and intentionally inaccurate display can be granted a concerning degree of authority by some [168]. Designing not just for personal and social reflection and interpretation but also for contestability [156] merits further exploration. Hirsch et al. propose contestability based on their work designing a machine learning system for the highly sensitive context of assessing psychotherapists, where therapists' careers and patients' wellbeing are at stake [156]. Emotional biosensing can produce sensitive data suggesting users are emotionally unwell or have a recognized condition (e.g., inferring depression from mobile phone movement data [50]). Given that such inferences may or may not be accurate, and given that different interventions might work better for different people, being able to contest such inferences becomes essential.

1.2.4.2 In relation to other lenses

Thus far this chapter has outlined how materials (including our bodies), performativity, and sociality are all tangled up with affect, feeling, and emotion. Materials invite different ways of engaging with emotional biosensory data and evoke different kinds of emotional meaning. Performativity calls our attention to emotion as embodied experience and ongoing (inter)personal activity, where even data displays become part of this performance. Considering sociality attunes us to emotion as socioculturally situated, performed, and interpreted, rather than treating emotion as discrete abstract categories. This chapter synthesized this rich history of prior design research and called forth generative new directions for further exploration for emotional biosensory designs in particular.

Our next and final three conceptual shifts draw from feminist new materialism, biopolitics, and cultural theory. The rich histories here come from a little further afield relative to design research. This chapter contributes to ongoing pathmaking efforts showing how these lenses are generative for design research, especially for emotional biosensing.

1.2.5 From Things to Phenomena, or, from Inter-Action to Intra-Action

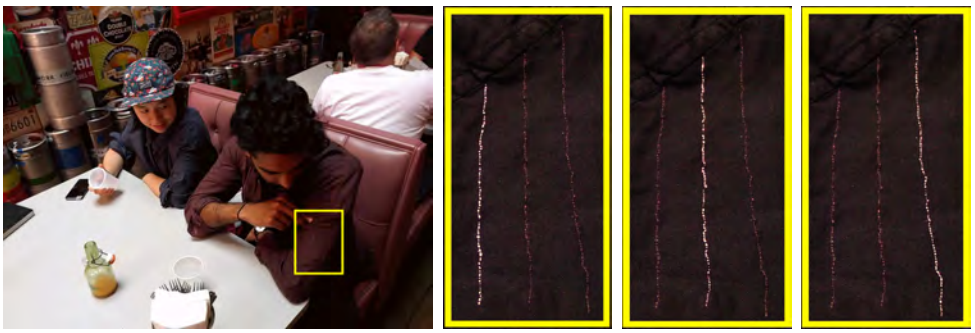

Figure 1.6: Where is the data in this entangled sensing and display phenomenon? Barad's agential realism [22] reframes the act of measurement, and the resultant data, as a series of material transformations. Environment and social context influence a pair of friends at lunch, influencing his emotions and body, influencing a skin conductance sensor, sending electrical signals to a microcontroller, discretized into a digital sensor value, run through a low pass filter to detect spikes, sending battery power to the threads, changing color one by one, seen and socially interpreted by the friends at lunch [168].

Taking materiality and performativity further, Barad argues for a shift from thinking about interaction to intra-action with her theory of agential realism. This section applies this to emotional biosensing, deconstructing typical notions of sensor, data, and display, and reconceptualizing these as ongoing series of material transformations. Agential realism centers phenomena (which are performed) rather than things (which are represented). Though her argument draws from Bohrian quantum physics to make fundamental onto-ethico-epistemological claims, here the focus is on how it reframes thinking about emotional biosensing.

1.2.5.1 What is agential realism?

While actor-network theory acknowledges the agency of things as well as people (e.g., [48, 189]), Barad's agential realism accounts for material agency while dismantling the presupposed divide between individual things or people. While interaction assumes separate things (including people) as a given and then looks at actions across this separation, intra-action acknowledges the fundamentally entangled nature of matter, including our bodies with the environment. This suggests attending to phenomena, not things or individual people, as the basic unit of analysis. Within phenomena, agential cuts enact local separations that define components. One can then reason about these components as the 'subject' or 'object' of a relation, or as 'cause' and 'effect.'

1.2.5.2 Reframing emotional biosensing

Agential realism can profoundly shift thinking about biosensing. Biosensory data is co-created by phenomena of intra-acting body, responsive circuitry, electrical signals, and digital signals. These components are locally separable via agential cuts, but they are also inextricably interconnected as phenomena. This lens contrasts the conceptualization suggested by commercially available biosensing devices such as Feel or Spire [94, 328]. There, biosensors are framed as extracting physiological signals as pre-existing entities from humans, and then further 'detecting' pre-existing categorical emotional states in humans. Agential realism deconstructs any canonical notion of data. It forces careful attention to intra-actions of measurement and transformation, ongoing responses and becomings of reality rather than attempts to representationally mirror lived experience.

Socially as well as materially, agential realism shifts attention away from the individual toward interconnectedness. While many emotional biosensing devices invite a single user to interpret their own data, people often socially reflect on their feelings with friends and family. Aside from social verbal reflection, psychology studies how people also physically and emotionally respond to others without conscious or rational intention (e.g., [267]). Our feelings, meaning-making processes, and identities are not so inherently separate from one another. Drawing agential cuts invites designers to reconsider what they choose to treat as separate.

1.2.5.3 A design exemplar

Howell et al.'s emotional biosensing garments Ripple [168] can be analyzed through the lens of agential realism (Figure 1.6). The design's "multifaceted ambiguity" [168, p. 5] makes it difficult to disentangle emotional biosensory data from other intra-acting factors. The clothing-based thermochromic display changes color in respond to digital biosensory data but also in response to heat from the body or sunlight. Furthermore their skin conductance sensor and algorithm are "intentionally crude" [168, p. 4] and also respond to sweating from physical exertion. Thus the design befuddles attempts to separate cause and effect, or data from display. These design decisions are explained as attempts to support contestability [156] (described further at the end of Section 1.2.4). Though it is perhaps remarkable that the system was interpretable at all, Howell et al. self-critically reflect that for some participants the display seemed to hold a concerning degree of authority [168] (issues of authority are also discussed in Section 1.2.7).

Agential realism helps analyze Ripple as a series of material transformations along agential cuts. Physical and sociocultural environment intra-act with the body. Affect, feeling, and emotion intra-act with physical responses on the skin. These electrodermal changes intra-act with a sensor, transforming them into analog electrical signals along a wire. These signals are digitized into numeric sensor readings. These feed into a spike detection algorithm. In response to a spike, the algorithm sends current from a battery to the thermochromic threads. The current transforms across resistance into heat. The heat slowly transforms

the light-reflecting properties of the thermochromic pigment. Light reflecting off the subtle color-changing threads reaches the eyes of the wearer and other socially collocated people. The display influences sociocultural interpretation and performance, influencing emotional response and feeding back again. This, or environmental heat or physical exertion could be part of other entangled phenomena. It is difficult to locate the 'data' in this system. Rather, Ripple treats emotional experience, sensing, data, and display as ongoing, entangled phenomena.

1.2.5.4 Recommendations

Beyond this example, agential realism wends new pathways for design research with emotional biosensing. For example, Tholander et al. draw from agential realism in analyzing how materials shape design thinking [338]. Using agential realism throughout the design process can help attend to how materials shape meaning-making and to prompt reflexivity about which materials, roles, people, or categories are treated as separate in the first place. What if designers working with emotional biosensing stopped treating data as an inherently abstract, insight-laden 'thing' and instead turned their focus to phenomena of continually transforming materials and meaning? To make this shift, one useful starting point could be to apply the previously discussed lenses of materiality, performativity, and social interpretation specifically to the materials, practices, and social meanings of measurement and sensing. This can also lead to reconfiguring what counts as measurement and sensing. For example, smudges on a door from people's hands can be seen as an accumulated material measure and display of passerby count or group activity level. Depending on context and subject position, this might be related to, for example, a stressful busy night in a restaurant kitchen or a joyful exciting celebration occurring at the restaurant.

For designers especially agential realism presents an ethical imperative of "being accountable to marks on bodies" [22, p. 824]. For example, Introna's critical analysis of surveillance cameras and plagiarism 'detection' software provides a lucid, tractable engagement with agential realism. The analysis uses agential realism to trace agential cuts like roles and categories constructed in part by the surveillance camera technology. It also traces ethical consequences like how the software constructs 'plagiarism' in a way that disproportionately marks non-native language speakers as plagiarists [179]. Design is in some sense a process of formgiving and markmaking, and it is worth being critical of our own and others' work by tracing the effects of these marks onto bodies.

1.2.5.5 In relation to other lenses

Overall, agential realism underscores the importance of materials, performativity, and social interpretation to emotional biosensing (Sections 1.2.2, 1.2.3, 1.2.4) while deepening critiques of Affective Computing. Affect-as-interaction [36] (Section 1.2.4) might seem to conflict with intra-action [22]. Yet, for the purposes of designerly reworking approaches to emotional biosensing, these conflicts can be taken as mostly differences of nomenclature. Both concepts

emphasize the inextricable interconnectedness of ourselves with the world, and shift the focus from attributes of an individual subject or object toward performances or phenomena as ongoing and emergent. Biosensory data and surrounding emotional interpretations are fundamentally not discoveries of internal state that can be extracted and displayed unchanged. Rather, every measurement or transformation along an agential cut changes the potential meanings of emotional biosensing and enacts different marks on bodies.

1.2.6 (Post-)Biopolitics: Reducing Authority and Leveraging Negative Affect as a Resource

Biopolitics considers what counts as legitimate knowledge and ways of knowing. Drawing from Rabinow and Rose, biopower considers "truth discourses" regarding human life, "authorities considered competent to speak that truth," and strategies for life and health relating to those discourses, whether individual, governmental, or cultural [284, p. 197]. Biopolitics refers to contestations around those discourses, authority, and what counts as legitimate knowledge [284]. Artifacts have politics and "can embody specific forms of power and authority" [364, p. 121]. Many emotional biosensing devices play up their authority, promising consumers actionable insights and positive behavior changes (e.g., [234, 233, 94, 266, 239, 328]). Hong calls for greater attention to "who-and what-is given which kinds of authority to speak the truth of the 'self"' with self-tracking technologies [160, p. 1].

Emotional surveillance via video facial analysis could spread via technologies like Affectiva [3] and Google Glass [341]. Using Google Glass as a case study, Noble outlines harms of the surveillance gaze across race, socioeconomics, and gender [255]. Buolamwini analyzes racial harms of the 'coded gaze' [46, 47, 336]. Foucault's analysis of internalized self-discipline in view of an all-seeing authority [101] has been applied to self-tracking (e.g., [216, 240, 248, 312, 314]). Yet, Schüll describes how self-tracking devices that suggest behavioral adjustments in some sense externalize self-discipline [306]; others look to Schüll as well [314]. For example, responsibility to care for the self by drinking enough water can be delegated to Mother sensing technology [305, 241]. Spire reminds one to pause for a breathing exercise to reduce stress [328]. Other devices remind people to exercise and sleep [99], eat slowly [135], or take their medicine [265, 282]. Schüll suggests that in some ways the constant feedback and modulation based on information flows might resemble Deleuze's control society [65, 306]. Through this lens, emotional biosensing products can be seen as modulating our emotions according to feedback systems and algorithms created by designers and technologists.

Lindtner and Avle discuss the economization of everyday life and of citizenship and critique CSCW's complicity with Silicon Valley's visions of individual self-improvement and productivity [210]. Till drawing from Lupton describes how self-tracking technologies extract economic value from non-work behavior like physical exercise in the form of data [340]. Emotional biosensory data is already being monetized (e.g., [3]). Rose describes how somatic ethics are shifting and influenced by capitalism. For example, concern for one's physical health might have previously seemed narcissistic but is now seen as an expected way to feel

better, be morally better, and be a better worker [289]. Speculating, as emotional norms become embroiled in data and market logics, will negative affect be seen as a moral failure?

1.2.6.1 Recommendations

Returning to co-performance (Section **??**), Kuijer and Giaccardi raise essential ethical and political considerations for design in how artificial agents can shift norms of appropriate practice. They outline how these norms can be hard to contest because (i) the newly appropriate practice may depend on the nonhuman agent, (ii) artificial agents often claim the authority of scientific evidence, or (iii) designs can inflexibly embed decisions. When artificial agents are designed to too closely mimic human agents, designers often wield too much power in shaping norms of practice via embedded design decisions. To avoid these issues, co-performance leaves more flexibility in shaping practices open to humans [195].

Applying co-performance [195] to emotional biosensing, designers should critically reflect on the emotional practices and norms suggested by designs. Machines need not model or 'know' emotion in the same way that humans do. Instead, avoiding authoritative knowledge claims about emotion can help designs make space for humans to adapt emotional experience and practices for themselves. Designing for co-performance [195] and contestability [156] with emotional biosensing might also open space for alternative politics and voices about the meanings and roles of biosensory data in daily life. For example, biosensing responsive garment Ripple was designed to "seem unauthoritative to invite critical questioning" [168, p. 4]. With the touted authority of biosensory data, and known critiques of Western cultural narratives of the authority of data more broadly (e.g., [40, 63, 56, 123, 129, 158, 174, 247]), perhaps biosensory data displays with intentionally reduced authority are worth exploring. Instead of valorizing accuracy, objectivity, and data as authoritative ways of knowing with emotional biosensing, how can designs make space for alternatives?

A design exemplar in affirming negative affect, Imhotep et al. created the Bank of Hysteria for black women to call in and share their frustration and hysteria to "invest in [their] rage" as a collective bank of support and force for change [150, 175]. Negative affect is a valid response to societal issues. Designing a quick breathing exercise (e.g., Fig. 2) might legitimately reduce tension in the short term, but it is essential to not locate approaches to social issues only in the individual. An overly individual focus can marginalize someone's experience by implying they are the only one experiencing this problem, or suggest they are solely responsible for dealing with the negative effects, and it can downplay the need for structural change. Instead, emotional biosensing designs can leverage negative affect as a resource for building community, support, and collective action.

1.2.6.2 In relation to other lenses

Biopolitics in emotional biosensing design research engages performativity and social interpretation (Sections 1.2.3, 1.2.4). Performativity and biopolitics combined help question and critique what practices emotional biosensing designs foreground, and who gets favored or

excluded by those practices. Social interpretation and biopolitics help question and critique who gets to make social interpretations that are considered valid.

1.2.7 From Affect to Desire, and from Individual to Pre-Individual

Considering affect and desire through different lenses helps chart what goals emotional biosensory data is enrolled to serve and how that might be reimagined. These conceptual shifts invite questions like, instead of locating emotion in individuals, how might sensors tune in to broader emotional flows through society? Some work has looked at collective audience response (e.g., [276, 353]), but what are other possibilities? Instead of considering emotion as arising in a particular moment, what about tracing flows of desire motivating emotional trajectories?

1.2.7.1 From affect to desire

At an individual level, affect can be seen as a response or orientation with regard to the social or material world (e.g., I feel angry at a rude comment, or I feel happy about the weather). Desire can also be seen as orienting oneself to the world, pointing toward a desired object, person, activity, or cultural signifier. Desires can carry different emotional valences like romantic attraction, professional ambition, or a desire to help a friend. Considering affect can call our attention to moments of action/reaction. Without claiming any firm causal relationship between affect and desire, considering desire can call our attention to underlying drives motivating affect and orienting actions/reactions.

For emotional biosensing design, this could shift the focus from prompting reflection on the question, "How am I feeling?" to "What do I desire?" These questions are closely related but desires point to motivation (e.g., I feel angry at a rude comment because I desire respect). Rather than emotional biosensing designs imposing normative desires of self-improvement, users' desires could point in more personally relevant directions. For example, desiring respect might be more related to social and structural issues than an individual need to improve, and anger could be productively shared as a resource (Section 1.2.6).

1.2.7.2 From individual to pre-individual affect

While Affective Computing locates affect in individual bodies [49], and affect-as-interaction locates affect as emergent from culture and social interaction [36], treating affect as pre-individual helps consider structural forces shaping emotion and the self. For example, in Affective Economies Ahmed describes circulating affect around charged issues like terrorism and immigration and how people position themselves with regard to these issues [7]. Stewart's poetic Ordinary Affects describes moments of surging affect arising from events or places; the individual subject is constructed by engaging with these pre-individual affects [332]. Massumi draws from Spinoza to describe affect as a kind of pre-personal intensity, something

at the interface between our bodies and the world, in that moment of affecting and being affected. Once one starts interpreting it to understand how one feels, or decide what socially recognizable emotions those feelings might be, something gets lost—affect is that noisy buzzing intensity before interpretation [223].

For emotional biosensing design, attending to pre-individual affect can help consider broader societal issues and forces shaping emotion. For example, Kozel's AffeXity [194] explores affect as flowing through the city and personally embodied through dance. Drawing from Spinoza, Massumi, and Ahmed's approaches to affect, AffeXity explores how, "Urban dwellers are ever increasingly affectively manipulated by political and economic forces without the scope to not be affected" [194, pp. 77–78].

1.2.7.3 From individual to pre-individual desire

Deleuze and Guattari see desire not in the Lacanian sense of an individual's affinity toward an object of desire, but as pre-individual driving forces that move across and through individuals [66, 209]. "Desire is instrumental for Deleuze and Guattari because they locate within it the possibility for political, social, and economic transformation" [209, p. 365]. Yet, it is also important to consider Haraway's earthy attunement to the desires of individual critters [137], and acknowledge potentially unresolved tensions between these approaches. Again, designers should sensitively treat individuals' feelings and desires while also acknowledging structural forces.

Desire as pre-individual helps consider structural forces shaping desire. For example, the Situationists critiqued how capitalism directs our desires toward commodity goods, and sought instead to "produce a different kind of social practice for expressing the encounter of desire and necessity, outside of power as representation and desire as the commodity form" [354, p. 47]. Through détournement they sought to reroute existing capitalist cultural media toward new purposes. More recently, Neff and Nafus among others describe the "commodification of daily living" through data [250, p. 7]. Self-tracking products suggest one should desire individual self-improvement via data-driven insight and behavioral adjustment.

Designers working with emotional biosensing should critically reflect on the desires promoted by our projects. For example, emotional biosensing designs might tackle stress at work. A conventional approach could be to detect stress at the level of the individual and help reduce that stress through individual behavioral changes like taking breaks or meditation. This could address desires for reduced stress, improved workplace performance, and company profit. An alternative approach could be to leverage the negative affect of stress as a resource (Section 1.2.6), collecting data on workplace stress for collective action like negotiating for better workplace conditions or more reasonable deadlines. This could address desires for reduced stress while challenging notions that workers should constantly strive to improve their performance and that company profit should be optimized.

More broadly, how can design reroute normative societal desires of emotional biosensing toward alternative ends? One example is Queer AI [208, 221, 222], a manifesto and critical computing art project whose "first chatbot will be trained on erotic literature, feminist and

queer theory, and an ethics of embodiment" for "the advancement of new eroticisms" [222]. Different training sets of emotional biosensory data could help shift design.

1.2.7.4 Recommendations

Even as our projects try to serve the existing desires of users, they also construct desiring users [139]. Designers working with emotional biosensing should critically reflect on the desires our designs legitimize, and on the societal structures that make those desires seem appropriate. Designs can be more adaptable so humans can shape norms. Furthermore designers can start from different sets of norms and legitimize different desires. For engaging different desires, starting from a basic belief in the validity of others' experiences, even and especially when they do not align with established norms or our own expectations, can help with this. Humility in emotional knowledge claims and adaptability in design (Section 1.2.4) can help designs respectfully engage difference. Giving and receiving care and affirmation seem like promising desires to legitimize. These suggestions may seem obvious, but they contrast products pushing self-improvement, which can engage insecurity or suggest that one is not 'good enough.' Care, affirmation, respect, and recognition for human experience are promising generative design directions, especially for what is not well understood by normative categories or seen as optimal by normative desires. More broadly, emotional biosensing designs should explore a wide range of alternative desires. By synthesizing and outlining different lenses, and advocating for already-begun but not-yet-mainstream directions, HCI conductance continue exploring emotional biosensing, broadening the design space to include richer alternatives.

1.3 Conclusions

Emotional biosensing technologies promote a particular normative vision of 'the good life' limited by a focus on individual wellness, self-improvement, and workplace productivity. While there is positive potential here, these limitations point to opportunities for broadening the design space with emotional biosensing. This chapter sketched how a broad shift from abstract representationalism to sociomaterial performativity opens critical alternatives for emotional biosensing: (Section 1.2.2) Rather than treating data as something immaterial to be represented, attending to the materiality of data sensing and display opens new possibilities for interpretation and experience. (1.2.3) Building on interpretation and experience, treating sensing/display not as passive representations but as active performances or responses offers opportunities for social meaning making and experiential, expressive displays. Emotional biosensing designs should treat affect, feeling, and emotion as embodied, dynamic, and fluid rather than abstract, static, discrete categories. (1.2.4) Continuing this performative shift, reframing affect from a kind of abstract information to affect as socially enacted in interaction adds sociocultural nuance to emotional biosensing. This chapter calls

for humility in the emotional knowledge claims made by design, leaving more open to human interpretation, adaptation, and contestation.

(1.2.5) Shifting further to posthumanist performativity, agential realism can help emotional biosensing designs attend to how materials shape meaning-making and prompt reflexivity about which materials, people, or categories are assumed to be separate. Attending to biopolitics (1.2.6) calls for embracing a diversity of voices and ways of knowing with emotional biosensing. Designs with intentionally reduced authority are worth exploring, and emotional biosensing designs can leverage negative affect as a resource for building community, support, and collective action. (1.2.7) Finally, reframing affect and desire as pre-individual, emotional biosensing designers should critically reflect on the desires their designs legitimize, and on the societal structures that make those desires seem appropriate. Emotional biosensory designs should prioritize care, affirmation, respect, and recognition over self-improvement. Designs can encourage people to trust themselves to be 'emotionally good/safe enough' with room to explore and change rather than only seek self-improvement according to predefined norms. More broadly, designs should explore a wide range of alternative desires with emotional biosensing. Finally, with the help of these conceptual shifts and our recommendations, this dissertation will continue exploring:

How can desiring with and through data be reconfigured away from commodity lifestyle and self-optimization toward alternative ways of feeling and living?

Chapter 2

Open-Ended Social Emotional Reflection with Color-Changing Garments

These projects explore the question raised in the previous chapter, *How can emotional biosensing be reconfigured away from commodity lifestyle and self-optimization toward alternative ways of feeling and living?*. These projects engage this question using research through design: designing, building, and studying people's experiences with artifacts. As appropriate for this method, the kind of knowledge generated by these projects is "provisional, contingent, and aspirational" [115, p. 937]. Designers taking this approach are "wary of impulses towards convergence and standardisation, and instead take pride in [research through design's] aptitude for exploring and speculating, particularising and diversifying, and–especially–its ability to manifest the results in the form of new, conceptually rich artefacts" [115, p. 937].

Exploring these lenses by creating concrete artifacts, these projects create ordinary-looking garments with small fabric-based color-changing displays that respond to sudden increases in skin conductance. Skin conductance is associated with various kinds of excitement, such as feeling stressed or happily excited. Measurements of skin conductance are difficult to distinguish from sweating due to physical exertion. The display responds to skin conductance, but by its material nature it also responds to ambient heat. Thus, the display is a highly ambiguous maybe-indicator of skin conductance, which maybe indicates an emotional shift.

Engaging Section 1.2.2 on material representations, these designs leverage the material qualities of thermochromic color-changing fabrics in everyday garments to invite subtle, socially-oriented, open-ended engagements with data. As participants wear and interpret these garments in social contexts, these data display garments are enrolled in aspects of social performance, engaging Section 1.2.3 on performativity. Rather than presenting discrete categories of emotional states to wearers, these projects treats emotion as emergent from interactions between people and socially situated in interaction, drawing from Section 1.2.4 on *affect-as-interaction*. Emphasizing the entangled material transformations from sensing, to computation, to heat-activated color-changing display, these designs engage Section 1.2.5

on *agential realism*. The designs leverage multifaceted ambiguity in an attempt to reduce the perceived authority of the display and invite people to make their own interpretations of their feelings, engaging calls in Section 1.2.6 on biopolitics. Yet, this attempt had mixed results, and sometimes the data display seemed to wield more authority than I as designer intended, as discussed in more detail later.

2.1 Hint: Reframing Biosignals as Social Cues

This study explored the social meaning of clothing-based displays of biosignals. How do friends make sense of their own and each other's skin conductance display in the context of a conversation? Along with collaborators, I developed Hint, a dynamic thermochromic t-shirt with ambiguous patterns that change color when its wearer's skin conductance increases, an indication of sudden arousal. We investigated how pairs of friends, each wearing the shirt, conversed and interpreted the display. Participants shared a broad range of interpretations, and emotions such as joy and embarrassment were associated with an increase in skin conductance. Additionally, participants expressed desires for their skin conductance displays to help validate their feelings and show emotional engagement with others. We explore ambiguity in the context of clothing-based information displays and discuss how skin conductance display became part of social performance in our study. From there, we suggest framing biosignals as social cues along with facial expression, gestures, etc., and begin to question what design territories this might uncover. This chapter draws from my lead-author paper [166]. "We" in Section 4.1 refers to myself as lead researcher in collaboration with co-authors on [166].

2.1.1 Introduction

Biosensing is on the rise in daily life. The Feel wristband monitors skin conductance, pulse, and temperature to track mood and give wellness advice [94]. Jawbone UP3 and Microsoft Band also monitor skin conductance for fitness and wellbeing [184, 233]. Much research uses biosignals to "detect" emotions, thereby providing unambiguous interpretations of emotional state [153, 242, 298]. Recent work has challenged this approach of detecting and algorithmically categorizing emotions and proposed an alternative approach, affect-as-interaction [36], which treats emotion as contextually situated and arising from interpersonal interaction [36, 205, 206]. This project explores affect-as-interaction in the context of clothing, investigating how clothing-based displays of biosignals function in personal relationships.

Our goal in this project is to explore how ambiguous biosensing displays could provoke multiple interpretations. We chose to work with skin conductance because it is inherently ambiguous and open to multiple interpretations. By creating clothing that unobtrusively responds to skin conductance, we explored human interpretations of affect in the context of social interaction. Specifically, we investigated 1) What kinds of interpretations do people

form about their skin conductance display in the context of a conversation with a friend? and 2) What roles do people desire, expect, or try to make skin conductance perform within their social interactions?

This work contributes a design exploration that leverages ambiguity to support multiple interpretations [116, 308] and engages the lens of affect-as-interaction. Additionally, based on our analysis of participants' interactions around the system, we suggest framing biosignals as social cues, and begin to question the design implications of this.

2.1.2 Background

2.1.2.1 Interpretive Approaches to Biosignals

Some biosignals research aims to "detect" emotion, but this approach has recently been critiqued [35, 36, 114, 205, 206]. As Boehner et al. [36] discuss, affective systems often model affect-as-information, assuming that discrete emotional states exist on an individual level and may be transmitted unchanged between computing systems or other humans. They propose an alternative model of affect-as-interaction, whereby emotions are worked out through interactions with others. This model situates affect in the context of interaction rather than symbolic representation.

Design research efforts have been made to situate biosignal displays in the context of human interaction. For example, Leahu et al. explore a performative account of emotion with a larvae-like creature, called Freaky, which "freaks out" when it detects fear in its wearer, thereby creating a shared human-machine performance of fear [206]. As another example, Boehner et al. contrast sending a particular categorized emotion along with an instant message with sending more contextual information, such as photos of the message composer; the latter affords working out emotions throughout the course of the interaction [36]. Our work engages affect-as-interaction in its design and analysis and contributes further exploration into designing affective systems through this lens.

2.1.2.2 Biosignals, Fashion, and Social Life

Researchers in and out of HCI have explored garments which display social or physiological information of the wearer [19, 53, 190, 205, 1, 321, 365]. While some of these examples are provocations or suggestions of future fashion landscapes, others measure skin conductance synchronicity in a social context [323], explore a composite display of a pair's skin conductance [324], or mention compelling anecdotes of social interactions while sharing skin conductance [276]. Recent work has also envisioned many ways that ambiguous dynamic clothing-based displays might prompt reflective and playful experiences in daily life [70]. We extend this work by focusing specifically on the clothing-based display of skin conductance information within close personal relationships to probe more deeply into the roles of ambiguity in clothing-based information displays and of skin conductance in social interaction.

2.1.3 Designing Hint

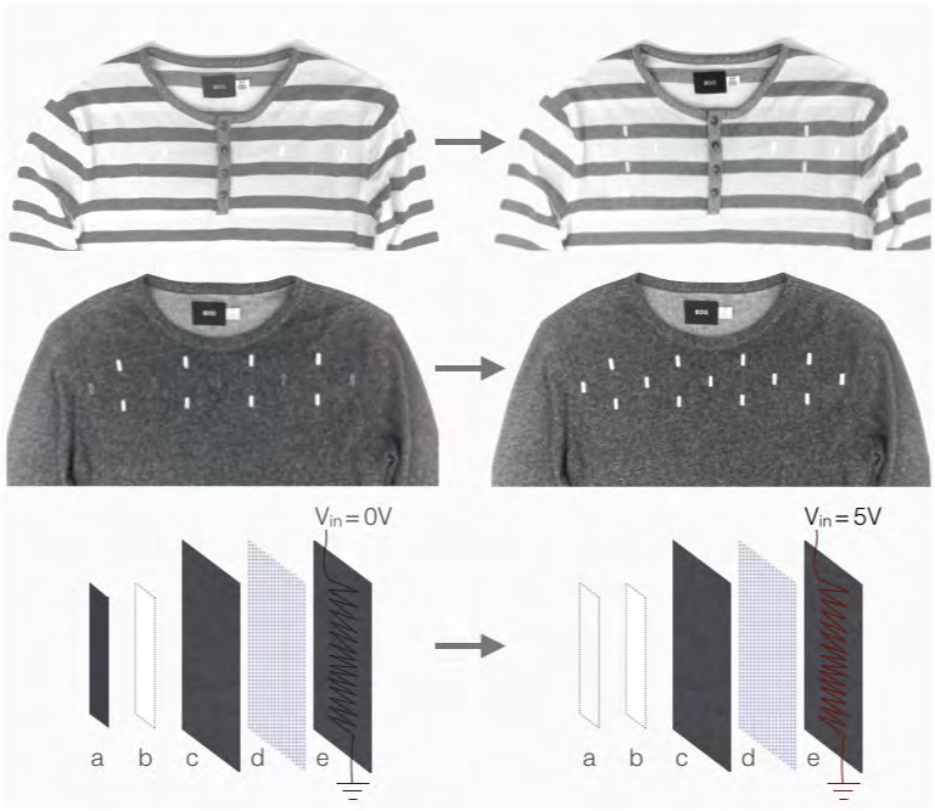

Figure 2.1: Shirts display small white shapes in response to sudden increases in skin conductance. Layers for one shape: a) thermochromic gray screenprint, b) white screenprint, c) original t-shirt, d) adhesive, e) conductive thread sewn into fabric. Passive: Some white shapes (layer b) are hidden beneath gray (layer a). Active: Supplying power to the conductive creates heat, turning (a) transparent, thus revealing (b).

Hint is a dynamic t-shirt. When the wearer's skin conductance increases, an indication of sudden arousal, small white patterns slowly appear (Figure 2.1). We designed Hint to look like an everyday t-shirt because we wanted participants to imagine this technology as something they might encounter in everyday life. So, we augmented t-shirts in neutral colors, used thermochromic pigments for their subtle changes, used screenprinting to apply the thermochromic pigments (as it is a common technique for t-shirts), and created two styles to allow pairs of friends to not match each other during our study. Locating the display on the shirt's front made it easily visible to others, to help probe social interpretation. Finally, the ambiguity of what the display change means helps our design engage affect-as-interaction:

Rather than attempting to detect emotions in the wearer, our t-shirt design merely suggests potential moments of emotional change as indicated by an increase in skin conductance, inviting participants to work out their feelings together throughout their conversation.

Several layers comprise the dynamic garment. By aligning two layers of screenprint, the top thermochromic gray layer (made of TurnThermo thermochromic pigment, Golden silkscreen medium, and Utretch acrylic gel medium in a ratio of 2:3:3 respectively) can fade to transparent to reveal the white non-thermochromic screenprint design beneath. This has the visual effect of a white pattern slowly emerging on the gray t-shirt. Conductive thread (electrically insulated, from [281]) is sewn into a separate fabric layer inside the shirt and adhered with two-sided fusible interfacing. Supplying power (5V, LiPo battery, Adafruit Powerboost Charger/Booster) to the conductive thread heats the fabric to about 86 degrees Fahrenheit, activating the color change. The display takes 2-3 minutes with power to clearly change from gray to white. It may stay white for up to 5 minutes, depending on ambient temperature, before returning to gray. Participants wore a Bitalino [317] skin conductance sensor on the back of their shoulder, which is less obtrusive than the more common locations of the wrist or fingers, and shown to be similarly responsive by [78]. Using a low pass filter roughly similar to [298], an Arduino script detects sudden increases in skin conductance and powers the threads accordingly.

2.1.4 Study

To study how people make sense of their own and another's skin conductance display in a social context, we recruited pairs of friends to wear Hint and have a conversation. For this early stage study, we cast a wide net for potential areas of further investigation. To probe emotional interpretations of the display, we wanted to foster emotional variation in participants' interactions, so we adapted conversation prompts from a psychology study related to increasing interpersonal closeness [17]. These included questions such as, "When did you last sing to yourself? To someone else?" To probe the social meaning of the public displays, we conducted the study in a semi-public workspace familiar to participants, which was occupied by other community members. Lastly, to explore differences in novice versus expert interpretations, we recruited both participants unfamiliar with skin conductance and those whose research involves skin conductance or other biosignals. To address all these aspects is beyond the scope of this short paper; here we focus on emotional interpretations.

In the study, the researcher first demonstrated the color change of a t-shirt and briefly explained that skin conductance is associated with excitement of various kinds, such as feeling stressed or happily excited. Each participant chose a shirt and put it on along with the sensor. They were provided with tea, cookies, and conversation prompts, and instructed to fill out a short questionnaire each time they observed a display change. The researcher then stepped aside and the participants were asked to have a conversation on their own using the prompts for 30-45 minutes. Afterward, the participants were interviewed as a pair about their experiences and interpretations with the system.

Five pairs of friends participated for a total of ten people (ages 23-34, 4 women, 6 men). All were platonic friends except for one couple who brought their baby. Two pairs (4 people) did biosignals research, while the rest were unfamiliar with skin conductance. Participants' interactions with each other and the system were video recorded. We analyzed their interactions using a grounded theory approach [52] and organized our observations into emergent themes. We refer to participants by pseudonyms.

2.1.5 Findings

Figure 2.2: Pairs of friends conversing and observing Hint.

2.1.5.1 Socially Situated Interpretation and Reflection

Participants associated their shirts' display change with a wide range of emotions situated in the context of their conversation, such as embarrassment, fear, joy, or passion when arguing a point. For example, Lily railed against the concept of a mind/body duality with her friend Alfonso. When he noted that her t-shirt had changed colors, Lily suggested that it was due to the intellectual passion of her argument. Later, she and Alfonso were laughing about memes, and Alfonso attributed the change in both their t-shirts at that point to the "pure joy" they were experiencing together. Participants' interpretations, which went beyond those mentioned by researchers when introducing the system, suggest a broader research agenda around skin conductance. Prior work focuses on detecting stress [153, 298], but as biosensing

moves into the varied contexts of daily life it is important to study other possible meanings of skin conductance such as joy or passion.

Sometimes, the ambiguous meaning of a display change was valued as a prompt for open-ended reflection. For example, when Lily pointed out that Alfonso's shirt had changed while he was talking about his internship last summer, Alfonso said it made him reconsider his feelings about his experience there. Ryan described the system as "a canvas onto which I could paint my own imagination about what was happening," and said he enjoyed reflecting on his feelings throughout the conversation. Designing an outward facing display, engaging affect-as-interaction, and leveraging ambiguity helped us go beyond detecting specific emotions toward supporting participants' reflection and multiple interpretations.

Participants often pointed out when their friend's shirt had changed, in part because many reported that it felt more natural to monitor their friend's shirt than to glance down at their own. The display was located on the upper chest near the collarbones. In the context of this study, this placement seems to have encouraged participants to talk about their displays. In the future designing for daily life, the location's potential to detract from eye contact should be considered.

2.1.5.2 Showing Emotional Engagement with Others

Mary, Hubert, and Eva seemed to want the display to help them show emotional engagement with others. Mary discussed her desire to be an active listener with her friend Sameeha, and expressed concern that her display showed her anxiety instead of engagement with her friend's stories. Mary's display remained white (indicating consistently high arousal) throughout their conversation. In explaining this to the researcher, Mary said, "I wasn't in a state to have a lot of emotional variation," due to her anxiety about the end of the academic term. Mary said, "I'm worried Sameeha will think I don't care about her stories, which I do, but, because I have this baseline anxiety... It's not that I don't have a change in emotion to some extent, it's just that there's something else that's also there." Mary was concerned that her limited emotional engagement, due to her anxiety, might be perceived as a lack of care.

For Hubert and Eva, who brought their baby, the system brought up what seems to be an ongoing discussion in their relationship about Hubert's perceived lack of empathy. Both do biosignals research. Hubert attributed his shirt's change to holding his crying baby. Later, Hubert was holding his baby again, and the baby was crying again, but Hubert's shirt was not changing color. Eva joked that, "Yours are not changing at all. I married an insensitive guy... You don't even feel empathy for the little guy who's crying." Later when the interviewer asked what they had been saying about "empathy," Hubert and Eva's reflections became more serious and seemed to reference prior discussions. Hubert said, "I'm supposed to have no empathy... I'm sure a lot of people perceive me as kind of a jerk... maybe I could just improve a bit there... I feel a lot of empathy for [baby and wife]." Eva agreed, "This is why [your shirt] turned white when he was crying [the first time]." What was originally a joking association between the t-shirt, empathy, and the baby crying was

later seriously offered as an interpretation by Eva in order to support Hubert. In both cases, participants wanted to show emotional engagement with someone they were close to and were concerned when the display showed what they interpreted as something other than engagement.

2.1.5.3 Validation

Ryan and Mary expressed desires for the system to validate their feelings. Ryan, who does biosensing research, shared a story about singing to his ex-girlfriend and his ex-girlfriend laughing at him in response. He said he felt embarrassed while telling the story, and experienced tightness in his chest. He said, "I wasn't sure my shirt changed then, but I wanted to believe it was changing because I felt something strongly... I just wanted some confirmation that what I was feeling was real." Whether a display change occurred was ambiguous to Ryan, but he wanted to use his belief to dispel that ambiguity in order to feel validated. Mary speculated that, "As a person with anxiety, sometimes I want people to know, 'No, I'm really struggling at the moment,' and I think there's something about [Hint] that feels like a validation of that, in addition to just my self report of it." In both cases, participants described wanting feelings of validation based on observing a display change.

2.1.6 Discussion

2.1.6.1 Two Kinds of Ambiguity

Two kinds of ambiguity were present in Hint, *ambiguity of observation* and *ambiguity of meaning*, and these are related to Gaver et al.'s ambiguity of information [116]. First, many participants reported feeling unsure about whether they had observed a display change, in part due to the t-shirt's subtle fade from gray to white. We call this ambiguity of observation, and propose that the slow temporal shift from one state to another can be one way to "use imprecise representations to emphasize uncertainty" [116]. Second, even if a display change were clearly observed, its meaning was still ambiguous, due to the many kinds of excitement associated with skin conductance. We call this ambiguity of meaning. Although ambiguity of information can stem from the artifact and the way it represents information, ambiguity in Hint stems from the inherent ambiguity of skin conductance data and its variable interpretations.

Prior work showed how people imagined ambiguity to be an asset for clothing-based displays in everyday life [70]. In the context of Hint, ambiguity received mixed responses. Ambiguity of meaning was seen as helpful in supporting a broad range of emotional interpretations and prompting open-ended reflection. On the other hand, some participants wished to reduce ambiguity of observation in order to feel validated by the system. Future designs of social biosignals displays should carefully consider and leverage different kinds of ambiguity.

2.1.6.2 Biosignals as Social Cues

Skin conductance display on Hint functioned like other social cues as part of social performance. Drawing from Goffman, all activity, including words, appearance, facial expressions, etc., of a person may be seen as a kind of "performance" which is used to influence the "audience" of those around them. These performances often fulfill accepted social roles. Goffman provides an example of two friends at lunch showing mutual interest and respect [126]. When wearing garments with ambiguous displays, the wearer and the garment are seen and interpreted together by their audiences [70]. Many participants seemed to want their skin conductance display to help them perform a social role, such as showing emotional engagement with others. In a sense, this biosignal display became part of their social performance along with social cues such as facial expression, tone of voice, etc. Whereas affect-as-information models skin conductance, facial expression, etc., as "social signals" with clear meanings that transcend context, for affect-as-interaction, we suggest framing these displays as "social cues," whose meaning is situated within the context of interpersonal interaction. A key difference between Hint and other social cues is that participants could not control their skin conductance or its display, at least in this study. This lack of control both detracted from their social performance and helped position skin conductance as something that could validate their feelings because it came from outside their conscious self-report.

Framing displays of biosignals as a social cue suggests many design directions. Perhaps designs could support validation and personal reflection by providing users with private biosignals displays, or support intended social performances with user-controlled public biosignal displays. Biosignals are already mediated by human-made sensors and algorithms, so users would be one of many human mediators. Consider the following reflection on an existing biosensing technology: Technologies such as Apple Watch allow users to share their heartbeat [15] as a meaningful signal. Thinking of heartbeat as a social cue, rather than a signal, lets us consider social contexts in which users might want to share a modified heartbeat, or lead to designs that question social performances to create tension, playfulness, or social critique.

2.1.7 Conclusion

We engaged affect-as-interaction [36] to design dynamic biosensing clothing for everyday contexts. Pairs of friends, wearing abstract t-shirt displays of their skin conductance, associated it with a wide variety of emotions, such as joy or embarrassment. The display's ambiguity was valued as a prompt for reflection but also hindered participants' attempts to feel validated. Participants sought to use their skin conductance display to help them enact social performances, such as showing emotional engagement with others. We suggest framing biosignals displays as social cues and briefly question design possibilities in which users can mediate their own biosignals displays.

2.2 Ripple: Exploring Tensions of Data-Rhetoric's Authoriy

Biosensing technologies are increasingly enrolled in personal emotional reflection. To critique a common approach of algorithmically interpreting biosensory data into discrete affective categories, and explore alternatives, we designed, implemented, and deployed a technology probe: Ripple is a shirt with patterns that change color responding to the wearer's skin conductance. 17 participants wore Ripple for 8-20 hours over 2 days of daily life. Participants' experiences and interpretations around Ripple highlight tensions of biosensing for personal reflection. While some participants appreciated the 'physical connection' Ripple provided between body and emotion, for others Ripple fostered insecurities about 'how much' feeling they had. Although as designers we attempted to foster critical questioning of biosensory data by making Ripple's display highly ambiguous, participants rarely questioned the display's relation to their feelings. Using biopolitics to speculate on Ripple's seeming authority, we highlight ethical stakes of biosensory representations for sense of self and ways of feeling. This section draws from my lead-author paper [168]. "We" in Section 4.1 refers to myself as lead researcher in collaboration with co-authors in [168].

Figure 2.3: Friends wore Ripple, a shirt with three pinstripes that change color in response to skin conductance, throughout daily life. (a) Interpreting the display over lunch. (b) Pinstripes changing color.

2.2.1 Introduction

Biosensory data shape our sense of our selves and others (e.g., [55, 298, 310, 364]). Personal self-tracking devices (e.g., [67–73]) and bio-responsive design explorations (e.g., [247, 2, 346, 369, 373, 98]) suggest that biosensory data will soon shape our everyday interactions with things, ourselves, and other people. For example, in a 2014 Microsoft Band 2 advert, a

woman wears the band above the quote, "This device can know me better than I know myself, and can help me be a better human" [184], while the product's current website promises "actionable insights" to help users "live healthier and achieve more" [3]. Although well established critiques highlight how Western cultural narratives of data as natural fact or truth are misleading (e.g., [40, 63, 56, 129, 141, 173, 176, 249]), these critiques have not reached many popular accounts of new possibilities with data (e.g., [12, 206, 267, 184, 3]). While claims to truth and "actionable insight" [3] from biosensing technologies may in part be marketing speak, they still shape our cultural imagination about what data is and what it can do [142, 374]. In light of these known critiques of data and the growing role of biosensory data in daily life, we feel designers (ourselves included) must critically consider how biosensory designs shape users' sense of self and others.

We designed, implemented, and deployed a technology probe [37], Ripple, to explore how biosensory data are enrolled in personal reflection, social interaction, and the minutiae of everyday life. Rather than presenting data and inferences as already interpreted facts, we designed an ambiguous biosensory data representation to explore alternative design spaces and foster critical questioning of the data by users. Ripple is a shirt with a pinstripe pattern on the upper sleeve that changes color in response to the wearer's skin conductance data, which can be associated with affective excitement. 17 participants wore Ripple for 8-20 hours over 2 days of their daily lives. We present key vignettes from their lived experiences, surfacing tensions that can emerge when biosensory data is made present in everyday life. For some participants, it seems Ripple altered what counts as emotion itself, raising insecurities and prompting new social comparisons and desires. We draw in Verbeek's theory of technological mediation and Rabinow and Rose's biopower narrative to call out ethical stakes of biosensing representations more broadly, beyond privacy. We advocate for future biosensing research to more critically reflect on its positioning within societal narratives of self, health, and data, especially how these technologies can shape our sense of self and others for better or worse.

2.2.2 Approaches to Emotional Biosensing

Here we introduce related theoretical approaches to measurement, representation, and interpretation of affect, feeling, and emotion. We use affect to mean a pre-conscious bodily sensation, feeling the personal recognition and labeling of that sensation by the individual, and emotion the social display or socially recognized category associated with that feeling [317]. Psychology takes various approaches to understanding affect, feeling, and emotion: For instance, while social appraisal theory emphasizes the role of interpretation in orienting ourselves toward objects (events, things, concepts), processes like mimicry, contagion, and empathy focus more on "direct embodied" transfer without interpretation [273, p. 6]. Drawing from psychology, affective computing "hope[s] to build computer systems that can automatically recognize emotion by recognizing patterns in these sensor signals" [152, p. 1].

Our design draws from Boehner et al.'s critique of affective computing. They argue much affective computing research treats affect-as-information, something that can be measured by

sensors and algorithmically inter-preted into discrete categorical representations of emotion. This approach treats emotions as pre-existing in individuals and able to be algorithmically detected independent of context [36]. For example, present day self-trackers Feel [15] and Spire [260] arguably treat affect-as-information: Both encode the user's internal state into discrete individual categories regardless of sociocultural context, displaying states such as "happiness" (Feel) or "calm" (Spire). Boehner et al. critique such approaches for reinforcing older models of cognition and ignoring the socially constructed and performative nature of emotion. They propose an alternative lens which treats affect-as-interaction, emphasizing how emotion is situated in and arises from sociocultural context. This lens shifts the goal of affective systems away from algorithmic interpretation toward supporting human interpretation of (their own and others') emotion in context [36].

Our material biosensory data display draws from Dourish and Mazmanian [79] on the materiality of data representations. How data is materially represented—e.g., categorical terms or graphs on screens [260, 5], or light emission by algae [102, 113]—"shape the questions that can be easily asked of it, the kinds of manipulations and analyses it supports, and how it can be used to understand the world" [79, p. 8]. For example, a digital timeseries graph affords seeking patterns over time. Prior work suggests potential for thermochromic garments to afford multifaceted interpretation in daily social contexts, drawing in associations around personal style [70].

We draw from Rabinow and Rose's concept of biopower. Biopower considers "truth discourses" regarding human life and "authorities considered competent to speak that truth," as well as population-level and individually internalized strategies for life and health relating to those discourses [288, p. 197]. Biopolitics refers to contestations around those discourses, who is considered an authority, and what forms of knowledge are considered legitimate [288]. Rose describes how health is increasingly framed as constantly at risk of disease, and as the responsibility of the individual who should seek to live their best life by managing risk and making informed decisions [83, 298, 310]. Informed decisions and behavioral adjustments are being guided by data [310, 355]. For example, technology (and the data produced by it) are used to define, detect, and model disease; "technology constitutes the concept of disease" [173, p. 10]. Biosensing technologies are often framed as having authority to reveal insight (e.g., [184, 260, 15, 3, 5]), engaging broader discourses around technology, data, and health.

In this project, we investigate enrolling biosensory data (in particular skin conductance) in reflecting on affect, feelings, and emotion. Our design intentionally contrasts dominant approaches to explore alternative design spaces. Instead of presenting algorithmically interpreted emotional categories (e.g., [260, 15, 172, 280]), we design for human interpretation of emotion situated in daily life. Instead of displaying data on a screen (e.g., [326, 94, 15, 233, 3, 5]), we represent data as color-changing fabric in clothing, leveraging the potential for thermochromics to support multifaceted interpretation [70]. Instead of framing the technology as having authority, we sought to open pathways to question the data display. We present detailed rationale in the design section.

2.2.3 Biosensing Designs

Both research and commercial work is emerging at the intersection of biosensing and clothing. In fashion, provocations and showcase pieces engage LEDs and shape change to suggest dramatic visions of future biosensing apparel (e.g., [19, 146, 2, 315, 369, 373, 20]), while biosensors in fitness wear track and optimize workouts (e.g., [16, 95]).

Prior designs have explored emotional interpretation. For example, Freaky is a larvae-like creature that "freaks out" when algorithms interpret biosensory data as fear, creating a shared human-machine performance of fear rather than a categorical representation [247]. Slovák et al. studied couples' interpretations of a laptop heart rate display, finding the display was seen to provide a sense of social connection [323]. Others have studied biosensing in specific social contexts such as a pub [324], lab [346], or symposium [281]. These studies show different social roles of skin conductance, such as responding to engagement [324]. MoodLight displays a pair's combined skin conductance as a light whose color ranges from blue (lower) through purple to red (higher). With MoodLight, Snyder et al. found that "surprisingly, none of [the participants] questioned whether the lights were accurately representing their internal state" [346, p. 149]. In the specific setting of the MoodLight lab study this lack of questioning seems not to have been problematic for any participants, and we see this study as an inspiring example of probing open ended social interpretation with abstract displays of biosensory data. And yet, this study prompted us to ask, how might we design a display where participants feel comfortable questioning or doubting its accuracy?

We are concerned with how Western cultural narratives of data as natural fact or truth are misleading (e.g., [129, 176]) and how this might play out specifically with emotional interpretation throughout the many varied contexts of daily life, which can be highly personal, subjective, and sensitive. Would 'data-as-truth' provide a sense of much-desired clarity on one's emotions? Conversely, what if the data were seen to mean something about a person's deepest feelings that they found surprising, or wrong, or hard to believe, or something they did not want to believe? Should the person be expected to capitulate in the unquestionable face of data-as-truth and accept that they 'in fact' do feel a particular way? Our hunch is that it might be really valuable for people to be able to question data's relation to their feelings, to give the person the final say on their own feelings.

We previously studied how friends wearing thermochromic t-shirt displays of their skin conductance interpreted those displays during a 45-minute conversation in an office. We found the display became enrolled in social meaning-making and self-presentation and that it might be desirable for users to enact social performances with biosensing displays [anonymous]. Ripple implements features to support social performances and expands both the length and contexts of the study to form a richer picture of biosensing in participants' daily lives.

Ripple builds on and extends prior work by studying an ambiguous clothing-based display of skin conductance in daily life. The always present yet unobtrusive display was available to participants as they experienced a range of situations and social circumstances, allowing us to probe social interactions around the display in tandem with participants' personal reflections.

2.2.4 Designing Ripple

Figure 2.4: (top) Ripple, a shirt whose three shoulder pinstripes change color in response to skin conductance, was produced in multiple colors and sizes. Pinstripes fade to white one by one, then all return to gray (left to right, top to bottom) .

How can designs make biosensory data present in ways that support critical reflection and human interpretation? Ripple is not the design 'solution' to this question; rather, Ripple is a design probe in the sense that "the designed application is itself thought of as a probe that forces new interaction, reflection, and reactions by users" [37, p. 1080] seeking to "open up new design spaces" [37, p. 1078]. We want to explore alternative design spaces because, although Western culture associates data with truth (e.g., [63]), we (the authors) feel it is important for people to question data's relation to their own life and systems of meaning. In our design, we sought to avoid algorithmically interpreted categories of emotion, and instead encourage spontaneous, open-ended human interpretation of feelings and emotion throughout daily (social) life. For example, we envisioned users noticing a display change, pausing for a moment to reflect, and perhaps linking the biosensory data to their feelings. We thought critiquing the data might take the form of dismissing the data as irrelevant at particular moments or asking more questions about what the sensor and display respond to, while not questioning the data would be instances where the display change would be interpreted to reveal something "true" about the person.

2.2.4.1 The Ripple Effect

Ripple is a shirt with three color-changing pinstripes on its upper left sleeve. When inactive, the pinstripes are dark gray, blending with base garment color. When the wearer's skin conductance suddenly increases, which is associated with various kinds of excitement, the pinstripes activate, changing from dark gray to white, then returning to gray one by one from left to right over about 9 minutes (Fig. 2). We envisioned this slow "ripple effect" as part of

the many rippling effects that occur in the ongoing "river" of emotions of daily life and social interactions, wherein our facial expressions, gestures, speech, thoughts, feelings, actions, etc., are continually acting and reacting with ourselves, one another, and the environment. Similar to how laughter, then a blush, might be effects rippling out from a teasing comment, Ripple's color change adds another visual reaction that is observable by self and others. The slower reactive display creates opportunities for self reflection and for others, to whom the wearer might have disclosed their shirt's function, to inquire about their skin conductance. For example, we imagined scenarios in which a wearer might return home with an active stripe, and a roommate or loved one might inquire about if moment of excitement may have occurred just prior to their arrival.

2.2.4.2 Inviting Critical Engagements with Biosensory Data

To invite critical questioning of data, we designed avenues for questioning or even disregarding the data by:

2.2.4.2.1 Engaging a Subtle Design Subtlety stems from the display's size, location, slowness, neutral colors, material, and sensor placement. The small display is located on the upper left shoulder (Figure 2.4), in the periphery of where oneself or others typically glance. The slow shifts from gray to white over 9 minutes can easily be missed by the wearer or others. The thermochromic threads blend in with normal fabric. The sensor is hidden underneath the shirt. Subtlety also enables curating "access" to the display and its meanings. Wearers could disclose the dynamism and meaning of the display to individuals of their choosing.

2.2.4.2.2 Acknowledging the Ambiguity of Skin Conductance We chose to work with skin conductance, included in many wristband trackers (e.g., [94, 3]), because it is inherently ambiguous: it can indicate mental, physical, or affective (distinct from emotional [317]) excitement, but not valence, where both positive and negative excitement are associated with an increase in skin conductance [152]. Instead of attempting to 'resolve' this ambiguity and represent our interpretation to users, we hope to encourage users' interpretation by simply changing a pinstripe to a different color in response to a sudden increase in skin conductance. Additionally, we felt other sensors such as heart rate might carry associations with physical fitness or medical checkups for participants, which might have distracted from our goal of probing reflections on affect, feeling, and emotion.

Furthermore, our algorithmic analysis of the skin conductance data is intentionally crude so as to foster moments in which wearers might see the display as inaccurately reflecting their emotions. To detect sudden increases in skin conductance we use only a simple statistical low pass filter adapted from [300] rather than various machine learning techniques used by [300] and others (e.g., [234]). With our algorithm, sweat due to physical exertion will also trigger a display change, and the display will respond differently to different people as they may have different degrees of skin conductance responsiveness, called electrodermal lability

[306]. By designing for moments when the display might be seen as inaccurate, we sought to support critique and confidence in disregarding the data as wearers might choose.

2.2.4.2.3 Embracing the Volatility of Thermochromics Prior work argues that the ambiguity of thermochromic clothing-based displays can support multifaceted open ended interpretation and suggests particular materials and fabric production techniques for this [70]. We extended these techniques by implementing them for garments worn throughout daily life. Thermochromics respond to heat, so it is ambiguous whether a display change is due to skin conductance, environmental heat, or body heat, and a cool breeze could inhibit the display's response. We included this additional layer of ambiguity to support the "deniability" of the display. For example, we envisioned that in explaining the shirt's color change to another, the wearer might choose to say that the shirt changed due to ambient temperature to avoid discussing their feelings. Together with our use of skin conductance, the data, algorithm, and display "enhance ambiguity of information," [119, p. 237] a tactic for leveraging ambiguity to foster interpretation by people [119].

2.2.4.2.4 Inviting Social Performances We introduced features that would allow users to "perform" their skin conductance display by squeezing two shirt buttons, one that triggers an immediate display response and another that immediately cancels any display response. This builds on our prior work suggesting desires for a clothing-based skin conductance display to help enact social performances [166].

We felt these factors might "make space for user re-interpretation by downplaying the system's authority" as suggested by Sengers and Gaver [1, p. 4] and afford questioning or disregarding the data. Display changes do not map to specific emotional categories, inviting participants to put forth their own interpretations of their feelings. Display changes can easily be overlooked, ignored, or forgotten, or their provenance can be explained as pertaining to ambient temperature instead of affect. By providing so little information in only a gray to white color fade, with so much ambiguity inherent in the data, algorithm, and display, we anticipated that Ripple might seem uninterpretable in some instances or for some people. Even so, we wanted to use Ripple to probe interpretation in the face of this multifaceted ambiguity.

2.2.4.3 Grounding the Design in Everyday Life

Due to our interest in interpretation of biosensory data in daily life, it was essential to ground the design in daily life with an everyday style and robust implementation. Whereas clothing-based displays are often showcased in settings of limited wear, like technical demos or runway shows, our lightweight system was worn all day by participants. Each pinstripe had about 2-7 Ohm resistance and received about 450mA from a 3.7V LiPo battery via an Adafruit Powerboost 5V regulator, switching on (100

2.2.5 Study

Ripple is a reflective design [308], intended to provoke reflection in both us (as designers) as well as our study participants. In the spirit of reflective design, we engaged Ripple as a probe to illuminate possibilities of new relationships, insights, and social interactions that might emerge from the public displays of biosensory data. Introduced by Gaver, Dunne, and Pacenti [116], probes are material prompts that are intended to generate inspirational responses from a community in order to identify new opportunities for and understandings of the role of design and technology in everyday life. In their words, "This allows us—even requires us—to be speculative in our designs, as trying to extend the boundaries of current technologies demands that we explore functions, experiences, and cultural placements quite outside the norm." Probes have been taken up by HCI research in a variety of ways. One way particularly close to our approach is the 'technology probe', a technologically functional prototype that "must work in a real-world setting" and is "meant to inspire people to reflect on their lives in different ways" [174, p. 18]. Technology probes can help iterate and refine to a specific design solution or helpt broaden the design space and provide "design inspiration" [174, p. 18]. In introducing their method of technology probes Hutchinson et al. provide as an exemplar Dunne and Raby's Placebo Project [93, 174]. The strange artifacts deployed in volunteers' homes are not intended to narrow the design space toward a particular desirable product or design solution to a known problem; rather, the goal is to "investigate people's attitudes to and experiences of electromagnetic fields in the home" [93, p. 11].

In this sense Ripple speculates on a plausible future device, a bio responsive T-shirt, and leverages ambiguity [119] to open opportunities for participants to explain their relationship to data through their situated interpretation: we imagined that these interpretations could range from dismissal of the data as arbitrary; to an embrace of the data as a reflection of their "true" self; to "middle ways" where the data is leveraged to conveniently suit the wearers beliefs or facilitates the building of an interpretive relationship over a longer period time.

To study these outcomes, and make room for others that we did not intend or anticipate, we studied our participant's experiences and interpretations with a combination of diary logs and qualitative semi-structured interviews. We invited pairs of friends to participate to specifically probe individual and social interpretations of biosensory displays. After a pre-interview about their backgrounds, the researcher introduced Ripple by saying, 'The pinstripes change color in response to a sudden increase in skin conductance, which is associated with various kinds of excitement such as feeling stressed or happily excited. Skin conductance is essentially how sweaty you are, but microfluctuations in skin conductance are associated with various kinds of excitement.' We also described how the shirt was volatile to changes in body temperature, describing how warm sunlight could make the threads change color or "a cold breeze could hide the color change."

Drawing from our prior work [anonymous], we began each study by asking participants to talk over conversation prompts while wearing the shirts. By fostering interpersonal closeness [17] with potentially sensitive topics (e.g., "If you could change anything about the way you

were raised, what would it be?"), we found that these prompts seem to help participants open up to one another and share reflections about their feelings and emotions while wearing Ripple. At the end of this first meeting, each participant was given a physical diary and instructed to make a note of each time they noticed the display change, each time they expected a display change but it did not occur, what they liked and disliked about Ripple, and what they wore with the shirt to probe how Ripple related to their sense of personal style.

After this first meeting, participants went about their daily lives wearing Ripple for about 8-20 hours. The next day, they met with a researcher for a qualitative semi-structured post-interview, in public venues, that lasted between an hour and ninety minutes. At these interviews, we used the diary entries as an elicitation method to spark memories and specific recollections of the situations in which display changes were noticed and reacted to.

We audio recorded the interviews and the first author transcribed them for analysis following the best practices of an "issue-focused" qualitative study [363]. Because of our analytical frame of affect-as-interaction, all researchers marked and coded specific moments of interpretation, paying close attention to how participants described, reasoned about and responded to their biosensory data. We organized these into themes and began to see tensions emerge between the space we provided for participants to interpret the data and the development of interpretations that raised ethical considerations in the design team. In the discussion, we introduce two alterative analytical frames (technological mediation, and biopolitics) that helped us better understand the ethics and politics at play in our design.

Eight men, nine women, ages 19-41, participated, referred to by pseudonyms. One man participated alone. Three pairs were married; all others were friends or housemates. Study procedures are IRB approved. The themes and quotes we present in the findings do not touch on all themes that emerged, but focus specifically roles and tensions they suggest for biosensing designs in daily life.

2.2.6 Moments of Reflection with Ripple

We saw participants enroll Ripple in moments of reflection throughout daily life, linking observed display changes to their own reflections on their feelings. Alex described trying to find a pattern in their display changes: "I kind of prepped myself for this—any changes in mood, and any changes in heartbeat, that would happen, I wanted to see if [Ripple] would do anything, and it did." Similarly, other participants described "trying to figure out how/why it reacts" (Natalie) and looking for a "correlation" (Deb) or "patterns" (Arthur) between activities, feelings, and display changes. Here, participants formed their own interpretations of their feelings in response to Ripple's ambiguous color-changing threads display.

As a subtle clothing-based display, Ripple was unobtrusively present throughout many varied contexts of daily life. For example, Jed received a job offer over the phone and attributed the display change in that moment to his excitement. Jennifer saw a display change while "watching some of the [Olympic] gymnastics," and commented that "it was really, really impressive and very attractive," and linked the change to her excitement.

Agustin noted a display change during a jam session with band members and attributed it to being in creative flow. Alex noticed Ripple's threads lightening during a difficult call with a customer, explaining that the display changed "probably because I was slightly frustrated. My heart rate and blood pressure definitely increased for just a little bit." Other kinds of situations that participants described when interpreting display changes include feeling startled by someone approaching them from behind (Alva) or almost falling (Jennifer), trying very hard to remember something (Arthur), enjoying or imagining good food (Erika, Jennifer), and receiving a paycheck in the mail (Valeria). Participants also attributed display changes to sweating from physical exertion, especially biking (Mark, Deb, Natalie). Participants' interpretations include a range of emotions that well exceed the abstract gray/white display change provided by Ripple.

Participants also considered how ambient temperature might influence the display as well, such as describing the presence of warm sunlight (Jed, Arthur) or body heat (Alex, Mark) as other possible causes of display changes. We did not observe any instances in which participants denied any emotional provenance of a display change by linking it to temperature instead, although we had envisioned this as a possibility and designed to support it. This could be because participants were curious to explore how their skin conductance responded throughout daily life, seeking patterns as described above, or perhaps a situation of wanting to avoid emotional disclosure did not arise over the two day study period.

As anticipated, participants did not always provide explanations for display changes. Deb said "when it changed unexpectedly it was more of a mystery—that made it more fun." Jia and Kanav both expressed that they were unable to find any pattern linking display changes to their feelings and asked if it was a deception study during the post interview. We find it unsurprising that such an abstract display seemed uninterpretable sometimes. What we do find surprising is the nature of interpretations that participants did form around Ripple, which our findings and discussion will explore further.

Ripple sometimes seemed to foster reflection in personal relationships. Wearing the shirts, spouses Alva and Brant were discussing their upcoming move when Alva's shirt, and not Brant's, changed color. During the post interview, Alva recalled, "We were talking about our move and how we're kind of getting stressed about it, or, well, I'm kind of getting stressed about it, and so I think it was being stressed and talking about being stressed [that made the threads change]." Alva attributed the display change to her stress. Alva and Brant went on to discuss how Alva has been feeling stressed about the move, and how sometimes Brant will suggest that she simply stop feeling stressed, but how they both know that does not really work. Their talk was lighthearted and interspersed with laughter, not tense, yet their interpretations around Ripple engaged with their ongoing discussion about stress, prompting them to reflect upon their feelings and how best to support one another.

Others described the display as highlighting connections between different facets of being such as mind, body, and emotions. Jennifer appreciated the displays' physicality: "It changes color when I get my adrenaline going, so it's kind of cool to see that in a physical way... I like that it connects my internal thoughts that are usually not on display with my body and me." She described Ripple as providing an "external way of processing what's normally

just in your head." Agustin enthusiastically related a "philosophical moment" with Ripple that came during an angry phone call: "I was calling my internet provider and I was pissed off, I was really angry." He attributed the display change at that point to his anger, and elaborated, "It made me reflect on how situations are clearly transmitted into my body, you know, 'cause usually I think about emotion as something that is not physical or non-tangible... but this was like, 'No, dude! These are emotions! They impact your body!"' In these cases, Ripple's tangible on-body display provided a sense of connection between mind, body, and self, serving as a resource for reflection.

Throughout, participants leveraged context in interpretation. Emotions arise from particular contexts, events, and interactions with people. The interpretations are more like stories of particular situations and their responses and actions within that context. Their approach to emotion is more akin to affect-as-interaction, rather than treating emotion as discrete categories akin to affect-as-information. As expected with tactics for leveraging ambiguity [119], the ambiguous nature of Ripple's display seems to have encouraged people to leverage context in their interpretations. Though the 2-day study is quite short, these vignettes suggest participants began to enroll Ripple in moments of personal and social reflection, and developed narratives linking display changes to feelings and events in daily life. In these cases, Ripple fostered the kind of open ended reflection we hoped to support.

2.2.7 Tensions of Emotional Biosensing

While some cases point toward potentially interesting or beneficial ways of reflecting with biosensory data, in other cases such open-ended reflection had unintended consequences that we find problematic. We elaborate a few concerning vignettes in more detail to draw out tensions that may impact future designs of emotional biosensing.

2.2.7.1 Calmer Feelings Overlooked

Skin conductance only responds to certain kinds of excitement, as explained by the researcher to participants when introducing Ripple. Its degree of responsiveness differs across people [306]. Yet, some participants linked what seemed to them like a lower frequency of display changes with being less "emotional" (participants' word choice) as a person. There is no evidence of technical malfunction here.

Jennifer seemed concerned that her display changed less often than Arthur's, her housemate. She kept asking him if he thought her shirt was changing, especially when she noticed his shirt changing. During the post interview, she attributed the lower frequency of display changes with her not being a very emotional person: "I also don't tend to be a very emotional person, so that was also something that was interesting to me... 'Cause that's something that I've kind of always thought, and then it kind of got reinforced by not having it change very often." When asked how she felt about not being a very emotional person, she replied that she was "fine with it," perhaps with a hint of disappointment. Mark described himself and his study partner as not very "excitable" when describing what he perceived to be a

relative lack of display changes. In our discussion we also bring in findings from a previous study in which a father held his crying baby and expressed concern that a lack of display response in that moment indicated a lack of empathy for his son. With Ripple, Erika expressed concern that the shirt not responding might indicate that she was not a very emotional person. When Erika's display changed at the end of the first meeting, her husband Jed said, "According to the shirt you have some emotions right now." She then broke into a huge smile and exclaimed, "Yes! I have emotions!" He replied, "See, you're not broken and unfeeling."

These cases suggest that, by calling attention to moments of excitement, Ripple also called attention away from calmer moments. Erika and Jennifer did not consider calm, which would not be associated with a change in skin conductance or a display change, in their interpretation. This highlights the partiality of the display and how it shaped experience in two ways: by what it responded to and, equally, what it did not respond to. Moments when the shirt did not respond also make a statement by contrast, by not recognizing various emotions. By calling attention to, and perhaps even rewarding, certain kinds of emotion with a visible display change, Ripple implicitly lumped all other emotions together as not worth displaying. Participants mapped non-response to lack of emotion, which impacted their sense of self for better or worse. Similarly, Ripple made excited emotions more present for participants when they noticed and reflected on a display change.

2.2.7.2 Social Comparisons and Desires

Comparing the frequency of display changes also took on social meanings. Over lunch Alva noticed that Brant's shirt kept changing while hers did not. She said, "I felt kind of left out, so I was like, 'I want my shirt to go off too,"' so she used the override on feature to manually initiate a change in her display. On the other hand, Brant said his display had been on nearly nonstop during all of lunch, so he used the override off feature. Alva's decision to create more display changes with the override on, and Brant's decision to suppress display changes with the override off, suggest a desire for their displays to change about the same amount. As another example, Erika seemed to feel that Jed's display changed more often over the course of the study. Jed teased Erika about how he had two or even three threads changing simultaneously, saying "It's pretty special, I know." Erika expressed concern that what she perceived to be a lack of display changes might suggest she did not have feelings, saying "It was definitely a little stressful." While Alva and Brant seemed satisfied using the override features, for Jed and Erika the comparison seemed to have resulted in a more persistent concern.

We have described a few chosen vignettes. Although a summary of participants' experiences could show the present range of interactions with Ripple, our goal is to analyze these few vignettes in more detail to consider potentials of emotional biosensing more broadly, to provoke new questions and directions for further exploration of design spaces in the future.

2.2.8 Discussion

While some participants related the display to their own narratives about their feelings, others seemed to alter their conception of feeling to align with Ripple's representation of skin conductance, even with the ambiguous nature of the data and display. Despite our attempts invite critical questioning, some participants seemed to invest a potentially harmful degree of authority in the data display.

On the one hand, some participants related the data display to their own personal narratives of how they were feeling, situated in the sociocultural context of their daily lives. Their emotional descriptions well exceed the kind of discrete emotional categories that affect-as-information approaches typically use such as happy, sad, calm, or stressed. For example, Jed's "excitement" at receiving a job offer over the phone is significantly different from Jennifer's "excitement" at watching Olympic gymnastics. Alva is not simply "stressed," she felt stressed about her upcoming move to a new country, and the public-facing display may have prompted a more thoughtful conversation about this with her husband. Agustin's anger is not an abstract, pre-existing category, it is part of his response to a frustrating call with an internet service provider, part of his felt experience and enactment involving his mind, body, and feelings. This suggests potential for personal biosensing displays to be enrolled in affect-as-interaction approaches to open ended interpretation and personal meaning making.

2.2.8.1 'Sharping what Counts'

Yet, interactions with Ripple also revealed tensions. For some participants, Ripple made some feelings more or less present and altered what counts as feeling. Here we draw from Verbeek's theory of technological mediation [362]. One aspect of this theory describes how technologies mediate our perception, amplifying some things and reducing others. Ripple's display amplified excited affect by responding with color change and reduced calm affect by not responding. Reflecting on their feelings, participants considered these moments of calm as non-feelings: Jennifer said the lack of display response "reinforced" her sense of not being "a very emotional person" (her words); Erika worried the lack of display response suggested she was "broken and unfeeling." Like other mediating technologies, Ripple "help[ed] to shape what counts as 'real"' [362, p. 8] for some participants with regard to their feelings. In this sense, Ripple shifted their conception of feeling itself to be defined according to the representational display. The biosensory data display was seen as a 'measure' of feeling and in turn shifted the concept it sought to measure.

In addition to shifting "what counts as real" [362, p. 8], with Ripple some participants almost began 'counting' felt moments. They did not report numerical counts of display changes, but they did compare 'more' or 'less' display change. Jennifer and Erika saw the difference between zero or more display changes in their own shirt as significant. Alva and Brant compared whose display was changing more over lunch, and sought to make their displays change about the same 'amount' by using the override features. Thus, Ripple not only shifted some participants' conception of feeling, it made feeling present as an 'ordinal

variable' in the sense of supporting comparisons about more or less.

We sought to avoid algorithmically interpreted categories of emotion, and instead encourage human interpretation of feelings and emotion in context. Yet, it seems even Ripple's highly ambiguous display was seen by some participants as measuring and representing the 'presence' or 'absence' of feeling, which is not at all what we intended.

In common parlance, "what counts" can also mean what is worthwhile or valuable. By responding to only some feelings, Ripple may have suggested that these feelings were worthy of recognition, or valuable, while others were not. Biosensory data, like other data, is inherently partial and embeds implicit values. We found Verbeek's theory of technological mediation helpful for analyzing this, and suggest that future biosensing research explicitly consider how representations of biosensory data 'shapes what counts' in terms of amplification/reduction, quantification, and values.

2.2.8.2 Do Artifacts Have Biopolitics?

Artifacts have politics and "can embody specific forms of power and authority" [365, p. 121]. We analyze (bio)political implications of Ripple and argue that biosensing designs should explicitly engage with biopower [288] to consider issues of authority and potential harms.

Participants seemed to invest authority in the data display, drawing from Rabinow and Rose's use of 'authority' relating to who or what is considered able to provide 'truth' [288]. As designers we attempted to foster critical questioning of Ripple's display by making it subtle, ambiguous, volatile, and able to be performed. We thought participants might question the relationship between the data display and their feelings, or choose to disregard the data display, but found surprisingly few instances of this. A few participants noticed display changes and did not offer any interpretations. Perhaps they did not consider the display relevant to their feelings but felt saying so could be impolite to researchers. Future work could use a different study design in which participants might feel more comfortable criticizing the design. That said, some participants as described above readily related the display to their feelings even when they seemed concerned about what they interpreted the display as suggesting. It seems they invested authority in the data display as able to reveal insights, conflating their interpretation of the display with the display itself.

Ambiguity in Ripple seems to have increased the authority of the data display rather than inviting critical questioning. Because Ripple's ambiguous display did not provide an interpretation linking the data to feelings or emotion, an interpretation which might have been accepted or dismissed as participants chose, Ripple could never be clearly wrong while at the same time it afforded a very broad range of interpretations by participants. This seems to have allowed it to take on a bigger role in their self-reflection (e.g., the authority to suggest whether one is "broken and unfeeling") than the roles we feel may have been warranted (e.g., suggesting noticing moments of excitement). Reflecting on ambiguity as a resource for design [119], it seems Ripple's ambiguity did invite active interpretation by participants as expected. However, the sensitivity of interpreting feelings plus the unexpected authority invested in the display enabled interpretations that we find concerning.

Why did participants invest authority in Ripple's data display, even when they disliked what they thought it meant? Our tentative proposition considers feelings and biosensing with biopower discourses of health and disease: While health is increasingly framed as at risk of disease [298], feelings can be seen part of health and thus also at risk. Biosensory data is used to 'detect' stress [153, 158, 262, 300] and depression [50, 123, 276] to suggest interventions to improve emotional health [366, 260]. Perhaps participants had internalized a sense of their own emotional health as at risk and sought to manage that risk via informed decisions relying on the authority of data. Erika interpreted Ripple's display as suggesting she was "broken and unfeeling." In our prior work, a man held his crying newborn while wearing a shirt that similarly responded to skin conductance. He interpreted the lack of color change at that moment as suggesting he lacked empathy for his baby. He expressed concern that he had no empathy as a person, prompting the mother to reassure him [anonymous]. In both instances participants seemed willing to lend credence to what they saw as the data's suggestion that their feelings were unhealthy. In short, the broad space for interpretation afforded by ambiguity may have provided a way to project one's fears and insecurities onto "data," thus making them seem more true or valid. We did not intend to foster such upsetting insecurities with our design and see this as a potential ethical concern.

Why is this concerning? While people might (mis)interpret feelings all the time, the authority invested in Ripple lent interpretations of insecurities more potency. We think some participants' interpretations are potentially harmful by fostering heightened insecurity in vulnerable moments (e.g., father with baby). As designers, we feel it is inappropriate for us to "diagnose" issues of emotional health that may be implicated in our design. Yet, we hope these accounts demonstrate the need to grapple with ethical issues even when they may extend beyond what HCI is immediately equipped to handle. While our probe was useful in surfacing these concerns, we are still struggling with how to best address them, motivating future work. Integrating diverse perspectives on emotional health into the design process and explicitly reflecting on artifacts' biopolitical implications seem like promising avenues to pursue.

For future design research, the role of ambiguity in emotional interpretation with biosensory data merits further exploration. Although ambiguity in Ripple functioned in a particular way, in other designs this could play out differently. Ripple primarily used the tactic "Use imprecise representations to emphasise uncertainty" [119, p. 237], folding together multiple layers of imprecision with a crude data analysis algorithm and a highly abstract, environmentally volatile display. Future designs could explore other tactics such as "Over-interpret data to encourage speculation" or "expose inconsistencies to create a space for interpretation" [119, p. 238], perhaps by presenting intentionally overly specific interpretations of emotional states that people might feel more confident disagreeing with, or presenting multiple conflicting such interpretations. Creating a space for interpretation could also have the potential to suggest an alternative framing for health and emotional wellness rather than letting this 'default' to dominant biopolitical narratives.

Considering the discourses of biopower in which designs and users operate helps think about potential dangers of affective biosensing. In our case, it helps explain the authority

invested in our data display despite our designerly attempts to foster critical questioning of data, and the potential for harm of this authority. For biosensing designs more broadly, biopolitics may help consider and contest what ways of knowing are seen as legitimate.

2.2.9 Conclusion

We contribute the design and study of Ripple, a technology probe [37] that contrasts prevalent design approaches of affective biosensing in order to explore alternative design spaces. Our analysis of these few vignettes of participants' lived experiences with Ripple point to broader tensions of affective biosensing technologies. Despite our designerly efforts to provide avenues for questioning or disregarding the data, the data display still held authority even as it fostered insecurities that may not have been warranted. Despite the display's multifaceted ambiguity, it still reconstituted feeling in its own terms. Our findings made us more attuned to how affective biosensing designs can suggest new ways of feeling, for better or worse.

Going forward, we suggest that designers of affective biosensing technologies continue to explore these tensions and related issues of measurement, representation, and interpretation. We have presented three theoretical lenses that helped us think about these tensions. Boehner et al.'s interactional model emphasizes the socioculturally constructed and performative nature of emotion and influenced our design approach [36]. Verbeek's theory of technological mediation helps analyze interactions between people and technologies to consider how biosensing designs shape what counts as real or valuable [362]. Rabinow and Rose's biopolitics helps consider how interactions with biosensing designs are situated within broader societal discourses of health and authority [288, 298]. Biosensing technologies do not 'detect' affect as passive observers, they actively shift our conception of affect, feeling, emotion, and become embroiled in questions of how or what we should feel or be.

Chapter 3

Life-Affirmation with the Heart Sounds Bench

This project moves from exploring wearable sensors to exploring sensing as it might be embedded in public infrastructure–specifically, in a bench that senses and sonifies heart sounds. The previous chapter's designs sought to foster emotional reflection. Though fraught with at times uninterpretable ambiguity and occasionally aggravating people's insecurities in the face of unintended data authority, Hint and Ripple attempted to invite a sort of social and personal 'knowledge' generation about how people are feeling by those people themselves. The Heart Sounds Bench presents a type and material of data–the live unfiltered sounds of people's beating hearts, with the sounds of multiple hearts blending together–that is at once both harder to draw 'clear' emotional 'insights' from yet also more immediately, viscerally emotional. This *'opaque' lack of 'insight'* is explored as a critical alternative, speculatively situated in contrast to prevalent "smart city" narratives riding on the supposed power and authority of data-driven insights from sensors embedded in public infrastructure. Again, the key methodological approach here is research through design, yielding insights that are "provisional, contingent, and aspirational" [115, p. 937].

"Smart city" narratives promise IoT data-driven innovations leveraging biosensing technologies. We argue this overlooks a potential beneft of city living: affirmation. We designed the Heart Sounds Bench, which listens to and amplifes the heart sounds of those sitting on it, as well as recording and playing back the heart sounds of previous sitters. We outline our design intent to invite rest, refection, and recognition of others' lives in public space. We share results from a study with 19 participants. Participants expressed feeling connected to a shared life energy including others and the environment, and described heart sounds as feeling intimate yet anonymous. Finally, we elaborate the concept of life-affirmation in terms of recognition of others' lives, feeling connection, and respecting difference with opacity, as a way of helping "smart city" designs embrace a multiplicity of desires. This chapter draws from my lead-author publication [165]. "We" in Chapter 3 to myself as lead researcher in collaboration with co-authors on [165].

Figure 3.1: The Heart Sounds Bench amplifies the heart sounds of bench-sitters, inviting a moment of calm yet vibrant life-affirmation.

3.1 Introduction

Smart city narratives "aim to evoke positive change and innovation–at least as the proponents see it–via digital ICT; essentially, building an IoT at the city-scale by installing networked objects throughout the urban environment (and even human bodies) for a wide range of different purposes" [294]. These narratives promise improved efficiency, safety, fitness, sustainability, and civic participation, often relying on data [349, 104, 21, 100, 10, 226, 47, 97, 187, 303, 76, 294]. Biosensing technologies–sensors measuring humans and the accompany data, models, predictions, and insights–undergird many smart city IoT applications. For example, video surveillance can detect heartrate [263], correlated with future involvement in violent crime [202] or percentages of joy, contempt, and anger [5]. Wearable trackers promote individual workplace efficiency [171], physical fitness [98], emotional wellness [328, 94], and self-improvement through algorithmically suggested behavioral micro-nudges [306]. Sidewalk Labs plans to revamp citing living with smart city sensing and technology [118, 145, 220, 316]. Knightscope robots patrol parking lots, and sometimes public space, using sensors to detect and report 'anomalies' as security risks that often conflate the existence of homeless people with criminal activity [359, 159, 318, 51, 127].

Critiquing this, Nissenbaum argues that such pervasive surveillance is unjust and tyrannical [253]. Regarding Sidewalk Labs, Crawford cautions against such in-depth intervention by a single company into civic infrastructure [57]. Sadowski and Pasquale critique the smart city ideal, tracing free market ideology that seeks to "spread market logics to all dimensions of human life" while "focusing on the narrow goals of promoting transparency and efficiency" [294]. Our work critiques and explores alternatives to these problematic smart city narratives through design research by engaging the heart sounds bench as a probe [36].

De Lange and de Waal outline a key tension in smart cities: "The challenge therefore in

our view is to balance these stories of personalization and efficiency on the one hand and of building collectives based on differences and mutualism on the other hand" [199]. Urban sensing can be used for personalization and efficiency, smoothing over difference for sameness, but an alternative role for urban sensing could be more like visionary urban scholar Jacobs' call for cities to celebrate "a great and exuberant richness of differences and possibilities, many of these differences unique and unpredictable and all the more valuable because they are" [180, p. 220-1]. Shifting from 'smart cities' to 'social cities' [199], we contribute a design probing affective experiences of affirmation and connection while respectfully engaging difference.

Widespread biosensing in daily life makes data- and algorithmic judgments about people's physical un/fitness, mental un/wellness, and criminal/terrorist risk [167]. These categories are far from neutral: one side is 'normal' and one side is 'other'. The 'other' category is usually seen as sub-optimal, in need of improvement, control, or discipline, or as something to be feared. This can contribute to *otherization*, a process whereby people come to be viewed as intrinsically different and alien [264, 295] (e.g., racism, Islamophobia). While data-driven approaches including biosensing often claim to escape social prejudice with objective insights, they can instead reify pre-existing stereotypes and bolster structural inequality with a false sheen of scientific authority [89, 254, 44, 47, 46, 47, 8, 7]. Our work engages biosensing in ways that challenge the need for data-driven categorization by presenting heart *sounds* without filtering or analysis.

Our work sits at the intersection of smart city narratives and affective computing, seeking to reconfigure both. Affective Computing seeks to automatically 'detect' human emotions in terms of discrete data-driven categories [49]. This risks flattening difference by claiming that such categories are universally generalized [36], and furthering otherization around emotional un/wellness [167]. At the same time, HCI is undergoing an affective turn whereby research seeks not only to support functional tasks, but also affective experiences, construed more broadly than Affective Computing's discrete categories of emotion, such as playfulness, reflection, or slowness [112, 310, 258, 252, 134]. Our work investigates how smart city sensing technologies may shape the affective experiences of city living while at the same time challenging the data-driven categorization prevalent in affective computing, by fostering a slow emotional experience with biosensory data that does not rely on data-driven categorization.

Being in public space can fulfill emotional desires not directly related to prevalent smart city narratives. Sometimes people want to get out and about, to see and be seen. As city planners and architects are well aware, the design of urban space influences the kinds of social interactions therein [358]. Contrasting the normative categorization of many urban sensing technologies, we focus on the particular affective experience of *affirmation* in public space.

3.2 Affirmation

Affirmation, defined as "emotional support or encouragement" [6], has emerged as a design goal [167, 367, 322]. We outline how affirmation is lacking in prevalent smart city narratives, and contribute the Heart Sounds Bench as a design exploration of affirmation. Listening to one's own heart sounds, and those of another co-present bench-sitter, invites a quiet moment of listening, bodily awareness, and engagement with other(s). Analyzing the results of our study with 19 participants, we further contribute an elaboration of a concept we name *life-affirmation* in terms of *recognition*, *connection*, and *opacity*. Recognizing and feeling connected to the life and experience of others contributes to affirmation, while accepting the opacity of what we cannot know about others helps further recognize and affirm difference. We call for designers to continue exploring affective experiences of urban public space while embracing a multiplicity of desires.

Though perhaps not discussed in these terms, affirmation can occur in public space: The bus driver who stops because he sees someone running. The stranger on the bus who moves their bag to make room on the seat, or the one who provides directions. The shopkeeper who greets those entering, before a purchase has been made. Even walking on a crowded sidewalk requires sharing space, acknowledging one another's needs for passage. Of course, these daily affirmations of one's existence and needs are experienced unequally depending on privilege. As designers, we draw inspiration from mundane moments of affirmation, while remaining reflexive about our social position and social norms.

Smart city narratives often miss this notion of affirmation. The emphasis on economic exchange constructs its subjects in terms of their ability of to produce economic value by leveraging efficiency and fitness, affirming capital not people. Additionally, biosensing technologies' potential for otherization, especially regarding criminal risk, is not affirmative. The Heart Sounds Bench responds to what we feel is a lack of affirmation in prevalent smart city narratives.

The built environment can also feel affirmative. If not intentionally designed to be unpleasant [299], public benches affirm the needs of passerby to sit. Resting may not be not an efficient use of time or part of a fitness regime. Sitting on a bench might lead to being approached by strangers, which could be unsafe. A better economic exchange might require passerby to pay for a seat at a cafe. The Heart Sounds Bench celebrates and leverages the potential of public benches to contest the smart city emphasis on efficiency, fitness, safety, and economic exchange, instead affirming the existence and needs of passerby for a moment of rest.

3.3 Related Work

Participatory sensing engages citizens in collecting data about civic issues such as air quality or for fostering curiosity, exploration, and discussion [337, 196, 339, 271, 270]. HCI is investigating fostering civic participation with smart city sensing [21, 58, 335, 73, 75, 272,

186, 138, 18, 256, 54, 128, 117]. Boehner and DiSalvo explored how civic tech is conceptualized by civic leaders [34]. Design artifacts can shape Deweyian publics [72] around political issues [77]. Public IoT is oriented toward communities, matters of concern, and matters of care [74, 28]. The Heart Sounds Bench is less about fostering discussion or participation in particular civic issues, and is more about the affective experience of being in public urban space.

Designers and city planners explore affective experiences of citing living. City Lab explores public interventions for building community [304]. Wallace et al. explored the hedonic pleasure of shopping on the high street with the Self-Reflector [351]. HCI has explored fostering community and curiosity in the smart city [269, 25, 45], exploring emotional reflection or emotional bonds with particular places [357, 331, 330], and supporting artistic critical interventions in urban space [197, 110, 109, 194]. Niemeyer's interactive urban lighting acknowledges passerby with colorful lights that follow them at night [251]. The Heart Sounds Bench builds on these explorations, looking particularly at the affective experience of affirmation.

Perhaps partly due to their affirmative potential, benches have been explored by designers and artists. Rogers' bold yellow benches provide comfortable seating [287]. Others design benches to encourage social interaction between strangers [64, 193, 147]. Grasso et al.'s interactive bench supports community emotional awareness [131]. Johnson's film documents the social life of benches [188]. Like other explorations, the Heart Sounds Bench has the potential to foster interactions between co-present strangers, because it can amplify the heart sounds of two sitters simultaneously. While this invitation exists, we also recognize that many might avoid sharing a bench with a stranger due to fear of harassment or violence. So, additionally, the Heart Sounds Bench records and later plays back heart sounds, suggesting a lingering presence to future sitters.

Somaesthetic design fosters directing attention inward for bodily awareness, often in a session set apart from daily life [163]. Somaesthetic design can leverage biosensors to help attune people to their bodies [302, 244, 162, 161]. Often a somatic connoisseur helps participants unpack and articulate their experiences after a session [301]. The Heart Sounds Bench in some ways builds on these practices, amplifying heart sounds to attune people to their own bodies. Yet, public space is immersed in daily life rather than separate from it, and lacks the guidance of a somatic connoisseur.

Listening can invite attention that we wanted to leverage to attune people to their bodies. Public sound art explores playful, critical, and expressive interactions in urban space. This includes mapping sensor input to audio output [111], collecting and looping snippets with a glove-based electret microphone [325], engaging cultural heritages through sound [105, 121, 120], or street art [133]. A variety of networked instruments support multi-person musical collaboration, (e.g., Ten-Hand Piano [23]). Transition Soundings is an interactive public sound installation built into a bus stop [32]. While these projects often explore social interactions or multisensory explorations with sound, the Heart Sounds Bench focuses on exploring the direct *sounds* of the heart, rather musical phrasings or the beats per minute typically used in self-tracking.

Biosensing is used to influence sound. Dancers wear biosensors on their bodies that translate their movements, heartrate, or other measures into parameters that are used to generate sound or influence the improvisation of musicians. For example, Jang outfitted a pair of dancers with strangely shaped bone-like back-worn sensors; the dancers gradually accept and explore one another's atypically shaped bodies [182, 181]. MacCallum and Naccarato explore issues of agency and control using dancers' heart rate to influence improvisation [244, 218]. Works such as these indicate the rich expressive possibilities of connecting bodies and sound. Our focus was to engage this expressive potential in a much more everyday setting with participants who may or may not have specialized movement or music training.

Oliveros' Heart Chant was a key inspiration for leveraging sound as a medium. In this participatory performance, people stand in a circle and sing long tones, with one hand on their chest and the other on the back of the adjacent person [257, 259]. The experience is slightly vulnerable because this close contact is atypical of the large personal space maintained in the U.S., and singing feels embarrassing for some. Through this structured, shared vulnerability emerges a feeling of affirmation as each person's voice and body are accepted as part of the co-performance.

Biosensing can influence interpersonal interactions. Heart rate has been engaged for physical games [219, 352], board games [103], gauging connectedness in conferencing systems [164], augmented mobile chat [144], or even broadcasting heart rate to online social networks [59]. Howell et al. found that an ambiguous clothing-based display of skin conductance had the potential to foster supportive social emotional reflection, but also to aggravate insecurities [168]. Eriksson et al. explored ritualized tangible representations of heartbeat for bereavement [88]. Slovák et al. found that remote heart rate sharing between close pairs in daily life could foster a sense of connection [321]. ReactionBot automatically adds emoji to messages based on facial expressions [213], with the potential to prompt emotional reflection. Snyder et al. probed experiences and interpretations around a color-changing light composite display of a pair's skin conductance [324]. Engaging the expressive potential of sound, our design presents live unfiltered heart sounds for collocated strangers, not colors, metrics, haptics or visualizations as others do.

3.4 Designing the Heart Sounds Bench

The Heart Sounds Bench is a reflective design [310] intended to provoke reflection in both users and us as designers. A reflective design strategy, engaging the bench as a probe [113, 36, 173] helps find experiential possibilities that may emerge with urban sensing. Probes can act as elicitation techniques by fostering alternative experiences with technology [36]. A reflective design output, these experiences and reflections generate concepts and directions for further research. Our approach draws from speculative and critical design that seek to challenge assumptions and spark discussion with provocative artifacts [82, 277, 290], and framings of data as enmeshed in social practices (e.g., [286]).

3.4.1 Interaction Design

The design provides a place to sit and rest, recognizing and supporting the needs of passerby like other benches. Yet, its vibrant color and unusual shape both invite the eye to notice it from afar while hinting at an unusual function.

Bench-sitters' live unfiltered heart sounds are amplified and played from speakers in the bench, inviting a quiet moment of listening and bodily awareness. We refer to 'heart sounds' rather than 'heartbeats' to call attention to the continuous *sounds* of the heart and body, rather than only the discrete beats per minute. Although not technologically novel, we chose to use stethoscopes instead of chair [14], phone [224], non-contact [279], or PPG heart sensors, because stethoscopes give rich heart *sounds* that provide a sense of unmediated immediacy. Furthermore, the familiar form factor of the stethoscope can help favor informed active consent in future public use. People readily understood the sensor and opted-in by holding it.

With one stethoscope at each arm of the bench, two people can listen to their heart sounds simultaneously. The bench can also record heart sounds and later play these back to future sitters. We wanted to explore how listening to heart sounds could foster a sense of people affirming themselves and others. With two people on the bench simultaneously, we could explore the potential for affirming a co-present other. We relate this to moments of city living when we acknowledge the co-presence of a stranger, such as while sharing space on the bus. With the prerecorded playback, we could probe the potential for affirming an absent other. We related this to moments in city living when we acknowledge the presence of those who came before based on the traces they left behind, such as tags or stickers. This prerecorded audio also included a voice stating the date, time, and weather. The date and time were included to indicate that these heart sounds came from the past. The weather was included to give some sense of context and invite participants to reflect on the environment around the bench. While no voice is neutral, we asked a professional therapist to read these details in a calm tone, because we felt his voice was particularly well tailored for prompting open-ended emotional reflection.

3.4.2 System Design

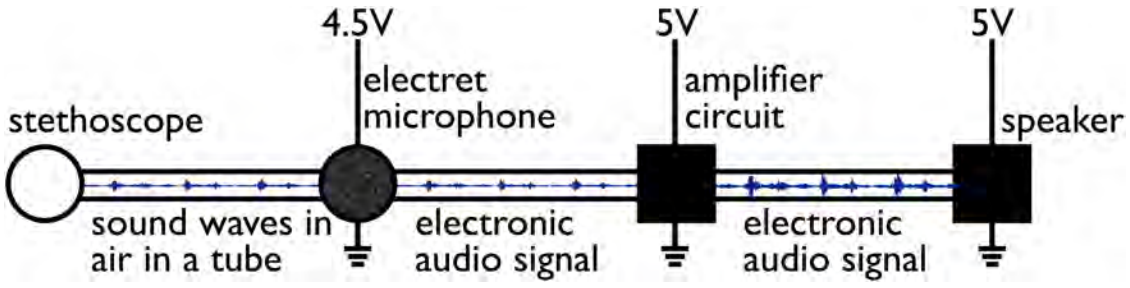

Figure 3.2: System diagram for each side of the bench.

At each side of the bench is a listening piece, an amplifier circuit, and a speaker. The listening piece is a modified stethoscope affixed to an electret microphone [177]. This connects to an audio amplifier [178]. The amplifier circuit connects to a speaker [140, 185]. The sounds from each stethoscope play through speakers on the corresponding side of the bench. The live real-time amplification of heart sounds is instantly responsive and recognizable as heart sounds. In addition to heart sounds, the stethoscopes are essentially a general-purpose microphone that also pick up rustling, tapping, and the vibration of people's bodies as they speak. The electret microphone receives a quiet steady DC voltage from 3 AA batteries in series. The amplifier circuit is powered by 5V DC from a wall adapter. Blankets folded on the arms of the bench reduce the medical feel of the stethoscopes and provide sound dampening between stethoscope and speaker to prevent feedback.

While bench-sitters' heart sounds were live via fully functional electronics, we used a Wizard of Oz technique to play back the heart sounds of a previous sitter. From a mobile phone connected to a speaker [11], we played back the same prerecorded heart sound for all participants. This enabled us to probe participant experiences of hearing the playback and speculating on how they would feel about being recorded. Future work on the Heart Sounds Bench can implement recording and playback as well as designing an intuitive way to choose when to record and when to play back.

3.5 Study

Our goal with this study was to probe affective experiences of sensing and affirmation. For this first trial, we wanted to give a sense of public space and unstructured time experiencing the design, while ensuring ability to focus on heart sounds without distraction. So, although we are interested in public space with all its vibrancy and risk, for this first stage of the project we chose to study participants' experiences with the bench indoors. Conducting the study inside in a private room enabled us to more deeply probe how people interpreted and reacted to the design. The private setting ensured that audio and video recording did not capture any unsuspecting passerby, an important ethical consideration for us.

The study setting provides some sense of public space. On the bench, participants sat less than 1m away from a crowded pedestrian thoroughfare via large corner ground level windows through which squirrels and birds sometimes enter. Yet, they also had space to clearly hear their heart sounds. So, the room evokes a sense of having a quiet secluded corner viewing a larger outdoor space.

Participants came in pairs to probe how they experienced hearing their own heart sounds, those of a co-present other, and the prerecorded playback of an unseen other. After a few introductory questions by the researcher that began to build rapport between participants, the researcher left participants sitting on the bench alone together in the room for about 20 minutes. About halfway, the researcher played the prerecorded heart sounds of the absent other. Returning, the researcher conducted a semi-structured interview with the pair about their experiences and interpretations with the heart sounds for about 45-60

minutes. Recruitment was conducted over organizational and public-facing mailing lists and communication platforms. Audio and video recordings of participants were transcribed for analysis and coded to find emergent themes [52]. Participants are referred to by pseudonym.

Future work will study the system in public. The indoor study focused on in-depth emotional reflection 20 minutes of experiencing the bench without distraction and 45-60 minutes of emotional reflection afterward. In public the duration of participation and depth of reflection will likely be less, while the larger N study of public behavior can surface trends and unexpected uses.

3.6 Findings

Figure 3.3: Participants often sat silently together listening to their heart sounds, or reflected on the experience together.

Nineteen people participated (9 women, 10 men, mid twenties to mid thirties). Pairs were strangers, coworkers, or friends. Three participated alone due to scheduling issues. Most participants alternated between quietly listening to their heart sounds and chatting with one another about the experience. Sometimes they took turns listening to their heart sounds one at a time. In describing their experiences, participants often cited nearby elements of public space such as passerby, trees, squirrels, sounds, and the sunset, indicating that the study setting did evoke some sense of public space for participants.

3.6.1 Life Energy

Several participants described feeling connected to a life energy or sense of being alive. Some focused on their own vitality, others on a sense of connection within the pair, while a few felt a sense of connection including themselves, others, and the environment.

Sally connected hearing her own and others' heartbeats to a sense of life pulsing through herself and others.

> *"**It's a nice reminder of what's pulsing through everybody**. It's nice to be able to hear somebody else's heartbeat, just makes you that much more aware*

> *of that you're around somebody else who's living and breathing." Later she added, "It just seems really sweet to me to hear that,* ***to hear somebody else's, the life pulsing through them****."*

She described first a growing awareness of her own body, then expanding her attention outward to an appreciation of the lives of others. While much HCI work with heart rate and the smart city focuses on fitness, participants' reflections on appreciating and feeling connected to the lives of others point to a distinct design opportunity.

In imagining public use of the bench in the future, Charlie envisioned feeling more involved in the moment, the environment, and the world.

> *"If it's outdoors, I think it would make me feel more involved in the moment, like involved with the environment. When I'm listening to my heart sounds, watching the gate [gestures to scenery through the window], it would make me feel more involved with the environment... Listening to the sound is like,* ***there's many metaphors about your heartbeat beating with the same thing around the world****... like* ***the heart beating with the world****... which makes me feel involved with this world, and more enjoy at that moment."*

He described feeling present in the moment with his own heart beating in connection with the world. This sense of presence and connection suggests an affective experience that could be explored in designing for the smart city.

Jay built on his study partner Charlie's sense of involvement and reflected on a sense of connection with nature.

> *"****This seemed like I was more connected****, even if it was just in this room, I feel* ***it seemed like it was extending outside of myself****... I [felt connected to] the world around me. And that something so internal and personal could have an effect on others around me. Even though it was seemingly just you [gestures to his study partner], but perhaps maybe someone could hear it outside [through the windows], or I guess just in the way that [pause]* ***trees just moving and we can kind of tell other things in the earth are doing or making other sounds or other sensory messages. It seemed like I was doing that too... The fact that we're embedded within nature*** *and doing this [the Heart Sounds Bench] gave it kind of like an outside perspective of* ***seeing myself as one and the same as other beings or other objects*** *that also do that...* ***that also show their signs of life****."*

Jay traces a connection between his heartbeat and the lives of other people, trees, or even objects.

John focused more on a sense of connection with the other person on the bench. Reflecting on his experiences with the Heart Sounds Bench and imagining its future use in public space, described the experience of hearing a co-present other's heart sounds:

> *"Hearing another person's heartbeat feels like, not something that's super revealing but at the same time it's something that's very personal and inherent to who you are.* ***This is like the force of your life*** *or something."*

Like others, John draws a connection between heart sounds and life energy. Again, distinct from a prevalent focus on physical fitness, this sense of 'life force' was a remarkable affective experience for many participants.

Odile focused more on her own sense of being alive. *"I think the rhythm of my heart being so steady reminds me... that I am alive."* Odile went on to describe how this reminder helped calm her and make her feel like she could manage her stress. Again, the association between heart sounds and vitality came up for many participants.

The connection between heart sounds and being alive makes sense given that the heart is essential to our biological life. Though this is a basic fact, the affective dimensions of being reminded of this seemed to be a remarkable experience for many participants. Feeling more connected to oneself or one's study partner seems to have been meaningful and enjoyable for several participants. While heart rate sharing has been previously found to foster a sense of connection [321], what surprised us were the multiple instances where participants described a broader sense of connection extending to many other people, the environment, the world, even trees and objects. We speculate that what might have contributed to this sense of broader connection is the externalization of the heart sounds through the speakers, as well as the ground level view out the windows onto trees, sky, and passerby. The Heart Sounds Bench centers the individual by helping them attune to their own heart sounds, expands this to a dyad, and then further amplifies this awareness through the broader environment.

In contrast to smart city sensing technologies that construct people in terms of economic value, safety threat level, or other models and categories, our design called attention to a shared embodied experience of being alive. Participants seemed to find this sense of shared life energy to be a meaningful and compelling experience, pointing to future opportunities for designs exploring this.

3.6.2 Vulnerability of Life

The stethoscope reminded several participants of prior experiences with stethoscopes such as doctor or hospital visits. For example, Sheena said she was reminded of medical emergencies when stethoscopes have been used on her. She arrived at the study just after a frightening experience on the subway. The Heart Sounds Bench seems to have aggravated her stress by bringing back bad memories.

Jay also related the heart sounds to worrying about 'mortality', as he put it. Speculating future public uses of the bench, Jay imagined worrying about the deteriorating health of older relatives.

> *"As much as this can be an intimate experience, it could also a disturbing or scary experience because... hearing the heart sounds of someone else, or even*

> *your own... Say I were to go with my father or an older member of my family, and essentially we've walked or something, and I hear their heart beating really fast. That can be a really quick reminder of their mortality, or in many ways engaging with someone else's health in a way that might be kind of frightening, and it might change the relationship between you and that person."*

An unexpectedly fast heartbeat could indicate frightening health concerns in a loved one. Heart sounds served not only as a reminder of being alive, but also as a reminder of the vulnerability of life. This seems related to both the medical associations of the stethoscope and the heart's essential cardiovascular function.

3.6.3 Intimacy

Several participants described hearing their study partner's heart sounds as intimate. In describing listening to her study partner's heart sounds, Amanda said, ***"It's weirdly intimate, like I don't know this person but I've heard an organ that keeps them alive."*** Others were reminded of intimate moments with a romantic partner, with an ear to their chest listening to their heart sounds. The stethoscope's live unfiltered heart sounds are extremely similar to what one hears by pressing an ear to another's chest. Some products for long distance couples sonify heart rate (e.g., [237]), and Slovák et al. found remote heart rate sharing to foster connection [321]. Yet, the unique richness of live unfiltered heart *sounds* rather than heart rate sonification could be more widely leveraged in designs.

3.6.4 Anonymity

3.6.4.1 Co-present study partner

Listening to the heart sounds of the co-present study partner seemed to feel both intimate and anonymous. While participants often expressed that it felt special or unique to hear such an essential sound from another person that they would not normally hear, at the same time they sometimes reflected on how this sound could also feel anonymous. Amanda, who described hearing her study partner's heart sounds as "weirdly intimate", also reflected, ***"I wouldn't know one heartbeat from another or from my own."*** Her study partner Nathan added, *"I sort of felt similarly that, any heartbeat, I didn't have like a clear distinction about which one was mine or what it meant about someone else...* ***kind of anonymous."*** Some participants speculated they would not be able to identify their own heart sounds or their study partner's from a selection.

3.6.4.2 Absent other

In addition to the live unfiltered heart sounds of study participants, we included playback of the heart sounds of an 'absent other' who previously sat on the bench. The playback began with a voice stating the time, date, and weather. Listening to the absent other's

heart sounds was mostly experienced as anonymous and not intimate. Kusha reflected, ***"With the heart sounds that were prerecorded, I was trying to build a story and imagine a person."*** Her study partner John added, *"I was much more interested in hearing [Kusha's]... I think I could have felt more connected to [the absent other's playback] if instead of just the date and the time there was some explanation of what the person was going to be doing..."* Jay described it as *"disembodied"*. Participants often wondered what the absent other was feeling or doing, but struggled to build a narrative. They linked this lack of context to not feeling connected with the heart sounds of the absent other. Nathan summarized, ***"I didn't know anything about that person or their context. It just seemed like an anonymous recording."***

Participants expressed a sense of anonymity, saying they could not know much about a person based on their heart sounds alone. This anonymity often impeded connection. While the heart sounds themselves were experienced as similar across people, through this inability to know, participants implicitly acknowledged that others' experiences could be quite different from their own. It may be a tricky interplay between connection and anonymity, but to avoid universalizing designs and respect difference, we see it as valuable that participants acknowledged how different the absent other's experience could be.

We had hoped the playback of an absent other's heart sounds could prompt curiosity or a sense of connection, but clearly more design work is needed here. The prerecorded heart sounds playback included some minimal contextual details of time, date, and weather, but this was evidently not enough context. Also, our choice of a less emotionally expressive voice gave less context. Finally, the experience could play out differently in public space.

3.6.5 Calming

Many participants described the experience as calming. Odile used the word 'calm' repeatedly to describe her experience. Kusha said she began the study feeling stressed, but then the heart sounds help her calm down. Participants also linked their experience of calm with seeing trees or the sunset through the window, and often suggested placing the bench in a park to enhance its calming potential. Although the researcher stated they were free to take breaks, chat, and put down the stethoscope, many participants sat quietly listening to their heartbeats. For many this seemed to be a calming experience.

3.6.6 Other Themes

Estelle, an electroacoustic musician, explored the Heart Sounds Bench as a feedback instrument. Many electroacoustic instruments operate on this principle: A feedback instrument relies on feeding the output (in our case, speakers) back into the input (stethoscope), often with amplification increasing intensity. The feedback loop is mediated by physical materials, so subtle adjustments (in location of stethoscope on bench) create nuanced expressive sounds. She described it in terms of cybernetics and how tools or musical instruments can serve as extensions of the body. Some participants playfully experimented with the system, tapping

on the stethoscope or using it to amplify their voice. Energetically amplifying not only the heart but also whatever the stethoscope encounters may have contributed to the sense of shared life energy by fostering attentive listening to unexpected sounds of both humans and materials.

While most participants had trouble distinguishing between their own and their study partner's heart sounds when both were amplified simultaneously, unsurprisingly those with musical backgrounds could readily distinguish due to the sound localization. Future work could include visual aids to help participants distinguish. Yet, aesthetically we also think it is interesting to have the heart sounds of two people blend together without the distraction of a visual display.

Almost all participants spent a few moments finding the right spot on their chest to listen to their heart sounds. For a few, this took several minutes and was frustrating. Yet, this searching could also contribute to growing one's bodily awareness, which was seen as valuable by some.

A few participants related the bench to meditation. Kusha described how she had been focusing on her heart during meditation, and the heart sounds helped her with that. Alan said he would want the system in his home so he could use it for daily meditation. Rohit said he has been trying to meditate more often and felt the system could be a helpful aid. Perhaps along a similar vein, many participants described the experience as calming, contemplative, centering, grounding, or talked about being in the moment.

When asked how they would feel about their own heart sounds being recorded and played back later after they were gone, almost all participants wondered whether heart sounds could be individually identifiable, citing this as a key consideration. They also expressed concerns about whether heart sounds in combination with other data such as video surveillance could become individually identifiable, or reveal unexpected insights about them. Deploying the bench in public space, it is essential to consider how the bench could potentially become an unwanted form of surveillance.

3.7 Elaborating Life-Affirmation

Synthesizing our findings and design intent, we elaborate on the concept of *life-affirmation* in terms of *recognition*, *connection*, and *opacity*. In accordance with designerly modes of knowledge production [115], this is not intended as a generalizable definition. Rather, by elaborating one particular conception situated around a particular design, we hope to open a path for others to continue exploring this concept. We do not claim that our bench currently supports life-affirmation in public because this is as yet untested; rather we contribute life-affirmation as a promising direction for future design exploration in public space.

The Heart Sounds Bench seems to have fostered a particular kind of affirmation we call *life-affirmation*. This life-affirmation can spread outward from self, to study partner, to other people and the natural environment. Participants described feeling reminded that they are alive, and feeling more drawn into themselves and connected with their body. They

described being reminded that their study partner is living and breathing too, and the strange intimacy of hearing their heart sounds. They described feeling more connected to "what's pulsing through everyone" (Sally), "the heart beating with the world" (Charlie), and "seeing myself as one and the same as other beings or other objects that ... show their signs of life" (Jay). There is a sense of shared vitality, that multiple beings are partaking in a similar process of living. Though at some level this is an obvious observation, the affirmation of this shared vitality creates a particular feeling participants found remarkable. We call this *life-affirmation*.

Revisiting our initial critique of smart city narratives, we see life-affirmation as a key element often neglected by an emphasis on efficiency, fitness, and safety. Being in public can provide a joyful sense of shared vitality, of seeing others and being seen. There is a unique pleasure to being in the midst of the hustle and bustle of a crowded, chaotic city street. This affective experience is an important aspect of city living that should not be overlooked in the push for efficiency, fitness, and safety.

The life-affirmation experienced with the Heart Sounds Bench seems to stem from sitting outside the action rather than being immersed in it. For the study, participants sat inside looking through ground level windows at a campus thoroughfare crowded with people streaming by. They often gazed through the windows or gestured toward them during the interview. Participants often suggested putting the bench in a quiet area outdoors with a view of natural scenery. Taking a step back from the action seemed to facilitate centering on oneself, before expanding that sense of connection outward to other people and the environment.

Life-affirmation is a conceptual tool that helps address calls to build connection while respectfully engaging difference (e.g., [199]). We elaborate three key aspects of life-affirmation - recognition, connection, and opacity - that contribute to its conceptual potential.

3.7.1 Recognition

Much work 'recognizes' normative categories of a person, flattening difference into categories. Instead, we call for recognizing others' existence and feelings as valid. Life-affirmation involves a kind of *recognition* distinct from the recognition typically sought by biosensing technologies, which often seek to recognize discrete emotional categories (e.g., [153, 297, 275, 38]), or identify or authenticate an individual based on biosensory data they give off (e.g., [151, 231, 60, 61, 320, 169, 108, 230]).

In contrast to that kind of recognition, participants described being 'reminded' or being 'more aware' of something they already knew: that they and others are alive. Recognizing this is technically trivial, but seemed to be a meaningful affective experience for participants. The biosensory data people give off, or "the signs of life" (Jay) that humans and plants alike give off, can contribute to life-affirmation. San Leandro Lights are anothe example of urban sensing that supports this notion of recognition: These street lamps create beautiful pools of light that follow pedestrians using sensors [251]. There is an opportunity for smart city biosensing to design for recognition. This recognition need not take the form of specific data-

driven categories; rather, a focus on simply recognizing or acknowledging people's existence, feelings, and experiences could support life-affirmation.

3.7.2 Connection

Connection is not unique to our work. Yet, life-affirmation offers a unique way to build connection between strangers while respecting difference. Recognizing this shared vitality led to a greater sense of connection for many participants. Slovák et al. also found heart rate sharing to foster social connection [321]. There, a sense of connection emerged within pairs of colleagues and cohabitant couples. In our study, participants described feeling more connected to their study partner as well as to other people, the environment, or the world more broadly. This seemed to stem from a sense of going sharing a similar life process as others, providing a sense of commonality. As another example, Hein's Modified Social Benches encourage social interaction between strangers [147]. Smart city sensing technologies tend to frame people as atomized individuals [294, 167, 250]. Connection and life-affirmation point to an opportunity for biosensing designs to emphasize social interconnection, as some work with self-tracking has already begun to do (e.g., [245]).

3.7.3 Opacity

While we celebrate the sense of connection of feeling "one and the same as other beings or other objects" (Jay), it is essential to recognize not only our commonality with others but also our difference. Our adaptation of Glissant's notion of *opacity* can help respect difference and support other ways of knowing. Opacity resists a tendency to build connection by understanding the 'other' via reducing them to hegemonic categories. A contemporary of Fanon, Glissant was a postcolonial philosopher and poet who analyzed Caribbean Creole's complex relationship with the language of the colonizer. In his essay 'For Opacity', Glissant argues for the *right to opacity* as a way of acknowledging difference while avoiding the reductive problem of transparency [124].

> "If we examine the process of 'understanding' people and ideas from the perspective of Western thought, we discover that its basis is this requirement for transparency. In order to understand and thus accept you, I have to measure your solidity with the ideal scale providing me with grounds to make comparisons and, perhaps, judgments. I have to reduce... I relate it to my norm. I admit you to existence, within my system." [124, p.189-190].

Understanding is often approached via transparency, which requires reducing the other to predefined terms or categories. This route to recognition affirms only a reduced representation of the other in terms of hegemonic norms. Glissant further problematizes understanding (*comprendre*) as taking or appropriating and proposes gives-on-and-with (*donner-avec*) as an alternative [125], but here we focus on opacity.

For smart city sensing, transparency is often valued as a way to build trust in the smart city [104]. Perhaps if we could know more about each other, we could fear each other less and affirm each other more. Yet, smart city sensing is a particular way of knowing that privileges particular norms and categories. We should not have to make ourselves legible in terms of hegemonic data-driven categories in order to be affirmed. In that translation too much is lost or reduced. Opacity resists transparency.

Opacity is distinct from privacy. While "privacy is an essentially contested concept" [243], its conceptualization often foregrounds appropriate information flows or the right to not be bothered [345, 307, 253]. In contrast, Opacity foregrounds ways of knowing, problematizing the production of 'information' in terms of predefined categories. We call for smart city technologies to more critically and reflexively engage the knowledge politics of their sensing and inference.

Opacity is related to, but distinct from, *ambiguity of information* [116]. Since Gaver et al.'s foundational paper on ambiguity, many information displays have leveraged ambiguity to prompt open-ended reflection. A display's lack of clarity can prompt users to 'supplement' this with their own contextual knowledge for interpretation. We see ambiguity as a valuable approach, and indeed much of our prior work engages ambiguity in data display [70, 166, 168]. Opacity similarly presents the user with a lack of clarity, but for a different purpose of acknowledging the limitations of our own understanding. To those not trained in auscultation, heart sounds are somewhat opaque and users did not seem to form specific interpretations of this data.

A comparative example is Affector, which shows abstract ambient ambiguous video feed of a coworker in their office. Affector is framed around ambiguity. As described by the designers, "In order to support reflection on both emotion and the role technology plays in it, Affector is deliberately designed to communicate emotion obliquely and enigmatically. It does not provide easy answers to how someone feels today; instead, it provides indirect evidence which users must interpret with reference to the data supplied by the system, as well as background knowledge of their friendship and contextual cues" [311, p. 351]. The ambiguity prompts users to supplement the data with their own contextual knowledge to form interpretations. Yet, the intended users likely can only guess at how their coworker feels. The 'oblique', 'enigmatic', or opaque design foregrounds the limits of our own ability to know others.

Data-driven insight is valorized in our current moment, but opacity argues for acknowledging the limitations of our knowledge of others. This joins our past work calling for humility in knowledge claims made with emotional biosensing [167] as well as related work calling for contestability in knowledge claims made with emotional biosnsing [156, 155].

Taken together, recognition, connection, and opacity contribute to life-affirmation, forming a novel conceptual tool to help reframe sensing's role in urban life, from smart cities to social cities. We reworked the concept of recognition away from recognizing data-driven categories toward recognizing others' lives, experiences, and feelings. This centers the affective experience of recognition rather than data-driven insight or predictive potential. We describe a sense of connection that can emanate outward from self-attunement, to a

co-present other, to many others across the world and the natural environment. While celebrating this sense of shared vitality and commonality, we also introduce opacity as a way of respecting difference. Opacity reminds us that we cannot know others entirely, and holds space for different ways of knowing that do not neatly translate.

3.8 Limitations

Conducting the study inside in a private room, though it enabled us to more deeply probe participants' experiences, hindered our ability to probe affective experiences of being in public. Most participants came from a similar age group and educational background, limiting our ability to engage questions of otherization woven throughout our argument. In future work deploying the bench in public, we hope to explore interactions where people might feel more 'other' to one another. Yet in public, two strangers sitting on the bench simultaneously listening to their heart sounds seems unlikely, given legitimate concerns around harassment. Future design iterations will continue to explore how the heart sounds of an absent other can be more evocative and engaging. Finally, life-affirmation does not solve problems. It does not address important issues such as sustainability or violent crime. Yet, it is still worthwhile to explore how urban sensing will shape affective experiences of city living.

3.9 Future Design Directions

Future design directions should continue to explore affective experiences with urban sensing, embracing a wide variety of feelings and desires. As anthropologist/geographer Harvey [143] puts it,

> "The question of what kind of city we want cannot be divorced from that of what kind of social ties, relationship to nature, lifestyles, technologies and aesthetic values we desire."

Rather than trying to converge on a common set of social ties, lifestyles, etc., urban sensing should explore a multiplicity of desires for vibrant social cities. These efforts at inclusivity and diversity have already begun (e.g., [350, 261, 227]). We contribute *life-affirmation* as one feeling to explore, elaborating this in terms of *recognition*, *connection*, and *opacity* for celebrating and respecting both commonality and difference.

3.10 Conclusions

We contribute the design of the Heart Sounds Bench to explore an often-overlooked potential for affirmation in city living. Our key contribution is life-affirmation as a conceptual tool for reworking smart city narratives. We do not claim that our design currently supports

this in public (as yet untested); rather we contribute life-affirmation as a promising direction for future design exploration in public space. Nineteen participants' insightful articulations of their experiences help us elaborate *life-affirmation* in terms of *recognition*, *connection*, and *opacity*. Recognizing others' lives, feeling connected, and embracing difference with opacity can be a meaningful affective experience of life-affirmation. Future designs with public urban biosensing technologies should explore a wide variety of affective experiences and a multiplicity of desires.

Chapter 4

Provocations for Future Work

"Our feelings and the honest exploration of them become sanctuaries and spawning grounds for the most radical and daring of ideas."–Lorde 1977 [214]

This dissertation explores ways in which biosensing is on the rise in daily life, and how biosensing technologies produce data about people's bodies, behaviors, thoughts, and feelings. With sensors embedded in clothing, wearable accessories, pills, walls, furniture, and mobile phones, this amassing data is analyzed to produce insights about how individuals can be more productive, healthier, safer, etc. Of course there is great positive potential here, and data science has proven itself to be one of the powerful epistemological approaches of the present moment. Yet, this dissertation critiques data science rhetoric.

Data science is one powerful way of knowing, yet it is not the only way of knowing. Sometimes claims of what data science can accomplish overreach. No one epistemological frame is the panacea for complex sociotechnical issues. As biosensory data is increasingly enrolled to make sense of how to live 'well', it would be too limited to use only data science as a way of knowing with this data. People have been grappling with questions of how they want to live, individually and collectively, for a long time. What does it mean to be productive, happy, or healthy? Whose values are those?

I call for more diverse approaches to meaning-making with emotional biosensing. My designs explore tactics for fostering emotional, social, and embodied ways of knowing with biosensory data.

This dissertation surfaces opportunities to critique, rework, and broaden emotional biosensing technology and the data produced by it, to explore different approaches to emotional knowing with data. This dissertation contributes conceptual shifts and critical alternative design tactics for approaching emotional biosensing differently. This dissertation marks a beginning, not an end. It offers questions and provocations for future work, not summative conclusions.

4.1 Sociomaterial Performativity

Sociomaterial performativity emphasizes material, embodied, and socioculturally situated qualities of data. Biosensory data has material qualities–it is often produced by physical and electrical responses of sensors *intra-acting* [22] with people's bodies and the environment. Data has social aspects, from the many people doing data collection and analysis to the social impacts of resulting insights. Data has performative aspects: Whenever people engage it, data becomes enrolled in ongoing social enactments of sense-making. Data insights are not only objective, but also subjective: They present a view from somewhere [136], from the many people and materials entangled in their creation and proliferation.

Section 1.2.2 highlights a conceptual shift *from digital to material data representations*. Emotion is embodied and situated in particular social and cultural contexts. Physical artifacts are laden with social and cultural meanings that designers can leverage to craft particular avenues for open-ended interpretation. Engaging materials in data representation invites situated embodied interpretation. Rather than treading data as something immaterial to be represented, attending to the material quality of data sensing and display opens new possibilities for interpretation and experience.

Continuing these shifts, Section 1.2.3 synthesizes a conceptual shift *from representation to performativity*. Treating sensing and display not as passive representations but as active ongoing performances and responses offers opportunities for social meaning making and experiential, expressive displays. This helps emotional biosensing designs work with emotion as embodied, dynamic, and fluid rather than abstract, static, discrete categories. Emotional biosensing designs do not represent emotion, they respond to and influence ongoing performances of emotion.

In a performative move, Section 1.2.4 presents a shift *from affect-as-information to affect-as-interaction* (coined by Boehner et al. [36]) as a way of foregrounding social performativity with emotional biosensing. *Affect-as-information* enrolls sensors, data, and algorithms with the goal of recognizing discrete emotional categories in individuals, where these categories are often claimed to transcend culture and context. In contrast, *affect-as-interaction* frames emotion as emergent from culture, context, and social interaction, and enrolls sensors, data, and algorithms to support human sensemaking of emotion.

Continuing performativity into new materialist theory, Section 1.2.5 applies Barad's *agential realism* [22] to emotional biosensing. This calls for a shift from thinking about interaction between predefined separate entitities toward intra-action of entangled ongoing sociomaterial phenomena. This deconstructs typical notions of sensor, data, display, and humans, reconceptualizing them as an ongoing series of material transformations. Agential realism centers phenomena (which are performed) rather than things (which are represented). Agential realism opens new pathways for design research with emotional biosensing. It can help attend to how materials shape meaning-making and to prompt reflexivity about which materials, roles, people, or categories are treated as separate in the first place. Attending to our material interconnectedness presents an ethical call to be accountable to material effects on others.

The Hint color-changing garments present abstract t-shirt displays of skin conductance. Pairs of friends wearing the shirts associated the display with a variety of emotions, such as joy or embarrassment. The display's ambiguity was valued as a prompt for reflection but also hindered participants' attempts to feel like the display could validate their feelings. Participants sought to use their skin conductance display to help them enact social performances, such as showing emotional engagement with others. This project suggests framing *biosignals as social cues*.

The Ripple color-changing garments present a refined abstract shirt display of skin conductance that pairs of friends wore throughout the many varied contexts of their daily lives. While in some cases the ambiguous display served to prompt moments of social reflection and social emotional support, in other instances the display seemed to wield a data-driven authority that could aggravate insecurities. Despite the display's multifaceted ambiguity, it still had the potential to redefine emotion in its own terms. The project calls for attention to how technologies mediate perception, shape what counts as real or valuable, and operate within broader societal biopolitical discourses of health and authority. This project highlights how biosensing technologies do not passively 'detect' emotion, instead biosensing technologies actively shift our conception of emotion itself and become embroiled in questions of how or what we *should* feel or be.

My work on color-changing fabric (Chapter 2) contributes design explorations of these conceptual shifts and resultant critical alternative design tactics for emotional biosensing. Engaging Section 1.2.2 on material data representations, these designs leverage material qualities of thermochromic pigments and fabric to invite social embodied sensemaking with emotional biosensory data. Presenting slow subtle color changind displays on clothing that participants wore and interpreted throughout their daily lives explores performativity with data (Section 1.2.3). The designs' abstract outward-facing data displays explore *affect-as-interaction* (Section 1.2.4) by situating emotional meaning as emergent from social interaction. Inspired by *agential realism* (Section 1.2.5), the design foregrounds the entanglement of bodily sweat, electrical impulses, heat, color change, and fabric threads.

In addition to exploring these conceptual shifts through design, these projects contribute particular critical alternative design tactics for emotional biosensing designs. (1) Instead of displaying emotional biosensory data on a light-emitting fast-switching screen, these projects display emotional biosensory data with the slow subtle changes of thermochromic fabric. (2) Instead of emphasizing precision, these designs leverage ambiguity to invite open-ended interpretation. (3) Instead of an individual data display, the outward-facing nature of the clothing-based displays is socially available and invites social interpretation. (4) Instead of treating data as digital and extracted from context, the designs treat data as material and entangled with ongoing social and material phenomena. (5) Instead of seeking to detect and categorize emotion, the designs invite open-ended embodied social emotional reflection and mediate perception of emtion.

This work invites designers and computer scientists working with biosensory data to more broadly consider many social and material factors that influence data insights. Considerations of social and material factors have the potential to enrich data insights with contextual

nuance. They also diversify the kinds of insights that are considered valid with biosensory data to include emotional, embodied, and social ways of knowing. This dissertation began exploring, and future work should continue exploring, ***questions around balancing ambiguity with interpretability, supporting situated social performances, and supporting more diverse ways of knowing with biosensory data***.

4.2 Affirmative Biopolitics

Section 1.2.6 discusses how, as biosensory data is enrolled to address questions of how to live 'well', this raises biopolitical issues of who or what is granted the authority to produce knowledge about health and life [288, 284]. Data-driven categorization is a common approach to knowledge production with biosensory data, yet these categories are not neutral. They can embed ideas about who or what is ab/normal, un/healthy, un/safe, or un/productive. Categorization creates 'others' [41], and such relational markers of difference can be closely linked to oppression. Affirmative biopolitics calls for embracing a diversity of voices and ways of knowing with emotional biosensing. This section calls for designing emotional biosensing designs with intentionally reduced authority to support contestability [156] and support many ways of knowing with emotional biosensory data. This chapter also calls on emotional biosensing design to shift away from valuing only 'positive' emotions toward leveraging 'negative' affect as a resource for building community, support, and collective action.

Section 1.2.7 continues the shift from locating emotion in individuals to attuning to broader pre-personal flows of emotion through society. It also invites a shift from emotion, which is in some sense framed as a response emergent from context, to an emphasis on desire as a motivating drive. Instead of considering emotion as arising in a particular moment, this invites designers working with emotional biosensing to trace flows of desire motivating emotional trajectories. These shifts call for designers to critically reflect on the desires that particular designs legitmize and on the societal structures that make those desires seem appropriate.

Exploring conceptual shifts from Sections 1.2.6 and 1.2.7 while continuing to integrate the aforementioned conceptual shifts from Sections 1.2.2-1.2.5, the Heart Sounds Bench (Chapter 3) explores how heart sounds might mediate sharing space with a stranger in public space. The Heart Sounds Bench shifts away from wearable emotional biosensors to explore possibilities for emotional biosensing to challenge and rework 'smart city' visions. Pairs of strangers sat on the bench and listened to their live unfiltered heart sounds blending together and emanating into the broader environment. Participants described feeling connected to a sense of shared life energy extending beyond the pair to include people, plants, and animals surrounding them. The project explores a prepersonal notion of affect as discussed in Section 1.2.7 by tapping into a sense of shared vitality. The project engages biopolitical considerations raised in Section 1.2.6 by avoiding the othering potential of categorization.

I analyze how participants' self-reported inability to glean categorical insight from listening to their own or another's heart sounds can function as a productive form of what Glissant names *opacity* [124], a respectful acknowledgment of the limitations of what we can or should be able to claim to know about the Other. Opacity pushes back against the smart city visions' push for transparency. This push for transparency is problematic because attempting to model the city in terms of data-driven categories requires reducing the Other to predefined terms, categories, or hegemonic norms. Although transparency is often lauded as a way to build trust in the smart city, we should not have to make ourselves legible in terms of hegemonic norms in order to be recognized, trusted, or affirmed. The Heart Sounds Bench leverages opacity to invite a respectful experience of *life-affirmation*.

The Heart Sounds Bench contributes critical alternative design tactics for emotional biosensing design. (1) Instead of an emphasis on efficiency or workplace productivity, the bench form factor invites sitting still and resting. (2) Instead of smart city visions' frequent calls for increased surveillance, or sensing from above, people on benches sense each other bidirectionally on the street level. (3) Instead of presenting data as abstract, the data only exists as sound. (4) Instead of inviting data analysis, the Heart Sounds Bench invites listening. Listening can be quite analytical for people with particular auditory training such as medical auscultation or musical ear training, but the system is designed for use by many people who do not have such specialized training and whose listening experience is less specifically analytical. (5) Building on this, instead of foregrounding gaining analytical insight from data, the Heart Sounds Bench leverages opacity for an experience of affirmation.

An affirmative biopolitics resists the othering potential of categorization to support belonging. Drawing from Braidotti's take on Deleuze and Nietzsche, *affirmation* still values critique, contestation, and acknowledging social issues, yet it emphasizes the creative potential of enduring these difficult times [42]. The Heart Sounds Bench begins exploring affirmation as a design goal, but there is much more work to be done. This dissertation has begun to explore, and future work should continue to explore, ***What if designs prioritized care and affirmation over self-improvement? What if knowledge claims with biosensory data were more humble, to hold space for other ways of knowing and for respecting the complexity of human experiences?***

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