# SWARM: An Actuated Wearable for Mediating Affect

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## ABSTRACT
We present SWARM, a wearable affective technology designed to help a user to reflect on their own emotional state, modify their affect, and interpret the emotional states of others. SWARM aims for a universal design (inclusive of people with various disabilities), with a focus on modular actuation components to accommodate users' sensory capabilities and preferences, and a scarf form-factor meant to reduce the stigma of accessible technologies through a fashionable embodiment. Using an iterative, user-centered approach, we present SWARM's design. Additionally, we contribute findings for communicating emotions through technology actuations, wearable design techniques (including a modular soft circuit design technique that fuses conductive fabric with actuation components), and universal design considerations for wearable technology.

## AUTHOR KEYWORDS
Wearable technology; accessibility; universal design; affective computing; emotions; stress management

## ACM CLASSIFICATION KEYWORDS
H.5.m. Information interfaces and presentation (e.g., HCI).

## INTRODUCTION
Identifying and reacting according to one's own emotional state is vital for physical and mental well-being (e.g., stress management). It is also critical to identify others' emotions for successful communication. Devices for measuring emotion (using signals like heart rate and perspiration) are becoming cheaper and more reliable; the emerging category of "smart watch" products is already beginning to integrate heart rate sensing (e.g., the Samsung Galaxy Fit). Within a few years, wearable affect monitors such as multi-purpose smart watches or specialty devices (e.g., Spire [spire.io]) may be as ubiquitous as fitness bands are today.

Our work extends current emotion detection techniques by introducing a wearable device to aid in interpreting and/or enhancing one's personal emotions and alerting the wearer

**Figure 1. Our modular cotton scarf houses canvas modules with conductive fabric circuitry designed to control heat, vibration, and audio actuations.**

of others' emotions; the device is designed to respond to signals gathered from various sensors (via Bluetooth). While this is potentially valuable for everyone, both areas of personal and group emotion management have particular implications for people with disabilities. People with vision or hearing impairments, for instance, may not receive important visual or verbal cues of others' emotions. Thus, universal design (making the device inherently accessible for many types of users) was central to our project.

We iteratively designed, built, and tested a wearable technology, SWARM, involving target stakeholders for user-centered feedback at various stages. After discussing related work, we expound on the iterative design of our scarf from a low-fidelity prototype to a final working design, including lessons learned and novel techniques developed regarding the fabric, hardware and software design, as well as user perspectives on wearing a device that reacts to emotions. We close by discussing the implications of our findings for wearable technology as a means of emotion management.

## RELATED WORK
### Affective Computing & Quantified Self
Quantified Self [quantifiedself.com] is a movement of using technology (primarily sensors) to provide people with quantitative data about their everyday activities, generally physical (such as using a pedometer). The data has also been applied to affective computing (using technology to determine one's emotional state), not surprising given the correlations between mental and physical health [13, 16, 25].

Affective computing is accomplished using many techniques, including biosensors, audio and text analysis, and

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facial recognition [6, 7]. Work is also being done to outfit the environment with sensors, such as pressure sensors in keyboards and computer mice, and implicit patterns of device use [8, 23]. From the raw numbers provided by the sensors, algorithms can determine a person's affective baseline and indicators of a change in emotion [4]. Researchers are studying how best to present this data to end users, ranging from data visualizations on a mobile application to environmental displays for everyone to see [3, 18].

Our work extends this line of affective computing research to explore two additional avenues. The first is intervention, where a system not only alerts the user of a change in their emotions, but also attempts to mitigate negative emotions and enhance positive ones in real-time using actuations. Similar interventions were recently proposed, though not yet implemented, in [9], whose authors proposed actuations for relieving stress while driving such as cooling the car's temperature. Our work goes beyond the proposals in [9] by involving a spectrum of emotional states and creating a prototype of the actuations to receive user feedback.

The second focus of our research is group detection, where the system conveys the emotional state of others, either individually or in aggregate (assuming a prevalence of wirelessly available sensor data per person). For example, as a person approaches a conference room where an important business meeting is taking place, her SWARM scarf might actuate to let her know if the mood in the room she is about to enter is tense or relaxed. This is particularly relevant for people with disabilities.

### Affective Computing & People with Disabilities

Due to the nature of certain disabilities, many people have difficulty identifying emotions – either their own and/or those of others. As a result of an Autism Spectrum Disorder, for instance, a person may have difficulty recognizing and articulating their emotional state, as well as difficulty interpreting and reacting to the emotions of others [2]. For people with vision or hearing impairments, identifying another person's emotional state may be difficult without being able to see or hear the visual or verbal cues associated with communicating emotions [10].

Prior accessibility research has explored specific aspects of emotion awareness for these populations. For instance, many systems attempt to teach children with ASD how to identify emotions based on body language (e.g., [15]). Researchers have explored using vibration feedback on a glove to emulate information from facial expressions for those with vision impairments [11]. Work has also been done to ensure automated American Sign Language systems include emotion expressions in the signing avatars as well as emotional states in captions [12, 20]. However, no prior work has sought to combine emotional interpretation suitable for use by people with varied disabilities into a single system.

### (Wearable) Affective Objects

An important aspect of affective computing is the affective object: "...any physical object which has the ability to sense emotional data from a person, map that information to an abstract form of expression and communicate that information expressively, either back to the subject herself or to another person" [19]. In evaluating the type of affective object to create, we explored a design space that would allow for real-time, on-body interventions. Thus our focus rapidly and firmly pointed towards a wearable object.

The ability for wearables to blend in with typical fashion designs is important, as it has implications for people with disabilities. Assistive technology that looks drastically different from mainstream devices draws unwanted attention to a person's disability and perpetuates a stigma often associated with disability [21]. Creating a wearable that looks fashionable and conveys information subtly to the user was therefore a key design criterion for our project.

Two notable projects inspiring our work were the modular scarf built in [1] and scarf, bracelet, and vest built in [24]. Designed for people with ASD to help relieve anxiety, both projects used wearable technology to embed many actuations into garments including haptics, cooling, and air compression. These projects helped bring awareness to the types of actuations that may be useful for users with autism. We extend this work by exploring additional actuations (to facilitate various affect interpretations) and employ a modular design for personalization (to address universal design for many types of users).

## SWARM: INITIAL DESIGN

In the first phase of our project, we identified which aspects of affective computing we wanted to address, designed the actuations, built a low-fidelity prototype, and presented the initial design to users for feedback. We named the project SWARM (Sensing Whether Affect Requires Mediation).

### Form-Factor

We designed SWARM as a scarf for several reasons. Firstly, we were inspired by weighted vests used in ASD therapy [22]. While there is some controversy over its usefulness, many people with autism use pressure as a means of helping to focus and relieve the stress of sensory overload [5]. A scarf could be wrapped around the wearer in a vest-like manner if such comfort were desired.

Secondly, as mentioned, previous work in [1] presented a promising modular and versatile scarf design that appeared viable for housing several different actuations in one garment. The vast number of ways in which a scarf can be folded further motivated using this style of garment.

Lastly, scarfs are currently fashionable and worn as an everyday garment, addressing our desire for a discreet design that does not draw unwanted attention as an assistive device [21]. Because many fashion items are gendered (in the U.S., "indoor" scarves are more commonly worn by women), we tailored our design and evaluation for adult women users.

| Mood | Actuations |
|---|---|
| **Stressed** | Cool body temperature<br>Hear/Feel soothing music<br>Use stress relief balls<br>Apply pressure (ASD) |
| **Sad** | Warm up body temperature<br>Hear/Feel cheerful or somber music<br>See soothing visualizations |
| **Calm** | None (scarf is dormant) |
| **Happy** | Maintain body temperature<br>Hear/Feel cheerful or upbeat music<br>See soothing visualizations |
| **Excited** | Cool body temperature<br>Hear/Feel cheerful music<br>See festive visualizations |
| **All** | Vibration alert notification:<br>(a) Short buzzing for personal notification<br>(b) Varied patterns to relay group emotions |

**Table 1. Six actuations for the personal emotion awareness scarf included vibration, heat, cooling, music, weights, lights.**

### Actuations

In selecting SWARM's actuations, we first limited the emotions addressed by the garment to five from Russell's circumplex model of affect: stressed, sad, calm, happy, and excited [17]. These gave us a balance of positive and negative emotions common enough to be familiar to our participants. We identified six actuations inspired by prior work such as [9] but also thought to be accessible and provide a rich, multimodal language for conveying emotion – heat, cooling, music, weights, vibration, and lighting (Table 1).

We imagined the overall scenario around the scarf's use as someone (or everyone) wearing biosensors (such as heart rate monitors) that send readings via Bluetooth to the scarf.

### Reacting to One's Own Emotions

Table 1 shows our initial design for how SWARM would react upon receiving a particular emotion notification about the wearer. For instance, in response to an excited state, SWARM could play upbeat music, or in response to stress, users could add weights to the scarf (analogous to weighted vests sometimes used in ASD therapy). We chose weights that could serve a dual role as embedded stress relief balls. Depending on a user's needs, SWARM's utility could be customized towards the goal of either reflecting a user's current emotional state (e.g., minor-key music when feeling sad) or the goal of transitioning to a new state (e.g., upbeat music when feeling sad).

### Indicating the Mood of Others

For alerting of others' emotional states, we designed only two classes of actuation due to our accessibility and discretion concerns: vibration and lighting. These would activate as a distinct pattern such as longer vs. shorter vibration pulses, or varying colors and patterns. To promote discretion for lighting, users could wear the scarf in a configuration that reduced visibility to others; alternatively, subtle color changes in the scarf could be considered aesthetically pleasing and fashionable by observers, who need not be aware that they encode information for the wearer.

| Actuation | Hardware |
|---|---|
| **Alert** | Vibration motors soldered to battery pack |
| **Heat** | 12V heating coil soldered to battery pack |
| **Cooling** | Columbia Freezer Zero ™ Neck Gaiter fabric |
| **Music** | Adafruit MP3 Shield on Arduino Uno |
| **Weights** | (a) Fabric bean bags used in weighted vests<br>(b) Balloons filled with sand |
| **Lighting** | (a) Battery-powered fabric ribbon LED strip<br>(b) Adafruit NeoPixel Matrix on Arduino Uno |

**Table 2. Initial prototype's hardware components**

While users with no vision would not be able to view the lighting, many visually impaired people have some usable vision, particularly for coarse, low-resolution color or brightness changes such as those we designed for SWARM's embedded LED display. Also, the vibrations could accompany the visualizations to ensure accessibility.

We did not want the scarf to speak the emotions of others, not only because of the accessibility concerns for those who are deaf but also because we did not intend for the wearer to constantly wear headphones, nor would it be discreet to have sound over speakers.

### Hardware Design

For initial prototyping, we explored low-fidelity items that would work well enough to present the concept to users, even if they were not lightweight enough for all-day wear. Our goal was to elicit reactions to the overall concept as well as each proposed actuation to determine whether the design was desirable before pursuing further development. We used the Arduino prototyping platform due to the extensive availability of lightweight hardware options; we also purchased ready-made components as well as nontechnical items to complete the initial design (Table 2).

### Fabric Design

We wanted to include each actuation as its own interchangeable module to provide personalization and customization (for instance, the ability to remove lighting modules for users without vision). In considering scarf designs, a hexagon shape emerged as a way to add visual appeal to the scarf while facilitating interlocking modules. Like the actuations, the design also became part of the initial user study to see how users reacted to SWARM's appearance.

After paper prototyping and then laser cutting felt designs, we decided on a honeycomb pattern with a higher-elasticity fabric between the shapes to allow for stretching the scarf around the body (Figure 2). In total there were 27 modules (three rows of 9-5"x6" pods with 1" of space in-between) to mimic the size of a typical scarf. We only needed eight modules for the technology we wanted to demonstrate (Table 2), so the others were empty placeholders for potential duplicate modules or to store weights. We designed the modules as pockets to insert either electronics or weights.

We also tested different fabrics, exploring both front-facing and inner-lining fabrics. The most important consideration was being thick and sturdy enough to house the electronic components such as the MP3 player shield and controller.

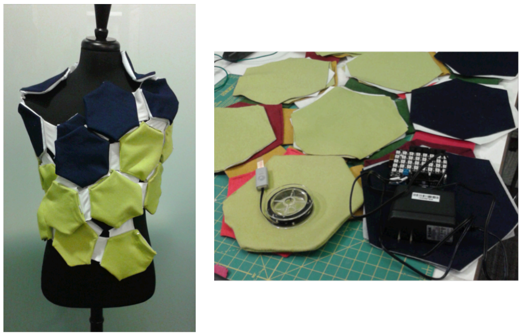

**Figure 2. Cotton fabric scarf includes detachable hexagon-shaped modules enclosing hardware such as battery-powered vibration modules and heat coil pads**

While we realized this did not represent the final design (which would have smaller, lighter components) we wanted the scarf to be comfortable enough to try-on. We also wanted a breathable texture (since many of the electronics would heat up when powered), as well as one that was soft and comfortable to wear (since this would rest against the skin, and users with ASD with sensory sensitivities might find rough fabrics particularly uncomfortable). We also didn't want the fabric to wrinkle too easily during stress ball use.

Ultimately, we preferred cotton for the outer layer because of its breathability and softness; we disregarded color. We used a denim knit to house most of the electronic components using no lining, and used a mid-weight knit lined with polyurethane for the modules that were either empty or included only the LED ribbon strip (Figure 2). We used a stretchy jersey knit between the modules and Velcro to seal each module as well as attach the knit between the modules. This allowed for fast assembly and would later be useful when demonstrating the modules to users.

## USER FEEDBACK ON SWARM'S INITIAL DESIGN

To help refine our design, we conducted a user study of the preliminary garment. Our goal was to get feedback on users' desire to have a garment that reacts to and/or relates emotions, the fashion design, the appropriateness of the actuations, and ideas for future features and improvements. For this initial round we focused on recruiting people with disabilities to confirm our motivating scenarios and ensure the features were accessible.

Our participants were eight adults aged 20 to 62. We had one participant who was both hard of hearing and low vision, four visually impaired participants, two auditory impaired participants, and one with high functioning autism. Though SWARM's aesthetics are targeted for women, we had two male participants in this initial group, one with a visual impairment and the other with autism. Their feedback was valuable to the project, since it confirmed that, as suspected, our design was better-suited for female users.

We used a semi-structured interview along with a written questionnaire to gather our data. The interview included gathering the participants' current strategies on handling their emotions, walking through each actuation to collect impressions, discussing the personal vs. group emotion awareness features, and having participants draw their preferences for where to place the actuators on a body diagram.

### Overall Reactions to the Scarf

Participants found the overall concept of having a reactionary garment appealing. On a 1 to 7 scale of "Not Useful" to "Very Useful", survey scores averaged 5.0 for interest in a garment that reacts to emotions and 5.38 for one that displays and reacts to the emotions of a group. They found the preliminary scarf design too bulky and heavy to be comfortably worn, however, likening it more to a blanket.

Overall, participants found the vibration alerts useful and a logical first step prior to any other actuations taking place. They felt the heating element was soothing and would change a somber or stressed mood. As our autistic (male) participant stated, *"If I'm stressed or feeling sad I wouldn't mind having a warm hug."* They felt the idea of fabric cooling them was just as helpful, but many wondered if having both heat and cooling were redundant.

The stress balls were liked, though one participant said they preferred a gel to the sand we used in our balloons. One of the Deaf participants also mentioned she would use them to massage her hands since she uses sign language to communicate and it leads to cramping. When introducing the dual function of the stress balls as weights, our autistic participant said he had never heard of weighted vests. Thus, while participants speculated that weights may be a useful feature for some, there was no one to attest to its true value.

All of the participants said some sort of auditory feedback would be useful but two participants mentioned they would want an alternative to music such as environmental sounds or talking (e.g., a talk radio show). (Our hearing-impaired participants had hearing aids that could pair with personal sound systems to allow them to hear audio.)

The LED lights were most controversial and had mixed reactions mostly regarding whether to publically share their emotional state. Three participants (all female) said they would like to have a visual display but only when they were in a good mood, not a bad one. The remaining participants did not want their emotions shown due to privacy concerns. For instance, one (deaf female) participant said she wouldn't want people to *"take advantage"* of that information. That same participant viewed the LEDs more as a back up to the vibrations in case she didn't feel them.

In terms of placement on the body, participants generally agreed – the heat, cooling, and vibrations were preferred around the neck, the MP3 player either near the neck or near the hands (depending on how the scarf was worn), and the LED lights throughout the scarf.

### Displaying Others' Emotions

We explored not only a personal emotion device but also group detection to address the perceived accessibility issues surrounding detection of others' emotions. Participants with more severe hearing and visual impairments confirmed they had difficulty detecting other people's emotions due to missing verbal and non-verbal cues. Our autistic participant said he did not have trouble detecting emotions, but explained that he was "high functioning," and thus did not have as severe symptoms as others.

When told about the group emotion detection concept in general, reactions were overall reluctant but willing. Four participants had concerns about the privacy implications of being able to detect the emotions of other people using technology. Two participants thought it would be better to limit the usage to certain scenarios (a classroom or meeting) and people (the teacher or boss). Only two participants explicitly wanted to use this feature for themselves - our autistic participant and one of the female visually impaired participants. The autistic participant explained that while he can detect emotions, he has a problem producing empathy and felt this would give him a cue. The rest of the participants saw this as being more useful for "someone else" but not themselves. The "others" included police officers, therapists, and people with autism; thus, they were willing to concede that certain monitoring of emotions to benefit others was worthwhile.

### Initial User Feedback: Summary of Key Points

By involving users from target demographics at this point in our design process, we learned that participants liked the idea of a scarf form-factor, with many mentioning they liked the modularity as well. Based on the questionnaire rankings, the vibration alerts, heat, cooling, and stress balls emerged as favorite actuations. The MP3 player was not as popular overall, but those participants who favored it felt it was vital to changing their emotional state. Being able to wrap one's self with the scarf and using it as a weighted garment were not as important as initially thought. No one mentioned additional actuations they would like to see included in the scarf. From these findings we began to refine our design to create a working, lightweight, slender scarf.

## SWARM: FINAL DESIGN

In this second phase of our project, we used the user feedback to refine the appropriate hardware and fabric to produce an updated, fully functional, comfortable scarf.

### Actuations

From the user study, we removed lighting (due to users' privacy concerns) and cooling (as heat was more favored and we agreed might be redundant to cooling)..We ultimately removed the stress balls, also, due to the circuitry and fabric design outcomes, as described in sections below. We continued our focus on five basic emotions: stressed, sad, calm, happy, and excited. We also continued to focus on both personal and group emotions given users' interests.

For personal emotion actuation the designs were fairly straightforward: we envisioned two short vibrations that would alert the wearer of a change, followed by heat (if they were stressed or sad), and music playing (in all cases, with the song choices varying from slow to fast) While simple in its execution and design, the concept was substantial because it would elicit feedback on a wearable technology receiving notifications about a change in one's emotions and automatically reacting to that information.

For group emotion actuation, we took a cue from our participants as well as prior research (for instance, [11]) and explored varying vibration patterns as a means of relaying emotion. Accordingly we programmed nine patterns, varying both the number of vibrations (between two and three) and length (from 250ms to 1000ms). Most patterns had a consistent duration, but one pattern toggled long and short. The patterns were meant to be enough to demonstrate the concept to the participants and begin a discussion of what types of patterns they would desire.

### Cell Design

As we began the actual fabrication, modularity was a focus because participants in the first study liked the customization it afforded, and also because it facilitated easier replication of the fabrication processes for future explorations.

Initially, we explored printed circuitry and electronics such as inkjet printers and conductive pens. However, paper and Kapton film are the only sensible outlets, making the cell rigid and less supple for wearability. This led us to the soft circuitry work of Wilson [14], whose hard-to-soft component techniques inspired us to work with conductive silver ripstop fabric and felt. After several failed attempts to laser cut the circuits and adhere them to felt, we decided to invert the process by adhering the conductive fabric onto a large section of the felt first, then used a raster setting to cut out the negative space. This resulted in a successful soft circuit pattern. While the felt worked, we opted for cotton canvas to achieve more flexibility, with some regret since the felt provided a stronger support for the components.

We therefore created "soft cells" or fabric modules that each contained their own microprocessor (in our case a Beetle [dfrobot.com], a miniaturized version of the Arduino Leonardo). The Beetle accompanied by an actuator could, in theory, stand alone, but when linked could create a "chain" of cells to generate a suite of actuation (Figure 1b). We generated two unique cell circuit designs for vibration and heat (Figure 3), which was followed by one music cell, and a master cell that would be used to control them all with the I2C protocol and power them with a 3.7V by 800 MAH battery. We were unable to find a flexible 6-watt heater so we generated our own heat cell by including a coil of 40-gauge wire connected on the backside. They required additional power, and therefore we added a 3.7V by 800 MAH lithium battery in each module. In total the SWARM scarf consisted of 12 cells, 10 functional and 2 empty (due to the desired length of the scarf) (Figure 1a).

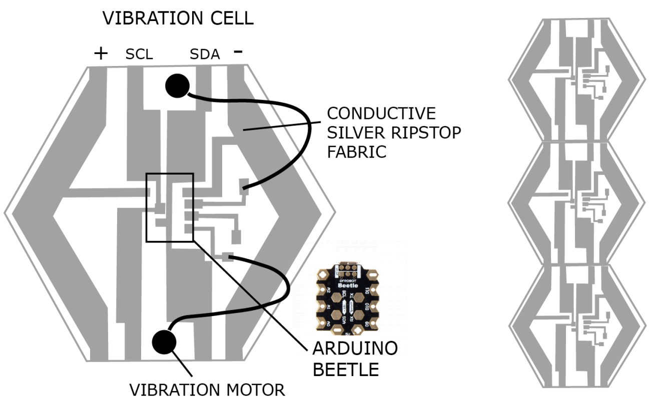


**Figure 3. Circuit diagram for vibration and chain of cells**

Adding hard components such as microprocessors or actuators to fabric is not a trivial task, so we initially used CircuitWorks® conductive epoxy [chemtronics.com] but this resulted in undesirable higher resistive connections. We then switched to Z-Tape [3m.com], a conductive adhesive transfer tape that consists of silver nanospheres embedded onto a 2D array in an adhesive surface that act as conductive double-sided tape. While this did work for attaching hard components, we discovered that over time the consistency of the connection started to fail as the silver spheres were absorbed into the fabric. To ensure secure connection to the haptic motors, we soldered copper shim stock pieces to wires and secured them with the Z-tape.

Finally, we needed a way to connect all the cells. Initially, for simplicity, we attempted to connect them with a metal agent such as safety pins or hooks and eyes, but found these connectors moved too much and interfered with the consistency of the power. Some of the loss in power was also due to the Z-tape coating being absorbed by the fabric, which also occasionally lost connection with the board. These types of issues in connecting hard and soft components are not new problems [18]. We were not able to route consistent power over multiple cells and resorted to hardwiring the cells together to ensure quality testing and omitted the master cell in exchange for a USB connection to a laptop. While this wasn't ideal, it still enabled some modularity that would resonate with users later in the studies.

### Fabric Design

In creating a soft fabric covering for the circuits, we found lightweight woven cotton that had a visually appealing black-to-white gradient (Figure 1a). We wanted to continue incorporating the hexagon but did not want the honeycomb shape for the scarf overall. Given we could not confirm the usefulness of the large design that mimicked a weighted vest and our multiple rows led to the undesirable bulky design, we only included one row of modules. We played upon the gradient in the fabric to cut 12-5"x6" rectangles and adhered 5"x5.75" hexagons in an inverted gradient atop the rectangles on both sides. Initially we included a fusible interfacing on the rectangles but removed it because the double-sided adhesive on the hexagons served as a stabilizer as well and we were concerned about stiffness.

The rectangles were left open at each end to ensure that the cells could be inserted and moved if needed. While safety pins did not work for our circuitry design, we found them useful for connecting the fabric as they allowed for a connection that was hidden from view but easily adjusted and flexible. To prevent additional time hand sewing a blind stitch, we laser cut the fabric to the correct dimensions, sewing on the sides of the rectangles and used anti-fraying products on the top and bottom. Despite having two cells empty of circuitry, we removed the stress balls for fear of jarring the circuitry and because the fabric wrinkled.

## USER FEEDBACK ON SWARM'S UPDATED DESIGN

Recruiting a new set of participants, our goal for this study was to again gather feedback on the scarf's overall concepts and fashion design, but also more detailed feedback on the actuations, placement, and wearability of our soft circuits. Participants were nine women, ages 18-61. Two participants were visually impaired, three auditory impaired, one was autistic, and three had no disabilities at all (to test the universal suitability of the technology).

We again used a semi-structured interview plus written questionnaire to gather data. We presented concepts in the second user study in phases, much like the first study. Users were introduced to affective computing overall, then shown the scarf and asked to put it on, evaluating each concept then concluding with the human diagram drawing. As mentioned in the prior section, we needed to mitigate some of the circuitry and fabric complications encountered. Thus, we demonstrated that the scarf was able to heat up and vibrate, gathering overall reactions to those actuations. Unfortunately only the first five participants experienced the heat directly as the heating element stopped working during the study. For the patterned vibration actuations we had a separate set of vibration motors for users to hold and analyze, and the music was played through headsets connected to a mobile phone for demonstration.

### Overall Reactions to the Scarf

Participants again found merit in the scarf. On a 1 to 7 scale of "Not Useful" to "Very Useful", survey scores averaged 5.56 for interest in a garment that reacts to emotions, and 4.78 for one that displays and reacts to the emotions of a group (lower than the prior study due to the inclusion of people without disabilities). Participants found the scarf lightweight, often forgetting they had it on at the conclusion of the study. Participants with disabilities appreciated the discreet aesthetics of the design.

The heating module, even when not fully demonstrated, was again a highly desired feature. A few participants pointed out this would be helpful as long as the surrounding temperature was not also hot (a point made more prominent by our summer timeframe). The music player was also found to be a fun feature and, as one participant noted in her questionnaire, one that would motivate everyday use. Overall, participants did not readily associate the vibration patterns with emotions. Generally any method of vibration only meant alert, primarily associated with phones ringing.

Interestingly our 7th participant (who was hard of hearing) mentioned heat would be a better indicator of mood than vibration as she could envision the scarf's heat indicating stress levels or the overall intensity of someone's state. When mentioned to the 8th (hard of hearing) and 9th (autistic) participants in subsequent interviews, they both agreed this would be an even more discreet, distinctive, and distinguishable actuation. P9 also mentioned two concerns specific to people with autism: that vibration might be too much stimulation or it might be misinterpreted as an alert of incorrect behavior rather than of someone else's emotions.

Participants again agreed on placement with the heat and vibrations preferred around the neck and near the shoulders, and the MP3 player either near the neck or near the hands.

After the first five participants, the scarf began to fray in some places as well as wrinkle; we gathered that either stitching or leaving the interfacing would have prevented this. As a result, we re-sewed a commercially-purchased, jersey-knit scarf into a tubular shape. During the 6th interview, we placed the circuitry into this tubular scarf housing after the participant commented that the grey scarf looked stiff. That participant and the remaining three participants subsequently wore the inner circuitry with the jersey-knit scarf and found it very comfortable, although it was a little restrictive when tying it around their necks due to the hexagon shape of the inner circuitry pods and the USB cables.

### User Feedback: Summary of Key Points

Participants in this round of feedback found high value in being alerted of their change in emotions, as they might not be aware of certain stressors, for instance. Overall interest in using the garment as an everyday item was less in this study than the previous study, however, particularly among the participants without disabilities. This was partly due to the design and form of a scarf in that it would not coordinate with all their outfits or be appropriate in the summer, but also because it appeared to be more useful in specific circumstances. For instance, three participants mentioned it being useful for people who could not otherwise convey their emotions (including elders in general, one participant's aunt who was wheelchair bound and not able to speak, and one participant's autistic son). Another participant mentioned she could see it used for law enforcement (a comment mentioned in our prior study as well). Notably our autistic participant did indicate she would find it useful for confirming emotional states and that she could see herself wearing it every day (though the exterior of the scarf would need to be interchangeable so that wearing the same scarf every day would not draw undue attention).

Unlike the first study, only one participant mentioned privacy concerns with detecting a group's emotions, explaining that people may not want to have their emotions detected. Most participants, however, envisioned the sensing would be optional if worn on-body or simply similar to the use of cameras today if sensed in the environment.

Utilizing the tubular knit scarf in the study produced the idea of having interchangeable outer shells to allow for matching in everyday wear. The knit fabric also allowed more movement than the woven cotton modular design. In addition, when asked to draw where on the body they would want the actuations, participants were almost unanimous in their responses, seeming to lessen the need for modularity over flexibility in how the scarf could be worn.

Participants did feel the heat and music were mood-changers, as we envisioned, and appreciated the vibrations as an alert of their *change* in emotions. The varying vibration patterns for *distinguishing* emotions were not received as intuitive, however, with the suggestion of using heat instead an avenue for future exploration.

## DISCUSSION

This project assumes accurate physical sensing devices that can detect and project emotions wirelessly. We recognize this is not the current state of emotion detection technology; however, the advancements in this field led us to envision what could result from such accurate and detailed devices. Though our scarf did not actuate to the full capabilities we envisioned for the second study, we were still able to receive valuable feedback, including confirming interest in group emotional awareness using sensing technology and future uses for personal and group actuations (such as using heat as an indicator of emotional state). This combines previously segmented work in many areas such as wearable computing, affective computing, and assistive technology.

The scarf design also accomplished discreet emotion awareness, broadening the prior use of specialized clothing as a therapeutic device for people with ASD to a fashionable, more universal technology. The form factor also led to a lightweight, flexible fabric circuitry wearable technology contribution.

The sleeve we ultimately created proved useful for the final design; having an interchangeable outer shell addressed the everyday wearability issue participants expressed. Also, modularity and customization (a desired feature given the individual preferences for actuation, particularly from the first study) could still be accomplished through attaching the inner electronic components more permanently, and then simply changing the wrapping to match other garments and the weather. Preferences for modules were not seen as specific to any particular user group (such as all participants with visual impairments) but instead were individualized, further motivating the idea of completing several modules then allowing a choice of inclusion.

Participants with disabilities saw the scarf as most useful. Participants without disabilities did not make a personal connection with the intended use of the scarf. Certainly our probe is not in-depth enough to make strong conclusions; however, this does indicate the need for more investigation into future uses of emotion detection systems.

## CONCLUSION & FUTURE WORK

SWARM is meant to compliment a user's current strategies for coping with their emotions, and also provide more information that may not be available, particularly for users with disabilities. We pushed this boundary by exploring scenarios beyond personal emotion detection to that of interpreting others' emotions.

People already use technology to regulate their emotions – our participants mentioned listening to music, driving, and calling others when experiencing emotions from stressed to excited. Thus, envisioning explicitly combining emotional reactions into one device is not inconceivable. As indicated by our participants, one's emotional state is not necessarily something people want broadcast, but more personal awareness (as in the Quantified Self movement) was desired. We propose systems for reflecting on and increasing awareness of one's own and others' emotional states as a future area of accessibility research that might be also useful for everyone as we move towards a smarter, sensor-filled world that knows how people are feeling and can help people address this context.

As part of our future work, we are recreating the soft circuitry using copper fabric and rivets to secure hardware components. We are also sewing additional fabric scarfs for the outer shell. Lastly, we are updating the software to create a wireless solution that will eventually integrate with physical sensing devices such as a heart rate monitor to generating a full emotion detection system.

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