Designing for Tangible Affective Interaction

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ABSTRACT

In this paper, four interactional modes of pervasive affective sensing are identified: in situ intentional, retrospective, automatic, and reconstructive. These modes are used to discuss and highlight the challenges of designing pervasive affective sensing systems for mental health care applications. We also present the design of the Grasp platform, which consists of a hand-held, tangible stone-like object with accompanying peripherals. This device is equipped with a force sensor that registers squeezes, includes capabilities for wireless transmission of data, and comes with a crib for initiating the wireless connection and data transfer. In addition, the platform includes an app on a tablet that can render squeezes in real time or visualize the data from a given time period. In this paper, we focus mainly on the design of the tangible interaction and address the challenges of designing for in situ tangible affective interaction.

Author Keywords

Tangible interaction; affective interaction; pervasive affective sensing.

ACM Classification Keywords

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

INTRODUCTION

There is a well-documented need for pervasive tools that facilitate monitoring and sensing affect within mental health care [9, 14]. Clinical psychologists and therapists commonly rely on self-reports written retrospectively in notebooks or, somewhat more technologically sophisticated, through the use of a questionnaire on a mobile device. Therapists "ask patients how often they experience anxiety, on average, how many panic attacks they had during the past week or month, how intense their pain generally is during the day, or how depressed their mood has been" [25, pp. 1-2]. These global, summary, or retrospective self-reports of behavior and affective states suffer from the limitations imposed by imperfect recall and unreliable autobiographical memory [25, p. 4]. In the context of mental health care, patients can also suffer from conditions that have a negative impact on recall, such as depression [24]. To meet these challenges, psychologists have developed techniques, such as ecological momentary assessment (EMA), to get a more nuanced picture of how these psychological states are experienced in real life. However, most of these techniques require that the patient is capable of taking written notes or interacting with a mobile app.

Advances in the use and widespread adoption of mobile phones, wearables, fitness trackers, and biometric sensors present new opportunities to provide support for mental health care [14]. In this paper, four interactional modes of pervasive affective sensing are identified: in situ intentional, retrospective, automatic, and reconstructive. These modes are used to discuss and highlight the challenges of designing pervasive affective sensing systems for mental health care applications. We also present the design of the Grasp platform, which consists of a hand-held, tangible stone-like object with accompanying peripherals. This device is equipped with a force sensor that registers squeezes and includes capability for wireless data transmission. A crib registers the presence of the device, and initiates the wireless connection so that the user can request stored data. In addition, the platform includes an app on a tablet that can render squeezes in real time or visualize the data from a given time period. In this paper, we focus mainly on the design of the tangible interaction.

The description of the research process of designing and evaluating the Grasp platform addresses the challenges of designing for in situ intentional tangible affective interaction. These challenges include how to allow users to sense, register, report, and analyze their emotional state intuitively and effortlessly. The designed objects can be conceptualized as computational composites [28], and thus, the challenges entail not only designing an interface but also working with "physical form, temporal form and the interactive gestalt," as proposed by Vallgårda [28, p. 591].

PERVASIVE AFFECTIVE SENSING

In affective computing, the logging or registration of data concerning affective states is often supported by biometrics or other automatic methods. Based on cognitive science and experimental psychology, the goal in affective computing is commonly to provide unobtrusive, non-invasive, and objective measurements of affect [19]. From the perspective of affective interaction [3, 11], however, the goal is not necessarily to minimize the obtrusiveness but to design the technology so

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that the interaction becomes part of an affective experience. Thus, the aim of the design is to enable the user to express and understand feelings rather than to create objective measurements of affect [27]. The research presented in this paper is inspired by the perspective of affective interaction.

Pervasive affective sensing can be defined as the process of monitoring and translating various indicators of emotional states into meaningful information, expressions, or experiences. According to Kanjo, Al-Husain and Chamberlain [14], pervasive affective sensing includes gathering data related to affective states with the use of pervasive tools and analyzing these data. Pervasive affective sensing has many application areas, such as mental health care, and a plethora of different techniques for monitoring emotional states are available, such as self-reporting, monitoring of physiological and biological signals, facial expressions, speech, phone usage, network data, and social media use. Kanjo, Al-Husain and Chamberlain [14] label these monitoring techniques "different sensing modalities used in natural settings." In addition, a range of pervasive tools that support such monitoring techniques are currently available, a selection of which is discussed below.

Krøger, Guribye and Gjøsæter [15] discuss how pervasive affective sensing can be divided into two main approaches, passive and active. In the context of lifelogging, Kalnikaite et al. [13] describe a passive approach as automatically recording data "without the need for user effort or involvement" (p. 2045). Conversely, active approaches require user effort and involvement to actively construct the data. Kalnikaite et al. [13] further state that passive registration of data "eliminates the burdens of users having to decide whether a particular incident is worth capturing, as well as the need to manually prepare and operate a capture device. One of the advantages is that no important moment gets missed, and users aren't taken 'out of the moment'" (p. 2045).

This quotation points to a key challenge of pervasive affective sensing: deciding what data or incidents are relevant and thus worth capturing and analyzing. These decisions can be made automatically or be left to the user's discretion. Although the challenge is portrayed as a burden in this quotation, an active approach can also be seen as a way of empowering the user by providing autonomy in the process of interpreting and selecting what is relevant in the pervasive affective sensing process [27].

In psychological and behavioral research, the umbrella term experience sampling methods (ESM) is used by Scollon, Prieto and Diener [23] to denote a number of self-reporting techniques. These methods can be divided into three categories according to variations in the time of data registration: interval-contingent, event-contingent, and signal-contingent sampling. Respectively, data collection occurs according to a set time interval, when a specific event occurs or when prompted by a random signal [23]. The latter is also called ecological momentary assessment (EMA; see [25]). An advantage of this method is the possibility of capturing patterns that pertain to the recorded emotions, such as spatial, temporal, or situational correlates [23].

	Synchronous	**Asynchronous**
Active	In Situ Intentional	Retrospective
Passive	Automatic	Reconstructive

Table 1. interactional modes of pervasive affective sensing.

Many technologies support ESM or EMA. MoodMap [20], for example, prompts users to report their emotional state three times a day. Ecological momentary assessment, supported by pervasive tools, is presented as an alternative to static retrospective reports. This technique then "allows subjects and patients to report repeatedly on their experiences in real-time, in real-world settings, over time and across contexts" [25, p. 3]. Although these technologies are supported by technological tools that prompt the user to report his or her affective state, these techniques are examples of an active form of pervasive affective sensing, as the users themselves have to enter the data and register the event or affective state. Psych-log [8] is a tool that supports EMA and ESM through a mobile app and a wearable sensor and combines self-reporting with biosensor and activity data.

A set of techniques used in passive registration is biofeedback. These techniques focus on registering biological signals. Devices utilizing biosensors can measure body temperature, blood pressure, heart rate, galvanic skin response, and more. Biosensors combined with mobile phones make it possible for data interaction to occur in real time [14]. Biosensors were previously mainly used in research, but they are now available in many off-the-shelf, relatively cheap, interactive products such as wearables and fitness trackers.

In Table 1 we identify four modes of pervasive affective sensing to explore these issues and to clarify the conceptual approach to the design of the Grasp platform.

These modes vary across two dimensions. The first is constituted by the role of the (human) user as either active or passive in the interactional process. The second dimension is constituted by the synchronicity or asynchronicity of the recording with the subjective experience of the affective state. Following Kanjo, Al-Husain and Chamberlain [14], we include the ability to monitor and analyze data related to emotional states in our understanding of pervasive affective sensing. This is particularly relevant for understanding the difference between the reconstructive mode and the automatic mode, as discussed below. The four different modes are meant as analytical categories, and a given pervasive tool or technique can cut across or combine different modes.

The top right category in Table 1 is labeled the *retrospective mode* of pervasive affective sensing. This mode occurs is when the user actively registers the affective state with a pervasive tool asynchronously with the emotional experience. Many commercial mobile apps are available in this category, such as Optimism [22]. In this category, many generic notepad tools or simple web-reporting tools can be used to support retrospective self-reporting. This mode is not bound by a given modality, and different representations of emotions, such pictorials, animated cartoons, or emoticons, can be used instead of or in conjunction with verbal reports.

The bottom left category in the table is labeled the *automatic mode*. In this mode, the user is passive, and the pervasive sensing is mostly automated. Although sensing and reporting itself are automated, these actions might require some effort from the user, such as wearing and regularly charging a wearable device. The automatic mode can use different sensing modalities, such as biosignals or mobile phone usage. An example of an automated biofeedback application is the MoodWings system [18]. It is a wearable device in the form of a small butterfly meant to be worn on the wrist. The wing actuations of the butterfly work as a real-time representation of the wearer's stress level based on electrodermal activity and electrocardiogram data. This application monitors and analyzes inferred affective states and thus delivers feedback synchronously with the emotional experience. Another example is the MoodScope application [16], a mood-sensing application that analyzes smartphone use (such as e-mails, phone calls, and text messages) to infer the user's mood. MoodScope even comes with an application programming interface (API) that can be used by other apps on the mobile phone to deliver real-time feedback based on the inferred emotional state.

The *reconstructive mode* (bottom right in Table 1) can apply the same passive, automatic techniques for monitoring and logging as in the automatic mode, but this is not analyzed in real time, and no real-time feedback is given. A well-known example is the Affective diary [26] that applies body sensors and capabilities of a mobile phone to log events and "affective bodily memorabilia" (p. 366). The user can access these logs later to reconstruct and understand emotional experiences. Another example is EmoSnaps [21] that uses photos taken automatically to categorize facial expressions as a method for emotion recall and uses an event-driven approach where predefined interactions with the mobile phone (such as unlock screen) are used to trigger the camera. Although many pervasive tools use this interactional mode, the potential and the research challenge of this reconstructive mode are related to using secondary and historical sources to reconstruct emotional experiences from large amounts of data.

The *in situ intentional mode* (top left in Table 1) applies when the user actively engages in affective interaction with an interactive artifact with the intention of creating documentation or tracing a given moment, event, or affective state. An example is a commercially available wearable device, the Empatica E4 wristband [5], which has an event mark button so the user can tag a given moment or event intentionally. In Empatica, such events can be correlated with other data from the apparatus for automatic sensing implemented in the wristband. In our categorization, only an event-driven experience sampling method (not signal-driven or interval-driven) is called in situ intentional sensing of affect.

TANGIBLE AFFECTIVE INTERACTION

A particular design challenge for the in situ intentional mode is to minimize the effort the user has to expend when using the pervasive tool. As the user is supposed to actively and intentionally register affect at the same time as the emotional experience, the design of the device should take into consideration that the user might suffer from serious emotional distress at the time of use (for example, having a panic attack or suffering a major depressive episode). Following the perspective of affective interaction, the interaction should also in some way be designed to help the user cope with, understand, or express an emotional experience.

Several studies have used tangible interaction as an approach for registering and expressing emotions (for example, the Subtle Stone [2] and EmoBall [7]). A relevant tool, based on tangible interaction through squeezes, is the Skweezee system [29], which consists of a soft object filled with conductive padding that can be bent and squeezed and detects a wide range of deformations. This allows different interactional inputs, such as stretching, cutting, punching, or crumpling the Skweezee. This system is also used in therapeutic settings and can be used for pervasive affective sensing.

More generally, tangible interaction can take advantage of familiarity with common objects [10]. "The use of everyday things, like pillows, carpets and paper, is characterized by our familiarity with the things and what we can do with the things" (p. 92). Thus, this focus on familiarity can help build on users' pre-existing understanding and interaction with familiar objects from their everyday world. One such familiar object is a stone. A stone, of the right size, is graspable, pressable, and clenchable.

RESEARCH THROUGH DESIGN

The research reported in this paper was conducted as a research through design process [6, 30].The overall design process was user-centered, and users and domain experts were involved at different stages. Expert users in a focus group were involved at an early stage to evaluate initial design conceptualizations with a low fidelity prototype. At a later stage (see [15]), other expert users participated in evaluating a more refined conceptualization with low-fidelity prototypes tablet interaction surfaces for viewing and discussing data submitted through the use of proto-personas. With the use of proto-personas, sensitive topics can be discussed while real users are shielded from participating in an evaluation scenario.

In this paper, informative design iterations of the electronics and the tangible device relevant for an evaluation performed in two pilot-user studies and a field trial with three participating users is presented. The field trial included equipping the participants with a technological probe [12]. The aim was to understand the user experience in a real-world setting and encourage the users to reflect on their use of the device.

DESIGN OF GRASP

This section describes the design process for creating a device that allows users to easily capture and express affect, in situ with intent. In other words, a description of the creation of a device that aims to allow the user to effortlessly capture a representation of his or her emotional state, as the event emotional state presents itself, at that given moment, with a degree of control over the registration.

The initial idea behind Grasp emerged from one of the designers observing the challenges of recalling a week's worth of emotional events when prompted in one-on-one conversations with therapists. To alleviate recall bias [25], a tool that enables a very low-threshold interaction for registration of emotional events was designed. The following sections detail the most notable iterations during the design process.

Proof-of-Concept

A rudimentary proof-of-concept (POC) device was brought to a focus group of domain experts to validate the usefulness of such a device and whether the intended method of interaction could be practical in a therapeutic context. The focus group consisted of ten domain experts in fields ranging from family and child therapists to therapists who work with drug addicts and therapists who work with patients with other mental disorders (see Figure 2). The focus group was presented with a rough POC device (see 1), and the session was video recorded and transcribed. The POC device incorporated the essential interaction envisioned for the device: Squeeze the device to store (i) the varying hardness of a squeeze over (ii) the duration of the squeeze. This was visualized interactively for the test panel by translating the squeeze intensity on a graph on a computer monitor.

Figure 1. A photo from the focus group study of the Grasp platform of, a therapist grasping and clenching the device to the right.

The focus group was asked to imagine whether such a device (in a more refined form) could be used in therapy. A wide range of usage areas was discussed, and the experts gave promising feedback on strengthening dialogue between the patient and the caregiver: "What is interesting is that [using the device] you get a measurement that has a different quality [from biometric measurements]. It is what it is, and a reliability measurement is irrelevant because there is no need to question the correctness of the measurement. It is [the user's] squeeze, and nothing but [the user's squeeze]." The expert panel clearly did not think that reliable measurements would be important for the tool. Instead, they emphasized that the squeezes should have personal meaning and that the patient's ownership of the squeeze would be a useful quality of the tool. And in regards to describing pain: "But with regard to pain, physical pain, this has to be great. Commonly, you use these scales, and implement a 1–10 scale (what scale are you on now?), and then the patient should formulate from this. It's entirely abstract."

Other areas were also discussed, and we received promising feedback. Overall, the expert panel was positive about the design concept and immediately envisioned many applications of the tool in their respective domains, such as pain management, addiction monitoring, family therapy, etc.

Based on these findings from the POC, we refined the concept. The focus group clarified that the device needs a very low threshold of use to be of value. Formal requirements for a device that could be used by real users were formalized based on the focus group's input.

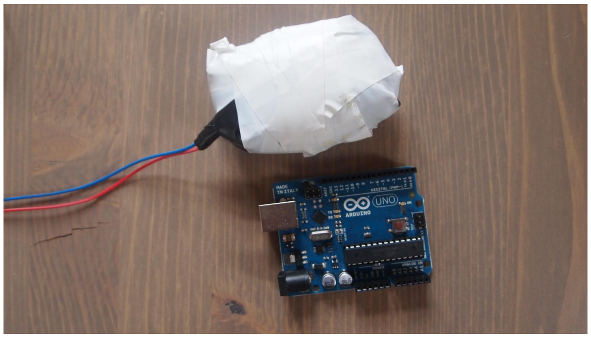

Figure 2. An Arduino providing the technical interface to a sensor encapsulated in a soft material, suitable for grasping and clenching.

Requirements

The requirements for Grasp are categorized according to their functional, non-functional, and interactional and material properties.

FUNCTIONAL: CONCERNING BEHAVIOR AND FUNCTION

F1. The device should store a timestamp with a squeeze event, with the intensity (valence) of the squeeze in second increments.

F2. The device should be able to transfer these data to a device for visualization.

F3. The device should have sufficient power to work for several months without charging.

F4. The logged data should be anonymized.

NONFUNCTIONAL: CONCERNING OPERATION

N1. It should be easy to maintain (charge and transfer data).

N2. It should be robust (withstand real-world use).

INTERACTIONAL AND MATERIAL: CONCERNING THE INTERACTIONAL AND MATERIAL PROPERTIES

I1. The device should invite squeezing.

I2. The device should feel good to squeeze—correct squeeziness.

I3. The device should be handheld.

I4. Grasping and clenching should be inconspicuous and discreet in real-world use.

These requirements were addressed in an iterative design process in which different iterations were explored and investigated to evaluate the technology, function, and form. The figures and descriptive text follow the chronological order of the design process with references to the different requirements (F, N, and I) as they were addressed.

Electronics

The functional requirements are strongly related to the design of electronics. As pointed out by Kanjo et al. [14], applications used in affective sensing pose a challenge to hardware designers, as the continuous availability of the application can be a drain on available power resources. This compels hardware designers to be parsimonious about which resources should be incorporated into the system design and compels software designers to implement strict adaptive methods for system resource management. The importance of this became increasingly clear throughout the design process.

Figure 3 illustrates a rough prototype device designed to remedy requirements F1 and F4. This device can store squeezes anonymously in the software. However, the device was not handheld (I3), was not very power efficient (F3, a few days of power), and could not transfer data conveniently (F2).

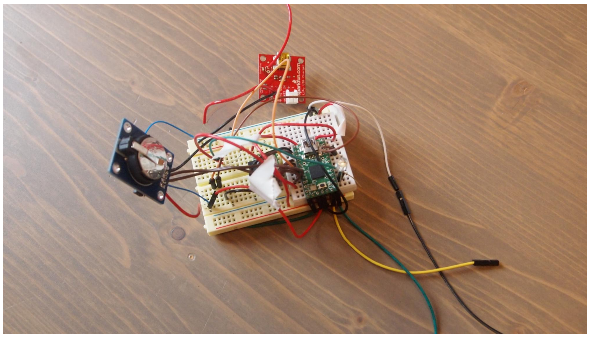

Figure 3. A breakout board with charging (red top), a CPU for storing and processing sensing data in the form of squeezes (green) and real-time clock (RTC) module for relating clenches to timestamps.

None of the nonfunctional requirements were met at this stage. However, this iteration showed that the other requirements could be met by optimizing this crude prototype.

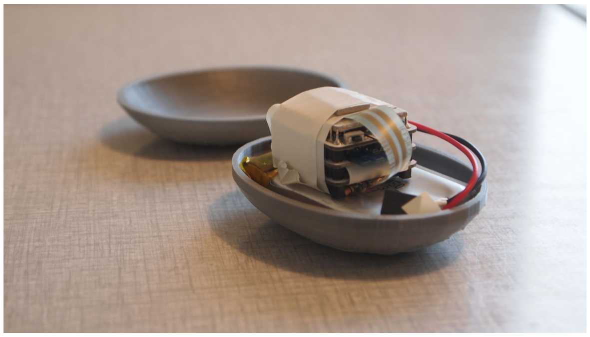

Figure 4. A more compact device with stacked boards, Bluetooth low energy (BLE), a lithium ion charging circuit, and flash storage.

Figure 4 shows another iteration with the design, utilizing a small form factor Arduino platform with the ability to "stack in" more features. In this manner, the issue of transferring data (F2) wirelessly over Bluetooth low energy (BLE) was solved. The device can be charged via a universal serial bus (USB), but the drawback is that the architecture does not lend itself to extreme power savings (F3). Stacked modules like these carry a significant extra electronic payload to satisfy a wide range of prototyping requirements. Additionally, a great deal of redundancy for input and outputs, voltage regulators, and other electrical components make these suitable for achieving a somewhat small form factor, but leave little room for freedom to design an outer shell small enough to invite squeezes (I1) in a handheld form factor (I2) that feels good to squeeze (I3).

To address the issues of power-hungry and sizable internal components, a custom printed circuit board (PCB) was created (Figure 5) that would resolve the power and size issues.

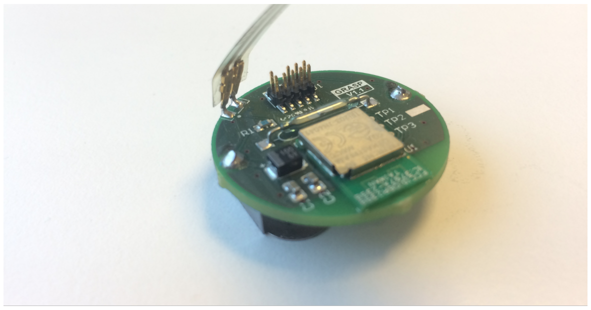

Figure 5. The Grasp platform reduced to a PCB with a radius of 15 mm, and a total height including the battery clip of 20 mm.

The PCB was designed based on a System on a Chip (SoC) incorporating an ARM Cortex M0 CPU and BLE peripherals. The hardware and the protocol stack are managed independently from the application software, and the former are assigned protected memory areas and a separate execution context. To ensure that the device does not consume excessive amounts of power, it is vital to keep the device in a low-power idle mode whenever it is not in active use or the hardware requires CPU interaction. To that end, the firmware follows an entirely event-driven design pattern. User inputs in the form of BLE stack events and the application of pressure generate soft or hard interrupts. The interrupt handling routines transfer signals to the main application context with a First In First Out (FIFO) scheduler. The scheduler functions as an event dispatcher for the BLE stack and an internal state machine, which tracks the execution context and the current application mode. The system goes into low-power mode whenever the scheduler contains no events and is awoken from low-power mode only when necessitated by hardware triggers or user input. This software design prevents busy waiting and reduces power consumption to approximately 3 μA when idling, which is the majority of the time in a typical use case. The device in its current state can operate for a year on a single coin cell battery (CR2450) under typical usage conditions. This eliminates the need for extraneous charging equipment and the hassle that periodic charging imposes on the user (F3 and N1), thus making it easier for the end user to keep the device operable. With electronics in a form factor more suited for encapsulation (I3), the process progressed toward creating a squeezable casing.

Casing

The casing for the electronics underwent through several exploratory iterations. The iterations consisted of evaluating and testing a wide range of three-dimensional (3D) printed and natural materials to satisfy the requirements (I1, I2, I3; see Figure 6).

Figure 6. A collection of casing tests with 3D printed materials (sandstone, metallic plastic, resin, SLA), vulcanized plastic, silicone moulded surfaces, coated prints, and a natural stone.

The force sensitive resistor (FSR) requires directional force to sense pressure. A casing that would compress in the correct direction was needed. The universal form factor for the casing design is a top part and a bottom part with a compressible material between these parts. The challenge was to find a shape in combination with a compressible material for the membrane connecting the parts that would convey a satisfactory squeeze and have comfortable material qualities. A sense of a good squeeze is to some degree a difficult quality to achieve. Our design goal was that the physical load on the membrane between the two parts should initiate the sensor and electronics at a moment that felt like a soft squeeze for the user. Effort was directed at emulating the heat transfer of a stone by incorporating metal in the plastic casing via 3D printed metallic plastic and 3D printed sandstone.

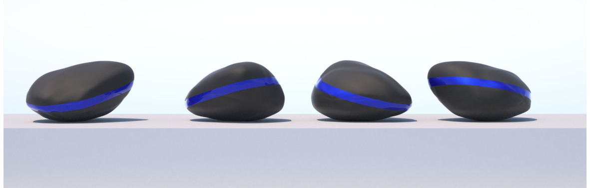

Figure 7. The final 3D organic computer-aided design of the stone shape, with the membrane following the natural seam of the stone.

Early in the design process, informal test users reported that the geometric 3D printed shapes presented to them felt unnatural and uncomfortable to squeeze. A variety of stones from a nearby beach were collected to evaluate natural and organic shapes. A stone that users would position in their hand in a compressible orientation was found in the collection. The real stone was used as a reference, 3D scanned, and re-meshed to create esthetic seams along the natural shape of the stone (Figure 7). This seam, in combination with the form, would invite the user to put it in a position in his or her hand that allowed compression of the sensor. This design with slight differences in membrane thickness, material, and alignment underwent informal evaluation by coworkers, friends, and family members until a final design with a stone-like and graspable shape with a smooth finish (Fig. 8) was chosen.

This final iteration (Figure 8) is the device evaluated in this paper. The electronics are encapsulated in a 3D printed material, separated by a membrane in a squeezable material that enables the electronics to record and store squeezes, as well as interact with a crib for easy data transfer. The device emits no sound or other feedback to signify a squeeze has been stored. The act of squeezing is felt by the user, and this can be construed as feedback, in the same manner one senses a mouse click or a tap of a finger.

Figure 8. A woman clenching a stone.

Crib

To enable easy data transfer, and still have the device use low power, a crib is used to initiate the transfer of data to a visualization device. When the stone is placed in its crib, the crib triggers an event in the device to initiate data transfer and interaction.

Through several iterations (Figure 9) of the shape, form, and materials, a design that would transfer data in a user-friendly manner was finalized. These iterations led to the last iteration shown in Figure 10. To initiate data transfer, the user has to place the device in the lower part of the crib, as seen in Figure 10. This initiates BLE communication with an app running on a tablet that retrieves the data stored in the stone.

This design satisfies the functional, non-functional, and interactional requirements used to guide our design process. In this form, the Grasp platform functions as a portable stone-like object that allows for tangible and physical interaction with a crib to transfer data to a tablet application for data visualization.

By providing the user with a tool that is small and inconspicuous, the stone can be interacted with privately and used pervasively. This is intended to make data registration effortless and enables users to register data consistently. The act of grasping or clenching the stone is a natural reaction and a low-threshold way of interacting with the device, enabling use in a wide variety of situations.

Figure 9. A wide range of look and feel were prototyped, and the final design was chosen (far right).

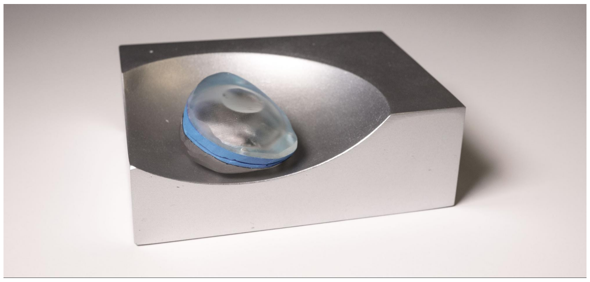

Figure 10. Current iteration of the Grasp stone in its crib.

Furthermore, the stone can function as a transitional object (see [1]). transitional object is any object used with the intention to represent security or comfort for the patient. The object is further meant to represent the relationship between the patient and the therapist. In this way, the stone can serve as a reminder of a shared goal or a shared bond. The stone responds to squeezes (Figure 11), which, in turn, are stored in the stone's internal memory as numeric values with a corresponding time stamp.

USE CASE

The use case that has been envisioned for the Grasp platform is a therapeutic context, i.e. a patient-therapist relationship, in which the platform can be used to alleviate recall bias. In this context, the Grasp platform can help the patient recall past events and emotional states, provide the therapist with a possible starting point for a conversation, and allow the two to collaboratively analyze changes and patterns in the collected data.

A person undergoing therapy who might benefit from using the Grasp to serve as a transitional object that stores emotional events receives a Grasp at a clinical visit. The therapist instructs on use, and they jointly agree upon affective states or emotional events that should be registered until the next visit. During this period, the stone functions as an extended memory and as a transitional object.

When the user returns to the therapist, the stone is put in the crib and the data visualized on a tablet. The patient does not have to clearly remember the events, as the stone will store a record of the events for him or her, and will present them to the patient in a suitable visual format. In this therapeutic setting, the visualizations are intended to facilitate the dialogue between patient and therapist.

EVALUATION

We conducted a small-scale field trial [4] with three participants. Each participant was given a Grasp stone to try out for a 4-day period as a technology probe [12]. They were given minimal instructions on how to use it, only that they should decide on a specific thing that was related to affect and try to use the stone to register and monitor this state or these events over the next few days. After the trial, we conducted qualitative semi-structured interviews with the participants that lasted between 20 and 30 minutes. In the interviews, we asked the participants about their experience of using the stone, what they chose to use it for, the practicalities of handling and taking care of the device (where they kept it, how it felt in the pocket, etc.), how they experienced the interaction with the device (how it felt in the hand, the weight, the texture, the size), and how it influenced their own perception of the issue they chose to log or capture. We also discussed the different settings and contexts of use (social, private, public, indoors, outdoors).

The participants chose a wide variety of applications, and we had not foreseen all of them. One chose to use the stone for registering the experience of muscular pain, another chose to use it when listening to music and tried to express rhythm by grasping the stone while listening as a way of capturing an aspect of the experience of listening to music. The last informant chose to use the stone to log affect related to hunger and food cravings.

The participants were generally very positive about the design and usability of the device. Although such typical praise is somewhat expected in this situation [4], several important issues came up in the interviews.

One participant really liked that the device was very discreet and inconspicuous and had kept the device in the pocket of a jacket and pressed it to log events in public places (such as on the tram). In more informal and semi-private social settings, such as at home with friends visiting, the device lay

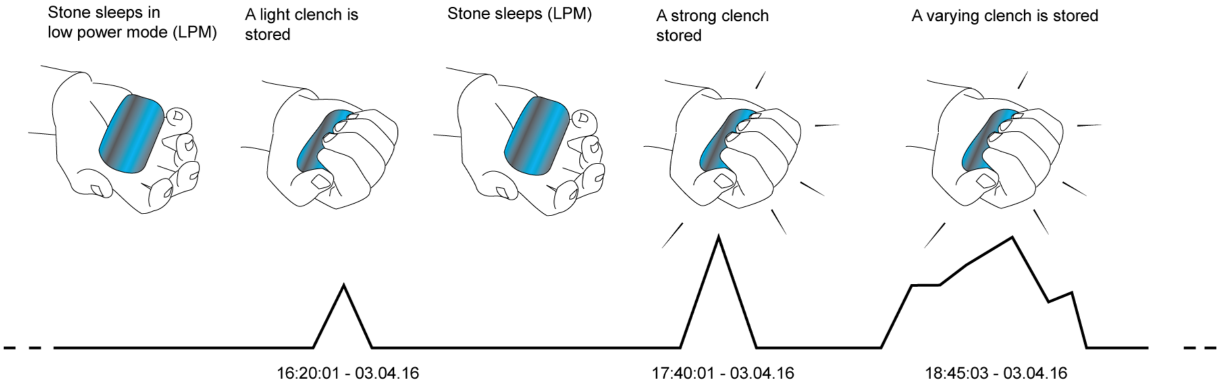

Figure 11. The tangible interaction for storing grasps of varying strength.

on a table and immediately became a "conversation piece." The stone was a somewhat unfamiliar object, and thus the focus of attention.

The participants were all adults and reported that the stone fit well in their hands and was comfortable to squeeze, grasp, and clench. In one exception, one participant wore a ring that interfered with clenching the stone. Further, the texture and weight of the device were experienced as a good fit.

One participant had tried to press the stone in a certain pattern to express messages or give different forms of feedback to himself when he looked at his log data later. In this way, he tried to tag different events and make a more nuanced log than what the device is designed to do. In the interviews, it became clear that he really wanted a feature that annotated given events, but he could have done this by taking notes on his phone or on a notepad. Another participant had thought of the interaction with the stone in a more binary way—thinking that one press of the stone was one incident and that it was either on or off and was unable to get the nuances of the hardness of a grasp.

The participants were also asked to what degree the Grasp stone helped them deal with the issue they had chosen to log. Beyond making them focus on the given behavior or emotion, the act of grasping the stone did reportedly not really alter their perception of the emotional state or affective experience. This observation was probably partly because the participants were only doing this as part of a trial and reflects on their loose commitment to the use of the device. However, one participant reported that knowing that the behavior was being logged contributed to altering the behavior in question. This points to how pervasive sensing can make the user accountable through intentional logging. This accountability is an important feature for therapeutic applications of the tool.

DISCUSSION

Tangible interaction with the stone-like object is supposed to provide sensory feedback to the user. This is achieved through the material form of the device; it responds to squeezes by yielding slightly. The sensation of pressing the stone is also meant to work as a reminder of the therapeutic relationship [1], and the computational registration of the squeezes makes the user accountable to the therapist. This resonates, to a certain extent, with the concept of the affective loop [27], but the feedback is delivered subtly and relies on having established a relation of trust between the therapist and the patient. This also points to how the full Grasp platform and the intended context of use will cut across the two active modes of affective pervasive sensing as defined above. Although the tangible interaction with the stone supports in situ intentional interaction, the data visualizations are to be used in a therapeutic session and thus support a reconstructive mode of affective interaction.

The challenge of designing for in situ intentional tangible affective interaction, as it is implemented in the Grasp stone, is also a way to respond to Boehner et al.'s [3] guideline for affective interaction: that it is supposed to support interpretive flexibility. The squeezes of the stone are not in any way categorized or predetermined by the system, but the definition of the emotion and its interpretation are left to be determined by the user in dialogue with a therapist. This allows for "emotional meanings to emerge in a situated way over the course of interaction." Further, the Grasp stone can register the hardness of the squeeze, and this can be assigned to somehow denote the value of the valence of the emotion. When trying to make sense of the data from the stone, this can be made a topic of conversation in the therapeutic dialogue, and thus, the reliability or consistency of the hardness of the squeezes is not critical for the conversation or the role of pervasive affective sensing in therapy.

Another challenge that arose during the work is the opportunity to combine the in situ intentional mode with an automatic mode of pervasive affective sensing. This will involve including another device with biofeedback capability. Although the accuracy and reliability of many tools for automatic and passive sensing of physiological and biological signals have increased dramatically in the last few years, this approach is very sensitive to inaccuracies or errors in measurements, and monitoring "human health behavior" reliably remains a challenge [17]. The combination of subjective in situ reports from tangible interaction with the automatic mode can provide opportunities for delivering interventions and give context to the interpretation of biosensor data.

Pervasive affective sensing has several inherent challenges, such as battery life and privacy [14]. Although the Grasp platform is designed to keep the interaction and handling of the device minimal, effortless, and low-threshold, this design choice has certain trade-offs. The utility of the device might be increased by adding functionality such as annotating squeezes or getting feedback from the device in the form of lights, sound, vibration, or a shape-shifting surface (e.g., e-ink). However, such features would increase power consumption and shorten the battery life. Giving feedback can also make the device more conspicuous and thus draw unwanted attention to use of the device, which can have a negative impact on privacy.

CONCLUSION

In this paper, we introduced four modes of interaction that pertain to pervasive affective sensing systems: in situ intentional, retrospective, automatic, and reconstructive. These modes were used as a backdrop for a discussion of the challenges of designing for pervasive affective sensing. In particular, the in situ intentional mode was emphasized. The study was conducted as research thorugh design project in which the design choices made during the iterative process are meant to address some of the inherent challenges of designing for affective interaction. Further research is needed before the Grasp platform can be used in a clinical setting, and one of the next steps will be to fully design and develop data visualizations on a tablet and examine how these can be used to support a therapeutic dialogue. At that stage, the platform will be ready for formal clinical trials.

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