Tensions of Data-Driven Reflection:
A Case Study of Real-Time Emotional Biosensing

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ABSTRACT

Biosensing displays, increasingly enrolled in emotional reflection, promise authoritative insight by presenting users' emotions as discrete categories. Rather than machines interpreting emotions, we sought to explore an alternative with emotional biosensing displays in which users formed their own interpretations and felt comfortable critiquing the display. So, we designed, implemented, and deployed, as a technology probe, an emotional biosensory display: Ripple is a shirt whose pattern changes color responding to the wearer's skin conductance, which is associated with excitement. 17 participants wore Ripple over 2 days of daily life. While some participants appreciated the 'physical connection' Ripple provided between body and emotion, for others Ripple fostered insecurities about 'how much' feeling they had. Despite our design intentions, we found participants rarely questioned the display's relation to their feelings. Using biopolitics to speculate on Ripple's surprising authority, we highlight ethical stakes of biosensory representations for sense of self and ways of feeling.

Author Keywords

Biosensing; skin conductance; clothing-based display; affect-as-interaction; biopolitics; technological mediation.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Biosensory data shape our sense of our selves and others (e.g., [11,16,52,56,57,71]). Personal self-tracking devices (e.g., [80–86]) and bio-responsive design explorations (e.g., [42,60,66,74,75,78]) suggest that biosensory data will soon shape our everyday interactions with things, ourselves, and
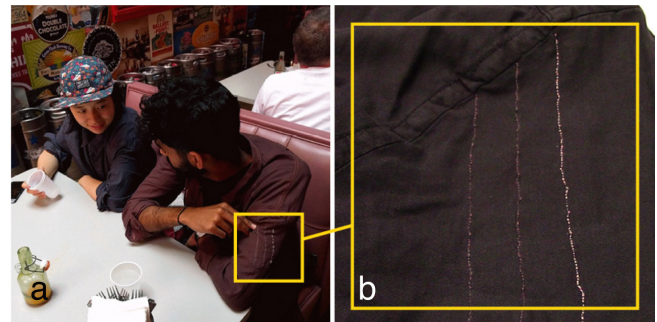

Figure 1. Friends wore Ripple, a shirt with three pinstripes that change color in response to skin conductance, throughout daily life. (a) Interpreting the display over lunch. (b) Pinstripes changing color.

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" [79], while the product's current website promises "actionable insights" to help users "live healthier and achieve more" [87]. Although well established critiques highlight how Western cultural narratives of data as natural fact or truth are misleading (e.g., [7,8,12,27,28,35,39,43]), these critiques have not reached many popular accounts of new possibilities with data (e.g., [1,40,46,79,87]). While claims to truth and "actionable insights" [87] from biosensing technologies may in part be marketing speak, they still shape our cultural imagination about what data is and what it can do [29,76]. 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 biosensing displays shape users' sense of self and others.

We designed, implemented, and deployed a technology probe [6,24,38], Ripple, to explore how biosensory data displays 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 display 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 left sleeve that changes color in response to the wearer's skin conductance data, which can be associated with emotional excitement. 17

participants wore Ripple for 8-20 hours over 2 days of daily life. 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 considerations of biopower 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.

APPROACHES TO EMOTIONAL BIOSENSING

Here we outline a few theoretical approaches to sensing and interpretation of affect, feeling, and emotion that motivate our work. 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 [62]. Psychology takes varied 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 [47:6]. Drawing from psychology, affective computing "hope[s] to build computer systems that can automatically recognize emotion by recognizing patterns in these sensor signals" [31:1].

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 interpreted into discrete categorical representations of emotion. This approach treats emotions as pre-existing in individuals and able to be algorithmically detected independent of context [5]. For example, present day self-trackers Feel [83] and Spire [82] 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 [5].

Our material biosensory data display draws from Dourish and Mazmanian [15] on the materiality of data representations. How data is materially represented—e.g., graphs on screens [82,88] or light emission by algae [21,22]—"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" [15:8]. Data and its display are tightly intertwined in interpretation. For example, a digital timeseries graph invites viewers to seek patterns over time. Our prior work suggests potential for thermochromic garment data displays to encourage open ended interpretation in daily social contexts [13].

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 [51:197]. *Biopolitics* refers to contestations around those discourses, who is considered an authority, and what forms of knowledge are considered legitimate [51]. Schüll and others describe 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, optimizing their daily behaviors, and making informed decisions [16,17,52,53,56,57]. Informed decisions and behavioral adjustments are being guided by data [56,69]. For example, technology (and the data produced by it) are used to define, detect, and model disease; "technology constitutes the concept of disease" [35:10]. Biosensing technologies are often framed as having authority to reveal insight (e.g., [79,82,83,87,88]), engaging broader discourses around technology, data, and health.

In this project, we investigate enrolling a biosensory data display of 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., [82,83,89,90]), we design for human interpretation of emotion situated in daily life. Instead of displaying data on a screen (e.g., [80,81,83,85,87,88]), we represent data as color-changing fabric in clothing, leveraging the potential for thermochromics to support multifaceted interpretation [13]. 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.

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 and emotionally responsive apparel (e.g., [3,19,20,23,30,60,61,74,75,91]), while biosensors in fitness wear track and optimize workouts (e.g., [84,92,93]). Prior designs have explored social interpretation with biosensory data. For example, Slovák et al. studied couples' interpretations of a laptop heart rate display, finding the display was seen to provide a sense of social connection [64]. Others have studied biosensing in specific social contexts such as a pub [65], lab [66], or symposium [49]. These studies show different social roles of biosensory data, such as responding to social engagement [65].

Prior designs have explored emotional communication. For the classroom, Subtle Stone allows students to indicate one of seven emotional states to the teacher with a color-changing stone, leveraging the abstract color change for discreetness [4]. 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 [42]. In outlining design guidelines for affect-as-interaction, Boehner et al. cite eMoto as a mobile phone messaging system that supports affective expression open to human interpretation [68]. Affective Diary combines traditional journaling with recorded biosensory data to support open-ended personal reflection [67]. Leveraging different physical and digital materials for different contexts, these designs explore different ways of communicating and reflecting on emotion.

Snyder et al. probed open-ended social interpretation of abstract displays of biosensory data with MoodLight, a color-changing light that ranges from blue to purple to red in response to the combined skin conductance of two participants. They found, "surprisingly, none of [the participants] questioned whether the lights were accurately representing their internal state" [66:149]. This prompted us to ask, how might we design a biosensing system where participants do critically question the display?

We seek to critically examine how "data are generated, curated, and how they permeate and exert power on all manner of forms of life" [39:2]. Specifically, how this might play out with emotional interpretation of biosensory data could be highly subjective and sensitive. Would the seeming power and authority of data provide a desirable sense of clarity on one's emotions? Conversely, what if the data were seen to mean something about a person's feelings that they found surprising, wrong, or did not want to believe? Should they be expected to capitulate on their own sense of self and accept that they 'in fact' do or do not feel a particular way according to the data? Our hunch is that it might be of vital importance to be able to question data's relation to their feelings, to give people the final say on their own feelings. Rather than emotional biosensory data displays that seem unquestionably authoritative, designing for contestability [34] can be valuable.

So, we designed Ripple to seem unauthoritative and invite critical questioning, and build on prior work. We previously studied social interpretation of thermochromic t-shirt skin conductance displays during 45-minute conversations in an office. We found the display was enrolled in self-presentation and that it might be desirable to enact social performances with biosensing displays [36]. Ripple's design supports social performances and expands both the length and contexts of the study to form a richer picture of biosensing in participants' daily lives. The always present yet unobtrusive display was available to participants as they experienced a range of situations and social circumstances,

Figure 2. (top) Ripple, a shirt whose three shoulder pinstripes change color in response to skin conductance, was produced in multiple colors and sizes. (bottom, from left to right) Pinstripes fade to white one by one, then all return to gray.

allowing us to probe social interactions around the display in tandem with participants' personal reflections.

DESIGNING "RIPPLE"

How can designs make emotional biosensory data present in daily life in ways that support human interpretation and critical questioning?

Ripple is not the design 'solution' to this question; rather, Ripple is a design probe [6,24,38] in the sense that "the designed application is itself thought of as a probe that forces new interaction, reflection, and reactions by users" [6:1080] seeking to "open up new design spaces" [6:1078]. In our approach to critique through design, we draw from Nafus in *Quantified: Biosensing Technologies in Everyday Life* [44]. She quotes Latour to argue for the critic as "not the one who lifts the rug from under the feet of the naïve believers, but the one who offers the participants arenas in which to gather" [41:246]. Ripple does not directly find fault with existing technologies; rather, it explores alternative avenues of engagement with emotional biosensory data displays in daily life.

We want to explore alternative design spaces because, although data is seen as having the authority to provide truthful insights (e.g., [8,53]), we feel it is important for people to question data's relation to their own life and systems of meaning. Drawing from affect-as-interaction, our design avoids algorithmically interpreted categories of emotion. We sought to encourage spontaneous, open-ended human interpretation of feelings throughout daily (social) life, and critical questioning of the data display. 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 it 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 would be interpreted to reveal something "true" about the person.

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 the 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 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 the 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.

Inviting Critical Engagements with Biosensory Data

We wanted Ripple to seem unauthoritative to invite critical questioning. So, we designed avenues for questioning or even disregarding the data display by:

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 (Fig. 2), in the periphery of where oneself or others typically glance. The slow shifts from gray to white 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 can disclose the dynamism and meaning of the display to individuals of their choosing.

2) Acknowledging the Ambiguity of Skin Conductance

We chose to work with skin conductance, included in many wristband trackers (e.g., [81,87]), because it is inherently ambiguous: it can indicate mental, physical, or affective excitement, but not valence. Both positive and negative excitement are associated with an increase in skin conductance [31]. Instead of attempting to 'resolve' this ambiguity and display a definitive 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 skin conductance data is intentionally crude to foster moments when wearers might see the display as inaccurately reflecting their emotions. To detect sudden increases in skin conductance we use a simple low pass filter adapted from [54] rather than various machine learning techniques (e.g., [54,77]). With our algorithm, sweat from physical exertion also triggers a display change, and the display responds differently to different people with differing electrodermal lability [55]. Designing for moments when the display might seem inaccurate, we sought to support critiquing and disregarding the data.

3) Embracing the Volatility of Thermochromics

Prior work argues the ambiguity of thermochromic clothing-based displays can support multifaceted open ended interpretation and suggests particular materials and fabric production techniques for this [13]. 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, while a cool breeze can inhibit the display's response.

We included this additional layer of ambiguity to support "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. Combined, skin conductance data, algorithm, and volatile display "enhance ambiguity of information" [25:237], a tactic for leveraging ambiguity to foster interpretation [25].

4) Inviting Social Performances

Ripple also allows 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 [36].

Overall, we felt these factors might "make space for user re-interpretation by downplaying the system's authority" as suggested by Sengers and Gaver [59:4]. Drawing from affect-as-interaction, display changes do not map to specific emotional categories, instead inviting participants to form their own emotional interpretations. Display changes can easily be overlooked, ignored, forgotten, or disregarded. Multiple strands of locally enacted cause and effect intertwine in sensing and display; e.g., was it the warm sunlight or a moment of embarrassment that caused a display change just now? By providing so little information in only a gray to white color fade, with so much ambiguity in data, algorithm, and display, we anticipated that Ripple might seem uninterpretable or even random in some instances or for some people. Even so, we wanted to use

Ripple to probe interpretation in the face of this multifaceted ambiguity.

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 2-7Ω resistance and received about 450mA from a 3.7V LiPo battery via an Adafruit Powerboost 5V regulator, switching on (100% duty cycle) or off (0%) with an Arduino controlled transistor. Each pinstripe is a single conductive thread as in [13,50]. Snaps inside the shirt (technique from [9]) provided removable but secure electrical connections to threads. Participants wore a Bitalino [63] skin conductance sensor on the back of the left shoulder to hide the sensor from public view and secure it within the shirt. This sensing location is similarly responsive as compared to the more common locations of wrist or fingers [14], while hidden from view to better fit with everyday style. In a method similar to [54], a low pass filter detects sudden increases in skin conductance. Arduino code and PCB Eagle schematics are on github [37].

STUDY

Ripple is a reflective design [58], intended to provoke reflection in both us (as designers) as well as 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 [24], probes are material prompts 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" [24:25]. HCI has taken up probes in a variety of ways, such as 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" [38:18]. Technology probes can help broaden the design space and provide "design inspiration" [38:18]. In introducing technology probes, Hutchinson et al. provide as an exemplar Dunne and Raby's Placebo Project [18,38]. 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" [18:11] a particular area of interest.

As a technology probe, Ripple speculates on a plausible future device, a bio-responsive garment, and leverages ambiguity [25] to open opportunities for participants to explain their relationship to data through their situated interpretation. We imagined these interpretations could range from dismissal of the data display as arbitrary, to moments when the data display is seen to reveal insights, to blended approaches in which the data display is leveraged to suit the wearers' beliefs about themself or facilitate building an interpretive relationship over a longer period.

To explore these outcomes, and make room for others we did not intend or anticipate, we studied participant's experiences and interpretations wearing Ripple over two days of daily life. We invited pairs of friends to participate to specifically probe both individual and social interpretation. First, 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.' She also explained the shirt's temperature volatility, describing how warm sunlight could make the threads change color or a cool breeze could prevent color change. Then she asked participants to talk over conversation prompts while wearing the shirts, drawing from prior work [36]. By fostering interpersonal closeness [2] with potentially sensitive topics (e.g., "If you could change anything about the way you were raised, what would it be?"), we found these prompts seemed to help participants open up and share emotional reflections. At the end of this first meeting, each participant was given a physical diary and asked to note each time they noticed the display change, each time they expected a display change but it did not occur, what they liked/disliked about Ripple, and what they wore with the shirt to probe how it related to their sense of personal style. Then participants went about their daily lives wearing Ripple for about 8-20 hours. The next day, they met with the researcher for a qualitative semi-structured post-interview, in public venues, that lasted 45-90 minutes.

We collected data by observation, qualitative semi-structured interviews, and participant diaries [3]. Reviewing diaries during post-interviews jogged memories of specific moments of interpretation. We transcribed field notes and audio recordings of interviews for analysis with best practices for an "issue-focused" qualitative study [6]. We analyzed results through the lens affect-as-interaction, and thematically coded participants' processes for interpreting or questioning the display. Because of our specific focus on the situated nature and scope of emotional interpretation, we did not compare participants' interpretations to sensor data to assess the 'correctness' of interpretations. Organizing into themes, we saw tensions emerge. In the discussion, we introduce two lenses (technological

mediation, biopolitics) that helped us as designers reflect on the ethics and politics at play in our design.

Eight men, nine women, ages 19-41, participated, referred to by pseudonyms. Three pairs were married; all others were friends or housemates. One man participated alone. 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 on roles and tensions they suggest for biosensing designs in daily life.

MOMENTS OF REFLECTION WITH RIPPLE

We saw participants enroll Ripple in moments of reflection throughout daily life, linking observed display changes to their feelings. Alex described trying to find a pattern in 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 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,"* linking the change to excitement. Agustin noted a display change during a jam session with bandmates and attributed it to creative flow. Alex noticed Ripple's threads lightening during a difficult call with a customer, explaining, *"probably because I was slightly frustrated. My heart rate and blood pressure definitely increased for just a little bit."* Other situations participants described when interpreting display changes include feeling startled by someone approaching from behind (Alva) or almost falling (Jennifer), enjoying or imagining good food (Erika, Jennifer), and receiving a paycheck in the mail (Valeria).

Navigating multifaceted ambiguity

Ripple's highly ambiguous display responds not only to skin conductance but also sweating and ambient temperature. We explained this multifaceted ambiguity in introducing the display to participants. It seems participants enrolled this understanding in interpreting the display. Participants attributed some display changes to sweating from physical exertion, especially biking (Alva, Mark, Susan, Natalie). They considered how ambient temperature might influence the display, describing warm sunlight (Jed, Arthur), a cold morning (Jed, Erika), or body heat (Alex, Mark) as possibly influencing the display.

We observed no instances in which participants denied any emotional provenance of a display change by linking it to

temperature instead, although we designed to support this. This could be because participants were curious to find links between the data display and their feelings. As for social performance, participants used the override features exclusively for confirming the shirt's functionality or demonstrating it to others, not for performing or hiding emotional responses as we anticipated.

As expected, 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."* Study partners Jia and Kanav both expressed they found no pattern linking display changes to their feelings. 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, as we elaborate below.

Emotional Reflection with Ripple

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 caused the display 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 their ongoing discussion about stress, prompting them to reflect upon their feelings and how best to support one another.

As a reflective design probe, Ripple prompted participants to reflect more broadly on the potential of emotional displays. Friends Deb and Mark imagined a hypothetical shirt display so unambiguous "to the point of being able to display words that were matching your nuanced emotion at the moment" (Mark). He envisioned benefits of wearing the shirt around friends, explaining he is not very emotionally expressive and, ***"I would rather be more emotive and have people be more aware of [my emotions]."*** Even during disagreements with roommates, he felt the display might prompt an "honest conversation" leading to greater social understanding in the long run. At work, however, he felt the display would be "intrusive" and "inappropriate" if it displayed his dissatisfaction. He said his boss likely already knew he was sometimes angry, but *"the difference is that there, maybe he knows, but I'm not saying anything and I'm being professional."* Mark saw potential in emotional displays to foster understanding with friends, while wanting to maintain a professional cover of emotions at work.

On the other hand, Deb said a hypothetical unambiguous emotional display would be ***"the last thing I would want…***

I really want to be able to hide my feelings." She imagined working through a conflict with a friend and wanting to say she was not angry as a way of moving on, but the shirt could reveal that she was angry and thus prolong the conflict. She compared the shirt to her self-described frequent, pronounced, uncontrollable blushing to illustrate the frustrations of being too emotive: *"Blushing, I know how embarrassing that can be, and how it sends a signal that you're not necessarily intending to send, or is not even an accurate representation of how you're feeling... **I would much rather have more control of what I was projecting into the world."*** Deb wanted to be able to control and hide the expression of her emotions with friends and at work.

Others described the display as highlighting connections between 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 an *"external way of processing what's normally just in your head."* Agustin enthusiastically related a "philosophical moment" with Ripple: *"I was calling my internet provider and I was pissed off, I was really angry."* He attributed the display change at that moment to his anger, and elaborated, ***"It made me reflect on how situations are clearly transmitted into my body, '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 different facets of self, serving as a resource for reflection.

Ripple's ambiguous display seems to have encouraged people to leverage context in their interpretations, as expected with tactics for leveraging ambiguity [25]. A 2-day study is short, but these vignettes suggest participants *began* enrolling Ripple in moments of personal and social reflection, developing narratives linking display changes to feelings and events in daily life. In these cases, Ripple fostered the kind of open-ended reflection we intended.

TENSIONS OF EMOTIONAL BIOSENSING
While some cases suggest potentially interesting ways of reflecting with biosensory data, in other cases such open-ended reflection had unintended consequences we find problematic. We were surprised to find Ripple sometimes seemed to be granted a degree of authority that precluded participant questioning. We elaborate a few concerning vignettes in more detail to draw out tensions that may impact future emotional biosensing designs.

Calmer Feelings Overlooked
Skin conductance responds to some kinds of excitement, as explained by the researcher to participants when introducing Ripple. Its degree of responsiveness differs across people [55]. Yet, some participants linked what seemed to them like a lower frequency of display changes

with being less emotional as a person. There is no evidence of technical malfunction in these cases.

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 related to emotions. 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 child [36]. 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."*** It seemed like Jed chose these words to describe Erika's concern back to her to reassure her. During the post-interview, Erika recalled her concern during the first meeting: ***"The whole previous hour [before the shirt changed], I'd been like, 'Oh my God, I have no feelings.'"***

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.

Social Comparisons and Desires
Comparing the frequency of display changes also took on social meanings. Over lunch Alva noticed 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 make her display change. Similarly, 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 Jed's display changed more often. Jed teased Erika about how he had two or even three threads changing simultaneously, saying, *"It's pretty special, I know."* Erika reiterated her concern that her relative lack of display changes indicated a lack of emotion: **"It was definitely a little stressful. Because I was like, 'Oh my god, do I have no feelings? Am I not excited or something?'"** 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 depth to provoke new questions and directions for further exploration of emotional biosensing designs more broadly.

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 highly ambiguous data and display. Despite our attempts invite critical questioning, some participants seemed to invest a potentially harmful degree of authority in the data display.

Some participants related the data display to their own narratives of how they were feeling, situated in the sociocultural context of their daily lives. Their descriptions well exceed the kind of discrete emotional categories that affect-as-information approaches typically use like 'happy' or 'stressed'. For example, Jed's excitement at receiving a job offer over the phone is significantly different from Jennifer's excitement watching Olympic gymnastics. Alva is not stressed divorced from context; she felt stressed about her upcoming move, 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 phone call, part of his felt experience and enactment involving his body and feelings. This suggests potential for biosensing displays to be enrolled in affect-as-interaction approaches to open ended emotional meaning making.

'Shaping 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 [70]. 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;"* Erika worried the lack of display response suggested, *"I have no feelings."* Like other mediating technologies, Ripple "help[ed] to shape what counts as 'real'" [70:8] 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" [70:8], 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 as indicative of having more or less feeling. Jennifer and Erika saw the difference between zero or more display changes in their own shirt as significant, and compared the number of their display changes with that of their respective study partners. 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, comparisons that carried emotional meaning for participants about their sense of self.

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 these feelings were worthy of recognition, or valuable, while others were not. We found technological mediation helpful for analyzing this, and suggest future design research consider how biosensory data representations 'shape what counts' in terms of amplification/reduction, quantification, and values.

Do Artifacts Have Biopolitics?

As a reflective design [58], Ripple prompted reflection not only for participants but for us too as designers, for which we found biopolitics a useful lens. Our treatment of the biopolitics at play with Ripple is not meant as a definitive explanation rigorously grounded in empirical evidence; rather, it is intended as a provocation to motivate questions for future work. We argue biosensing designs should explicitly engage biopower to consider issues of authority and potential harms.

Artifacts have politics and "can embody specific forms of power and authority" [73:121]. Participants seemed to invest authority in the data display, where we draw from Rabinow and Rose's use of 'authority' relating to who or what is considered able to provide 'truth' [51]. As designers we tried to make Ripple seem unauthoritative to foster critical questioning of the display, 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 sharing critiques. That said, some participants 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 sometimes increased the authority of the data display rather than inviting critical questioning. Because Ripple's ambiguous display did *not* provide an explicit interpretation linking data to 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 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 potential moments of excitement). Reflecting on ambiguity as a resource for design [25], it seems Ripple's ambiguity did invite a broad space of active interpretation by participants as expected. However, the sensitivity of emotional interpretation coupled with the unexpected authority invested in the data display fostered 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 provocation considers feelings and biosensing via biopower discourses of health and disease: While health is increasingly framed as at risk of disease [52], feelings and emotional wellness can be seen part of health and thus also at risk. For example, biosensory data is used to 'detect' stress [32,33,45,54] and depression [10,26,48] to suggest interventions to improve emotional health [72,82,94]. 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 had no feelings. 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 [36]. 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 allowed by ambiguity may have provided a way to project fears and insecurities onto a data display, 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 upsetting interpretations 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. Embracing diverse perspectives on emotional wellness into the design process and explicitly reflecting on artifacts' biopolitical implications seem like promising avenues to pursue.

In future design research, the role of ambiguity in emotional interpretation with biosensory data merits further exploration. Ambiguity in Ripple functioned in particular ways; other designs might be different. Ripple's primary tactic, "Use imprecise representations to emphasise uncertainty" [25:237], folded together multiple layers of imprecision with a crude data analysis algorithm and a highly abstract, volatile display. Future designs could explore other tactics; e.g., "Over-interpret data to encourage speculation" or "expose inconsistencies to create a space for interpretation" [25:238]. Perhaps presenting intentionally overly specific interpretations of emotions, or multiple conflicting interpretations, might help people feel more confident disagreeing. Creating a space for interpretation could also have the potential to suggest an alternative framing for considering emotions rather than letting this 'default' to dominant biopolitical narratives.

Considering discourses of biopower in which designs and people 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.

CONCLUSION

We contribute the design and study of Ripple, a technology probe that explores an alternative engagement with

emotional biosensory data displays. Instead of presenting user emotions as discrete categorical states, Ripple's display is a highly ambiguous color-changing fabric pattern. Instead of seeking to present authoritative insights with our data display, we intended the design to invite open-ended emotional interpretation and critical questioning. Yet, our analysis of vignettes of participants' lived experiences with Ripple point to broader tensions of affective biosensing technologies. Despite our designerly efforts to invite questioning or critique, 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 of measurement.

Going forward, we suggest designers of emotional 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 affect-as-interaction emphasizes the socioculturally constructed and performative nature of emotion and influenced our design approach [5]. 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 [70]. Biopolitics helps consider how biosensing designs are situated within broader societal discourses of health and authority [51,52].

Our findings and analysis made us more attuned to how emotional biosensing designs can suggest new ways of feeling, for better or worse. Far from being a neutral observer, biosensing actively shapes our conception of affect, feeling, and emotion, and becomes embroiled in questions of how or what we should feel or be.

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