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Authors

Howell, Noura
Devendorf, Laura
Tian, Rundong (Kevin)
et al.

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Biosignals as Social Cues: Ambiguity and Emotional Interpretation in Social Displays of Skin Conductance

Noura Howell[1], Laura Devendorf[1], Rundong (Kevin) Tian[1], Tomás Vega Galvez[1],
Nan-Wei Gong[2], Ivan Poupyrev[2], Eric Paulos[1], Kimiko Ryokai[1]

[1]UC Berkeley
Berkeley, CA, USA
{noura, ldevendorf, rutian, tomas.vega, paulos, kimiko}@berkeley.edu

[2]Google ATAP
Mountain View, CA, USA
{ngong, ipoupyrev}@google.com

ABSTRACT
This paper explores 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? We 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.

Author Keywords
Clothing-based display; dynamic textiles; skin conductance; ambiguity; biosensing; affect-as-interaction.

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

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 [27]. Jawbone UP3 and Microsoft Band also monitor skin conductance for fitness and wellbeing [28,29]. Much research uses biosignals to

"detect" emotions, thereby providing unambiguous interpretations of emotional state, [e.g., 12,16,19]. Recent work has challenged this approach of detecting and algorithmically categorizing emotions and proposed an alternative approach, *affect-as-interaction* [4], which treats emotion as contextually situated and arising from interpersonal interaction [4,14,15]. 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 [10,20] 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.

BACKGROUND

Interpretive Approaches to Biosignals
Some biosignals research aims to "detect" emotion, but this approach has recently been critiqued [3,4,9,14,15]. As Boehner et al. [4] 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 [15]. 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 [4]. Our work engages *affect-as-interaction* in its design and analysis and contributes further exploration into designing affective systems through this lens.

BIOSIGNALS, FASHION, AND SOCIAL LIFE

Researchers in and out of HCI have explored garments which display social or physiological information of the wearer [2,6,13,14,21,23,26]. While some of these examples are provocations or suggestions of future fashion landscapes, others measure skin conductance synchronicity in a social context [24], explore a composite display of a pair's skin conductance [25], or mention compelling anecdotes of social interactions while sharing skin conductance [17]. Recent work has also envisioned many ways that ambiguous dynamic clothing-based displays might prompt reflective and playful experiences in daily life [7]. 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.

DESIGNING "HINT"

Hint is a dynamic t-shirt. When the wearer's skin conductance increases, an indication of sudden arousal, small white patterns slowly appear [Figure 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.
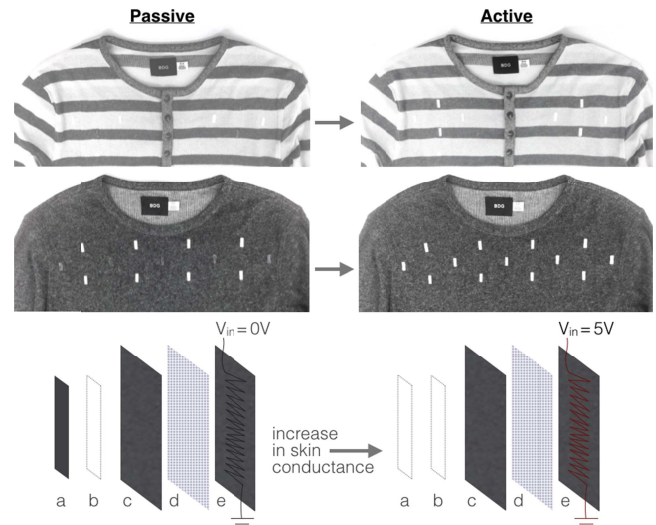
Figure 1: Shirts display small white shapes in response to sudden increases in skin conductance. Layers for one shape: a) thermochromic gray screenprint, b) white screenprint, c) original t-shirt, d) adhesive, e) conductive thread sewn into fabric. Passive: Some white shapes (layer b) are hidden beneath gray (layer a). Active: Supplying power to the conductive creates heat, turning (a) transparent, thus revealing (b).

This has the visual effect of a white pattern slowly emerging on the gray t-shirt. Conductive thread (electrically insulated, from [18]) 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°F, 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 [22] 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 [8]. Using a low pass filter roughly similar to [19], an Arduino script detects sudden increases in skin conductance and powers the threads accordingly.

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 [1]. 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

Figure 2: Pairs of friends conversing and observing *Hint*.

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 [5] and organized our observations into emergent themes. We refer to participants by pseudonyms.

FINDINGS

Socially Situated Interpretation & 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 [12,19], 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.

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.

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.

DISCUSSION

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* [10]. 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" [10]. 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 [7]. 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.

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 [11]. When wearing garments with ambiguous displays, the wearer and the garment are seen and interpreted together by their audiences [7]. 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 [30] 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.

CONCLUSION

We engaged *affect-as-interaction* [4] 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.

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