Emotion Regulation in the Wild: The WEHAB Approach

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ABSTRACT
Emotion regulation is crucial for living with others. However, it is also difficult, and everyone, at some point, fails to effectively regulate his or her emotions. Can technology help? Several startups have sought to answer this question by developing wearable technologies designed to support emotion regulation. However, they typically lack a grounding in appropriate foundational theories and research. In this paper, we present a multidisciplinary approach for designing wearables for emotion regulation in everyday life. We call this the WEHAB approach (WEHAB comes from the first letters of the four disciplines: wearables, emotion regulation, haptics, and biofeedback). Using the WEHAB approach opens up new ways to facilitate emotion regulation and to develop novel affordances for emotion regulation in everyday life ("the wild").

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INTRODUCTION
Although emotions are vital for everyday human functioning, they can also be harmful when they are of the wrong type, intensity, or duration for a given situation [35], as illustrated in the following examples.

April 10, 2017: A man who refused to be bumped from a plane screamed as a security officer wrestled him out of his seat and dragged him down the aisle by his arms. April 22, 2017: American Airlines started an investigation after a video surfaced on social media that showed a confrontation between a passenger and a flight attendant aboard one of its flights.

In both of these examples, many people lost control of their emotions: passengers, flight attendants, and security officers. For those acting in a professional capacity, losing control of their emotions causes damage to people and to the organizations in which they work. Gross [35] refers to such workers as having "emotion labor occupations", and includes in them flight attendants, police officers, customer facing services, military personnel, and emergency response personnel. There are a large and growing number of people in such occupations. For such people, controlling their emotions on the job is of paramount importance to avoid creating risks to both themselves and the people around them. Indeed, companies and organizations are looking into ways to help their employees reduce the damage caused by emotion dysregulation [13].

While emotion regulation behaviors are widespread and largely intuitive, in their day-to-day life, people occasionally fail to implement them effectively. Over the years, emotion regulation research has identified several reasons for such failures, such as failing to detect rising negative emotions and not selecting an appropriate emotion regulation strategy [91]. These in turn suggest simple interventions that can correct the maladaptive course of emotion regulation. For example, being cued as a reminder with appropriate emotion regulation strategies can help the person become aware that they are overreacting and make an attempt to substitute an alternative behavioral approach [5, 63]. Such observations give rise to the question of how technology affordances can assist with emotion regulation. Imagine an affordance—a vest, a wristband, etc.—that helps a person become aware of and take action to regulate rising and inappropriate emotions. We call this "emotion regulation in the wild", since engagement takes place in uncontrolled settings such as in the middle of a discussion with colleagues or interacting with the general public. Being in the wild imposes conditions on the affordance. For example, given the potential sensitivity of the situations in which such technology would be deployed, both the placement of the technology on the body and its engagement with the wearer should be as private as possible.

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Indeed, designing affordances for emotion regulation in the wild is very challenging, in part because it requires a multidisciplinary approach [71]. We believe that the four disciplines that need to comprise this multidisciplinary approach are wearables, emotion regulation, haptics, and biofeedback. The contribution of this paper is to present what we call the WEHAB approach (WEHAB comes from the first letters of the four disciplines). The WEHAB approach consists of two parts: the WEHAB solution space and the WEHAB framework. The WEHAB solution space contains the portion of each of the four disciplines that are necessary for designing wearable affordances for emotion regulation in the wild (see Figure 1). The WEHAB framework describes a generalized design for such affordances (see Figure 2).

As well as describing the WEHAB approach, we show how existing work has been limited by not making use of the WEHAB approach. Finally, we illustrate the value of the WEHAB approach by describing how we are using it in the design of a wearable affordance for emotion regulation in the wild.

WEHAB SOLUTION SPACE

To the best of our knowledge, no project has fully used the knowledge and methods from each discipline that apply to the problem at hand. In this section, we give brief overviews of the WEHAB solution space and how they relate to the problem of emotion regulation wearables. Note that when discussing each solution space (that is, the part of the discipline important to the problem at hand), we refer to the other solution spaces because of the multidisciplinarity of the approach. We start first with emotion regulation because it our ultimate goal.

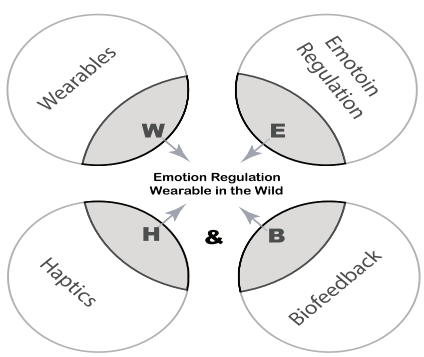

Figure 1. The gray portions comprise the WEHAB solution space, and the gray area of each circle is the solution space for the discipline indicated by that circle.

Emotion Regulation Solution Space

Emotion dysregulation is the inability, even when one's best efforts are applied, to change emotional experiences and actions under normative conditions. Symptoms of dysregulation include inappropriate affect, chronic worry, avoidance, sustained negative affect, and excessive sympathetic or parasympathetic arousal [20]. Emotion regulation refers to the processes people use to influence the type (i.e., which emotion one has), intensity, duration, and quality (i.e., how the emotion is experienced and expressed) of their emotions. The emotional states people hope to achieve when they engage in emotion regulation are referred to as emotion goals (e.g., feeling less angry). People tend to pursue emotion goals as a means to experience pleasure and avoid displeasure, obtain success, understand the world, and facilitate relationships. Emotion motives like these explain why people engage in emotion regulation [97].

Several models of emotion regulation exist [65] that generally overlap while highlighting different aspects of emotion regulation such as regulation strategies [64, 101], regulation ability [12, 34], and the temporal sequence of events [35]. Among them, we chose Gross's process model of emotion regulation (PM) [35] because it is a temporal model, and therefore amenable to identifying points for potential interventions.

According to the PM, there are four stages of the emotion regulation process: identification (i.e., evaluating whether an emotion needs to be regulated or not based on emotion goals, the situation, and the ongoing emotion), strategy selection (i.e., selecting an appropriate regulation strategy based on situational demands and regulation skills), strategy implementation (i.e., employing a specific tactic that implements the selected strategy: paced breathing, alcohol consumption, and exercise are all tactics of the response modulation strategy), and ongoing strategy implementation monitoring (i.e., determining whether the ongoing emotion regulation effort should be maintained, switched to a different strategy, or stopped).

Within this overarching model, the PM identifies five families of regulatory strategies one can deploy to change one's emotion. These include: situation selection (e.g., avoidance of the situation altogether), situation modification (e.g., changing specific aspects of a situation), attentional deployment (e.g., thinking of errands unrelated to the situation to distract oneself), cognitive change (e.g., reinterpreting the meaning of the situation), and response modulation (e.g., suppressing the bodily expressions of the emotion). These strategies are hypothesized to operate by interfering at different points in the emotion generation process. The model also suggests that strategies that intervene at earlier stages of emotion generation tend to require less effort and be more effective than strategies that intervene later. Using "<" to indicate the comparative ease of implementation, situation selection or modification < attentional deployment < cognitive change < response modulation [35].

One can identify three modes for emotion regulation: intrinsic (i.e., when an individual has a goal to regulate their emotions without involving anyone else), extrinsic (i.e., when a person has the goal to regulate their emotion by involving others or has a goal to regulate someone else's emotion), and both (i.e., when intrinsic and extrinsic emotion regulation co-occur) [35]. An example of the "both" mode is when James regulates Sarah's emotions (extrinsic regulation) in order to calm himself down (intrinsic regulation).

In this paper, we focus on the intrinsic mode, which we adopt for the WEHAB framework (described later in the paper). In the context of intrinsic emotion regulation, researchers interested in enhancing emotion regulation with the use of technology have mostly focused on facilitating cognitive change and response modulation strategies through smartphone apps and, more recently, through wearables, for the most part based on wristbands. The wearables have been referred to as calming technologies [3, 16, 22, 24, 66, 79, 99, 100]. The apps are mostly natural language processing (NLP) based or crowd-sourcing based. NLP-based smartphone apps have been developed to provide personalized response modulation strategy-based recommendations (for example, going for a hike, calling a friend, etc.), pulled from an individual's social network [70]. Anonymous crowd-sourcing-based smartphone apps have been developed to improve cognitive change (i.e., present an alternative human-generated explanation for an unhelpful thought [48]).

The four stages of Gross's PM can be used to reason about how people fail in regulating their emotions. [35]. The first reason is failure at the identification stage. This failure could occur due to a lack of emotional awareness, an inability to track emotion dynamics, or an inability to correctly trade off between multiple active competing goals. Even after a person has become aware of an emotion and has activated a goal to regulate that emotion, there can remain an inability to effectively trade off between the currently active goal and other competing active goals.

Tamir et. al. [95, 96] introduced a taxonomy for emotion regulation that distinguishes between two motives: hedonic goals that are aimed at increasing short-term pleasure or decreasing short-term pain, and instrumental goals that are aimed at inducing long-term meaning. Such motives can conflict: skipping a cocktail party may reduce momentary anxiety (hedonic) but reduce the satisfaction of having a larger professional social network (instrumental). This distinction is important when designing wearables because targeting hedonic motives as compared to instrumental motives may make the device more pleasurable if not ultimately more helpful [62]. For example, if a person who is suffering from anxiety is always recommended to call a friend (a tactic for distraction in a context of extrinsic emotion regulation), they will not develop the ability to deal the anxiety on their own, say, by using self-soothing strategies.

The second point for failure arises when a person is unable to correctly select or switch to an appropriate emotion regulation strategy. For example, people generally prefer reappraisal to distraction when emotion intensity is low, but prefer distraction to reappraisal when emotion intensity is high: at high-intensity levels, reappraisal is often no longer effective. However, people can misjudge the intensity of the emotion they are experiencing. A technology monitoring psychophysiological indicators of emotional intensity such as the electrothermal activity may therefore be designed to suggest optimal regulatory choices to a person.

Third, a person may be unable to effectively implement a selected emotion regulation strategy. For example, a person may decide to implement the tactic of paced breathing (i.e. attempting to make a specific number of breaths per minute), but reap only limited gain due to lack of skill. The person could fail to ensure that they are following paced breathing, to determine how effective they are in implementing the tactic, and to decide when to stop using this tactic. If they were cued with their physiology measurements as a biofeedback, they could be notified when their breathing is indeed properly paced, and when their arousal level has been reduced enough to stop paced breathing.

Fourth, failure at emotion regulation monitoring can contribute to failures at emotion regulation selection and implementation stages. For example, if one's arousal level is high, then the strategy of reappraisal is not suitable—it would be difficult for the person to find an alternate way of thinking about the situation. Instead, distraction may be more an appropriate strategy until one's arousal is sufficiently low. In many situations, the intensity of emotions gradually decreases, suggesting that an optimal decision strategy would be to switch from distraction to reappraisal. However, people are known to exhibit inertia in emotion regulation decisions, which suggests that they may benefit from technological prompts to facilitate appropriate strategy switches [93].

Importantly, people seem to differ systematically in ways that bear directly on how they go about regulating their emotions. For example, people exhibiting incremental beliefs about emotion (i.e., seeing emotions as the kinds of things that can be changed) compared to entity belief (i.e., seeing emotions as relatively immutable) seem to be generally more effective at regulating their emotions. Major dimensions of individual differences include regulation frequency (how often a particular form of emotion regulation is used), emotion regulation self-efficacy (how capable a person believes himself or herself to be in using a particular regulation strategy), and emotion regulation ability (how successful a person actually is in using a particular form of emotion regulation). Such factors play an important role in the success of emotion regulation and should be considered in the development of emotion regulation devices. For example, a machine-learning based tool could be trained on collecting useful information to account for such differences.

Anett Gyurak et al. suggested that, given the high demand for moment-to-moment emotion regulation in everyday life, for well-being purposes it is often critical that emotion regulation processes be relatively implicit (that is, automatic) [38]. Thus, it is important to design emotion regulation wearables as a technology that influences behavior in a subtle manner. Such technology has been referred to as mindless computing [4]. At the beginning, adopting new and more helpful ways of emotion regulations requires effort. Eventually, however, the transition from explicit (often called effortful) to implicit forms of emotion regulation are formed for the newly adopted ways of emotion regulation, and they become habitual and implicit. This is factor that is important in the design of wearables for emotion regulation.

Biofeedback Solution Space

The next solution space we consider is biofeedback. Biofeedback is a process that enables an individual to learn how to change his or her physiology through real-time physiological feedback. Simplifying, the circular model of biofeedback consists of three steps: (1) monitoring: measuring a physiological process of interest; (2) feedback: presenting what is monitored as meaningful information to the user; (3) implementation:

user behavior aimed at changing the physiology and developing mastery so that this behavior occurs automatically [85].

The most common processes that are monitored in biofeedback include electrical correlates of muscle contraction (electromyography or EMG), skin conductance (electrodermal activity, EDA), cardiopulmonary processes such as heart rate variability (HRV), and photoplethysmography (PPG), temperature, and brain activity (electroencephalography, EEG). Challenges encountered at the monitoring step include the lack of universal response norms (e.g., for peripheral vasoconstriction, skin conductance, and muscle contraction), variability between devices, and the negative impact of conditions such as room temperature and humidity.

The feedback stage involves presenting the signals measured in the monitoring stage in some perceptual modality. The choice of feedback modality depends both on the people using the feedback and the requirements of the problem to which people are applying the biofeedback (e.g., improving asthma via HRV biofeedback). Researchers have suggested that feedback solutions should strive to be simple, unambiguous, gentle (e.g., the use of smartphone assistants like Siri or Cortana), automatic, personalizable (i.e., the ability to let the user have control over their wearable haptic device), customizable (e.g., allows for thresholds to adjust over time as training goals change), responsive (e.g., users not having to go to an“app” to get an intervention), standalone (i.e., users do not need to stop what they are doing with their device for the intervention to occur), and minimally distracting [26, 85]. Following these desirable conditions for feedback has nudged biofeedback researchers and practitioners into settling on a very limited number of practical feedback modes and avoiding further exploration. In addition, most biofeedback sessions are conducted in a dedicated setting, for which auditory and visual feedback is adequate—there is no need to use a haptic approach for biofeedback. This may explain in part why the choice of haptics to implement biofeedback has not been thoroughly studied.

The implementation step in biofeedback involves the teaching of various behaviors that lead to desirable changes in the physiological state of the user. These include autogenic relaxation (repetitions of a set of visualizations that induce a state of relaxation including autogenic imagery), progressive muscle relaxation (consecutive two-step or three-step process of muscle tension followed by muscle relaxation), passive muscle relaxation (process of imagining muscles in a relaxed state that involves no muscle tension), and slow paced breathing aided by counting methods, one hand on the chest and the other on the stomach, and imagery techniques (e.g., cool air going in and warmer air coming out of the nostrils, balloon expansion while inhaling/contraction while exhaling, etc.). [9]

The circular model of biofeedback can be thought of as externalizing of the monitoring stage of Gross’s PM of emotion regulation. According to the PM, emotion regulation often involves several iterations of identification, selection and implementation. Imagine a person has identified a need to regulate the emotion of anger. This is the first stage of PM. They select the strategy of rumination and begin to implement it. Periodically, the person will monitor how well rumination is working, via interoceptive input (i.e., internal stimuli) to the brain. Based on this, they will make one of three choices: to continue with the rumination strategy, to abandon rumination and adopt a more contextually appropriate strategy (for example, reappraisal), or to stop because either they have reached their desired emotional state or have decided to quit altogether. From this perspective, using biofeedback to assist in emotion regulation can be thought of as partial externalization of the monitoring stage of PM. With biofeedback, the changes in the undesired emotion (e.g., its intensity, duration, type, etc.) induced by strategy implementation are perceived through changes in the person’s physiology and communicated through sensory modalities (visual, haptics, audio) rather than using the path of interoceptive input to the brain.

We are particularly interested in haptic feedback because of the need for confidentiality of emotion regulation in the wild: vibrotactile-based devices can be designed that are noticeable only by the wearer, wearable tactile actuators are small and can be easily be obscured beneath clothing. This is consistent with much of wearable research, which has concentrated on haptic feedback.

As mentioned above, biofeedback research has concentrated on visual and auditory modes of feedback. Some research results on visual and auditory modes feedback most likely apply to haptic feedback as well. What wearable research supports doesn’t necessarily agree with what biofeedback research supports or favors, however. We speculate that this is because the two communities are often pursuing different regulatory motives: wearable researchers are more interested in hedonic goals and biofeedback researcher are more interested in instrumental goals. For example, wearable research has argued that truthful heart-rate-mimicked biofeedback is not as effective as slow manipulated heart-rate-mimicked biofeedback for nervous populations [21, 58]. Reducing a person’s immediate level of nervousness is a hedonic goal. On the other hand, in the context of physiology measures deviating from an acceptable range, biofeedback research supports using physiology-mimicking representations such as perception of heartbeat or breathing sound over non-physiology-mimicked representations such as perception of sinusoid waves or square waves; truthful over manipulated or partial truthful representations; and real-time over reflective forms of interventions [85]. For example, biofeedback research suggests that it is helpful to give access to the heart rate, whenever the user wishes it, but it is even more important to help users with interpreting the heart rate signal in a positive way. Based on a user’s history and on how the information is presented to the user, he or she may interpret a fast real-time heart rate as something fearful ("I am losing control"). It would be better to help the user frame it as something positive to advocate courage in dealing with the current situation ("I am strong and ready") [88]. These reflect long term changes in behavior, and thus are instrumental goals.

Personalization (the ability to let the user have control over their wearable haptic device) has been suggested by biofeedback experts to be a powerful method to enhance the learning process and user experience. For instance, one person may learn best with continuous exposure to the feedback signal, while another person may learn best while using imagery with minimal feedback. Understanding and applying the biofeedback information to influence a change in physiology is certainly more complicated than swallowing a pill, but it constitutes the essence of the treatment, and needs to be accommodated in the research design and accepted by those who evaluate biofeedback research [90]. A drawback of using personalization is that it can introduce unwanted variability in the treatment group. However, using an active learning process that involves active participation and individualization of the biofeedback stimulus (and its body site, if applicable) to fit an individual learner, is a major ingredient of successful biofeedback training.

As an illustration of biofeedback that can have an effect on emotion regulation, we describe Heart Rate Variability Biofeedback (HRVB). HRVB teaches patients to restore autonomic balance by increasing parasympathetic activity, which in turn decreases sympathetic activity [30, 31, 32, 33]. As branches of the autonomous nervous system, sympathetic and parasympathetic activity prepare visceral organs for resources expenditure ("fight or flight") and resource replenishment ("rest and digest"), respectively. Research studies have suggested that HRVB is effective in reducing psychological and physical symptoms of anxiety, depression, chronic pain, asthma, hot flashes, migraine, epileptic seizure, etc [46, 85]. A healthy heart is not a metronome [89] and the time intervals between successive heartbeats (IBI) greatly differ; this is called Heart Rate Variability (HRV). High HRV provides the flexibility to rapidly cope with an uncertainty and changing environment including reflecting a greater capacity for regulated emotional responses [6, 10, 49, 78], while reduced HRV is associated with vulnerability to physical and psychological stressors, and to diseases [54].

HRVB training has been show to immediately produce large-scale increases in baroreflex gain (the degree of HR change in response to an inverse change in blood pressure) [56, 86] and strengthen the vagal tone (the contribution of the parasympathetic nervous system to cardiac regulation) [54]. Research studies have identified stronger vagal tone contributes to the better executive cognitive performance, better social functioning, as well as better emotional and health regulation [89]. The sympathetic nervous system activity increases the heart rate during inhalation (i.e., inhibition of vagal activity) thus shortening the IBIs, while parasympathetic nervous system puts on the brakes and brings the heart rate down during exhalation (i.e., vagal stimulation) consequently lengthening the IBIs. This phenomenon is called respiratory sinus arrhythmia, or RSA and the stronger the vagal tone, the higher the amplitude of RSA and vice versa. RSA is mediated by the vagus nerve and is largely responsible for generating heart rate variability [51].

Resonance frequency theory, proposed by Lehrer, suggests that an efficient way to increase vagal tone is through slow paced breathing at the resonance frequency. The resonance frequency is the breathing rate at which the baroreflex causes body gas exchange and oxygen saturation to be optimized and varies from 4.5 to 6.5 breaths per minute from person to person [53, 55, 103]. Vaschillo [103] found that an individual's resonance frequency correlates with the blood volume in that individual, and so a biofeedback-based technique to determine the precise rate of breathing is required for each individual. Similarly, Lehrer suggests that taller people and men have lower resonance frequencies than women and shorter people, due to larger blood volumes. Note that once the exact resonance frequency is determined (over the course of approximately three weeks), there is no need to recalculate it again. Lehrer also observes that many stimuli at this frequency, including breathing, rhythmic muscle tension, and emotional stimulation, can activate or stimulate the cardiovascular system's resonance properties [52].

HRVB practitioners have found that breathing diaphragmatically, at the resonance frequency, with a 40:60 or 33.3:66.7 inhalation to exhalation ratio, and with pursed lips during exhalation, not only maximizes HRV but also increases respiratory efficiency [46]. One obstacle is that, unlike infants, most adults do not practice diaphragmatic breathing because of several factors. Aside from simple lack of awareness about the technique, some reasons for this are concerns of self-image (some people tend to pull in their abdomen in an attempt to look slim and attractive) and an inability to engage abdominal muscles because of lack of muscle tone due to age or injury, and so on [72]. To master whole-body effortless-paced diaphragmatic breathing, a person needs to focus on activating the lower abdominal muscle. Some practitioners find it to useful to apply pressure at key locations (i.e., the Spina Iliac Anterior Superior, or SIAS) during exhalation, and to place either respiratory strain gauges or surface EMG sensors to visually track the expansion of the abdomen while inhaling [72].

Haptics Solution Space

We now consider the solution space of haptics, which is important for biofeedback being done in an inconspicuous manner.

A large portion of haptics research that has explored emotion regulation has focused on extrinsic emotion regulation using vibrotacticle actuators [68, 47, 11, 61, 57, 43, 102]. In this type of emotion regulation, someone else has the goal of regulating your emotions or you reach out to someone else to get help with regulating your emotions. The choice of vibrotactile feedback has been driven by the perception that a vibration effect can serve as a low fidelity substitute for the sense of human touch [14]. Therefore, touch-emotion related studies, including findings on calming effects of touch by Coan [19] and other scholars [23, 40, 104], as well as Keltner's work that communicated six distinct emotions via touch [41, 42], play a role in shaping haptic-emotion research studies. Most studies have explored vibrotacticle effects to effectively elicit, reduce, aggravate or transform a specific emotion. For example, Lemmens et al. [57] developed tactile patterns based on "butterflies in the stomach" associated with love by sequentially firing motors in the stomach area in a circular pattern, and "a shiver down the spine" to convey fear and anxiety applied on an arm or other parts of the body; the goal of this research was to enhance the emotional experience while watching a movie. McDaniel et al. [61] described six motion patterns (e.g., wave, spiral, shoulder tap, etc) to elicit emotional responses in visually impaired individuals. He suggested that longer duration haptic effects may be used to convey sadness whereas shorter durations ones may be used to convey happiness. Benali-Khoudja et al. [11] described haptic patterns including "divergent wave", a "vertical shutter", a "horizontal line sweep", etc., inspired from hand writing and voice recognition.

There are several advantages in using haptic interventions. They include (1) Haptics is provided through the largest organ of the body and is not prone to rapid decay of short-term sensory memory [17]; (2) Relative to vision and audition, the spatial resolving power of the skin is poorer than the ear's but better than the eye's [50]. One common measure indicates that people can resolve a temporal gap of 5 ms between successive taps on the skin [29]; (3) Haptic signals are simple, personal, and subtle, making them attractive for use in technological aids [29] especially when other channels including visual and auditory are overloaded or unreliable [45, 80]; (4) Stereognosis – the ability to perceive and recognize the form of an object in the absence of visual and auditory information by using tactile information – is useful for wearable technology that lack displays and digital interfaces; (5) Due to the lack of short-term sensory memory, haptics works well for learning.

There has been substantial research in exploring how vibrotactile attributes (such as amplitude, frequency, duration, etc.) can invoke an emotion. This line of research (e.g., [11, 43, 68]) has been followed for many years but does not align well with the understanding of those who research emotion and emotion regulation.

Some results such as those by Benali-Khoudja et al. [11] and Yoo et al. [105] have hinted that haptics, applied naively, most often have a negative impact and thus would not be suitable for emotion regulation. Benali-Khoudja suggested that about 91 percent of the tactile icons tested in their study might be inappropriate for expressing positive and relaxing emotions (e.g., serene and relaxed) [11], which indicates challenges with generating positive-valence-low-arousal tactile icons based on manipulation of attributes such as frequency, amplitude, duration, etc. Results from Mood Glove [60] also support Yoo's claim: the use of haptic sensations did not alter valence. Instead, it heightened participants self-reported arousal values, resulting in a more intense mood perception of a film scene.

All existing haptic-based approaches have made important contributions, but none of these have fully addressed the important characteristics of a haptic effect that may regulate an emotion. Hence, we believe that the question of whether a haptic effect can regulate emotion is still unanswered. Perhaps it will be resolved through crowd sourcing: companies developing wearable haptic devices are likely to open their wearable devices for creation and communication of more complex individual based haptic effects. Through trial and error, effective haptic effects will thrive and the rest will be discarded. That is why effect customizability (i.e., the device being programmable for creation of various haptic effects) is an important factor to consider when designing a wearable. Some examples of promising directions in facilitating haptic effect creation and customization are the tactile effect simulation tool Macaron [83], the tactile animation tool Mango [82], and the Mechanical Turk based tool for rating the affect of vibrotactile effects HapTurk [84] as well as creating and supporting search of vibrotactile lexicons [37, 67, 87].

Wearable Solution Space

The final solution space is wearables. For both emotion regulation and biofeedback, the vast majority of research has been in the context of lab-based experiments. In the wild, people are currently on their own to regulate their emotions by relying on the strategies and techniques that have been taught and evaluated in the lab. Can technological affordances aid those who fail to self-regulate their emotions in the wild? If so, the technology would most likely be based on wearables.

Wearable technology is moving toward the use of flexible and stretchable organic wearables, also known as enhanced wearables. State of the art biosensors are becoming insensitive to strain and can make real-time assessments of the physiological state of subjects, even when worn during normal, everyday activities [28, 39, 98]. Though these are not yet market-ready, we can anticipate that they will be in the near future, and can design in anticipation of this.

Recently, there has been considerable work in haptics design for wearability [59]. Understanding this work requires a deeper look into haptic technology. The term haptics is used both to describe the human touch sensation and to describe devices that are built to stimulate human touch. Human touch is divided into two afferent (conducting information to the brain) subsystems: kinesthesia and cutaneous. Kinesthetic sensations are mediated by muscles, tendons, and joints stimulated by bodily movement (e.g., the sensation from playing with a joystick). Cutaneous sensations are felt by the skin, such as pain, pressure, stretch, and temperature; these sensations allow humans to sense spatial forms, texture, movement, flutter, and vibration. Haptic devices are similarly classified into the two groups of kinesthetic and tactile (cutaneous) based on the sensations they create. Kinesthetic haptic devices display force or motion through a tool or to the user's joints, whereas tactile devices stimulate the skin i.e., create a distributed set of forces on the skin. Many kinesthetic haptic devices cannot be considered as wearable because in order to generate a force to display to the user, they must transmit the force from the ground through a fixed base. Kinesthetic haptic devices can be further categorized into three major groups: manipulandums (joystick like devices), gripping devices (e.g. most surgical systems that are manipulated using a device gripped between thumb and index finger), and exoskeleton (e.g., CyberGrasp which is VR glove that delivers reactive force in response to a person's actions inside virtual reality [94]). Kinesthetic exoskeleton devices can be wearable because they are grounded to the body, but they are often heavy and cumbersome due to the motors and power required.

In contrast to kinesthetic devices, tactile haptic devices are more easily designed to be wearable due to the actuators required. Tactile devices include stimulation methods such as normal skin deformation, vibration, temperature display, and skin stretch. One novel method for displaying normal deformation is haptic jamming [92], which is a specialized technology that creates 3-D surfaces with a variable stiffness tactile display using pneumatics and particle jamming. These surfaces are palpated by the hand. Currently there is no wearable haptic jamming device available on the market. However, in the context of emotion regulation, they could take the form of jamming jackets to simulate the sensation of hugging. A common actuator to display normal deformation are arrays of pins that are actuated independently in contact with surface of the skin [81, 77]. A haptic braille watch [25] is an example of a wearable pin stimulation haptic device. Haptic stimulation devices involve active touch via the fingertips to interpret further meaning, and are a promising approach for implementing reappraisal or distraction emotion regulation tactics. For example, one can imagine a person touching the surface of such a device to be disengaged from the environment by experiencing a gamified task via fingertips (e.g., pressing rising pins as quickly as possible) while attending a tense meeting. Or, a person could receive a braille message with an embedded meaning (e.g., "the faster your heart rate, the slower you should speak"). The limitation with such a haptic device is that the fingertips must be actively involved, which may make the emotion regulation too conspicuous. Skin stretch devices apply displacement forces tangential to the skin, which are perceived as stretching the skin [76]. Applying skin stretch is being investigated as an alternative to vibrotactile feedback. Skin stretch devices, for example the work by Chinello et al. [18], have similar limitations to normal deformation devices in being inconspicuous. Temperature devices are silent technologies that are usable in situations in which environmental vibration hinders the utility of vibrotactile approaches. The downside with temperature haptic devices is that environmental temperature can affect the haptic sensation, the temperature change can be slow to actuate, and temperature stimulation can sometimes be uncomfortable if the temperature variation is not carefully controlled.

Vibration haptic devices (vibrotactile) apply motion either directly to the skin or through a mediating structure. Vibrotactile devices are both wearable and can provide passive touch anywhere on body surface, so they do not require the fingertips to be engaged to experience the haptic effects produced. Consequently, the choice of vibrotactile seems more appropriate for emotion regulation in the wild as compared to an exoskeleton or other forms of tactile devices. The choice of the specific vibrotactile actuator to use is critical since they are usually the bulkiest and heaviest components in a wearable device. In general, linear electromagnetic actuators, including voice coils, solenoids, and C-2 tactors, are preferable to non-electromagnetic actuators such as an eccentric rotating mass motor (ERM). This is because most electromagnetic actuators, with the exception of Linear Resonant Actuators (LRA), can produce any vibration profile within their dynamic limitations and are capable of applying a con-stant amplitude vibration. Such degrees of freedom allow for creating rich haptic effects.

In designing a wearable haptic device, the goal is to maximize the level of wearability, portability, mindlessness [38], and the realism of the touch sensation while minimizing the cost. To maximize wearability, Pacchierotti et al. [69] presented a list of usability principals to consider when designing a haptic wearable. The list includes principles such as the device must: be comfortable to wear (ergonomic shape, naturally fits the wearer's body, exerts manageable pressure, comfortable materials used during construction, smooth design); not impair motion; be small and lightweight; be easily activated by the user; use properly chosen actuators (not irritating even when active for a long time, not exceed maximum temperature in contact with skin). Another important principal argues that a haptic effect is more effective when co-located with the desired action or behavior. For example, Brown et. al. [15] showed that locating force-feedback haptics on the same hand that is exploring a virtual object is more effective than locating them on the opposite hand.

WEHAB-BASED REVIEW OF EXISTING TECHNOLOGIES

Having reviewed the WEHAB solution space, we illustrate the potential value of using a WEHAB-based approach by examining four efforts in building affordances for facilitating intrinsic emotion regulation using biofeedback. In each case, we discuss, using the terminology of WEHAB, their strengths and weaknesses.

The Apple Watch/WatchOS 3 Breathe app is a commercial product [7] which creates a breathing pacer haptic effect. (Of course, the Apple Watch does much more than this app, but we focus on the app.) The device itself is well designed from a wearability aspect. It has a smooth design with no sharp edges or rough surfaces, an ergonomic shape, and is made of comfortable materials. The haptic effect is designed in a way that is not irritating and the haptic tactor is custom made. However, the haptics feedback is not personalizable, and it is applied on the wrist, which is not co-located with the desired action (breathing). Thus, from a haptics point of view, further design might be warranted. From an emotion regulation point of view, it is based on a response modulation strategy of paced breathing, and adopts a static pace that is not commonly recommended by biofeedback practitioners (which is usually 40:60 or 33.3:66.7 inhalation to exhalation ratio). Finally, from a biofeedback point of view, the haptic effect (as compared to the visual effect) consists of a ramp up followed by a long pause. Some of our expert evaluators speculated that the sudden long pause can cause in some the experience of panic symptoms. This is because the sudden pause is not an intuitive haptic effect in terms of cueing exhalation. Furthermore, the app doesn't provide any feedback about whether the user's breathing is correctly paced as the device is not equipped with biofeedback.

The next two efforts use similar experimental designs. Doppel [8, 24] is a Kickstarter wearable wristband with pre-built haptic effects in the forms of music rhythms, heartbeat, and breathing, and designed to up-regulate positive emotions and down-regulate negative emotions, and EmotionCheck *EmotionCheck* is a biofeedback device that emulates slow heartbeat haptic signals and applies them via a haptic wristband [21]. Both are early explorations of regulating emotions using haptics. We speculate that the choice of a slow haptic heartbeat signal was motivated by the idea that it mimics a bodily response characteristic of low emotional arousal (e.g. slow heart rate or breathing rate) and thereby entrains physiological systems towards that state [8, 21].

The researchers created a biofeedback intervention based on a haptic effect that mimicked heartbeat. In each experiment, they put subjects in a stressful situation that created stage fright and measured self-reported anxiety levels both pre- and post- stage performance. They concluded no significant drop in anxiety levels when haptic intervention was a truthful representation of the participants' heart rate. They also concluded that the haptic effect of a sham slow heart rate, though, produced a significant drop in anxiety and seems appropriate to help with emotion regulation. Choudhury et al. further concluded that when participants know that the slow haptic effect is a representation of their on-going physiology measures, the effect was more significant than when they believed otherwise.

While the work was pioneering, there were some shortcomings with respect to their technology's application to emotion regulation as we consider the problem in this paper. For example, neither Doppel nor EmotionCheck assist in selecting the strategy for emotion regulation, and instead focus primarily on haptic-based biofeedback.

A problematic issue with their experimental design was the lack of training of participants: subjects need to be well-informed and well-educated about how to interpret a biofeedback signal. In addition, with multiple training sessions, most individuals learn how to make sense out of the feedback and take appropriate steps to control their physiology. For example, with EDA, the typical number of training sessions varies between 4 to 8 sessions. For respiratory sinus arrhythmia (RSA), the number of sessions depends on how well a person can practice abdominal breathing: for some people, it can be done in as little as one session. Given the nature of their stress event, there could be only one session in this experimental design, and so it is not surprising that there was no significant difference in self-reported anxiety level between the control group and the group receiving truthful heartbeat-mimicked haptic feedback.

Another problematic issue with Doppel and EmotionCheck studies is their use of sham (or untruthful) forms of biofeedback. Biofeedback literature suggests that sham feedback (e.g. feigned slow heartbeat has limited value in the long run because most participants who receive sham feedback experience frustration with the resulting limited learning opportunities for taking control over their own physiology processes. Thus, they often opt out of the study as they lose motivation. For those who continue, they develop less control over their physiology processes. This also explains why the double-blind or even single-blind procedure is problematic with respect to biofeedback research; ongoing knowledge of changes in a physiological variable(s) is central to the learning process in biofeedback practices [106] so it is very difficult to come up with believable placebos. Therefore, instead of double-blind or even single-blind studies, wait-list controls with long-term follow ups in biofeedback studies that assess the effectiveness of the training are recommended. Furthermore, the use of haptics mimicking a slow heart-rate with a stage-fright stressor stimulus does not seem to be an appropriate protocol to investigate the effectiveness of haptics for emotion regulation: it is unclear what type of emotion regulation strategies (if any) participants are implementing while receiving the biofeedback (e.g., is the biofeedback haptic itself a distraction?). In addition, in biofeedback research, both repeated measure and long-term followup are usually done to understand the efficacy and the persistence of the intervention. In this case, the stressor is unrepeatable and so neither repeated measure nor long-term followup can be done.

An interesting example of using biofeedback for breathing is the work by Janidarmian et al. [44]. This work produced an affordance based on a protocol that first measured a client's baseline breathing pattern using accelerometers on the abdomen, and then alerted the client in real-time, using haptics applied around lower back body region, when their breathing deviated from the baseline. The strength of the haptic effect indicated the degree to which the current breathing differed from the baseline.

This work illustrates the co-location of the haptic effect near the body site where the action occurs: in this case, the abdomen. We speculate the reason they placed it on the back rather than the abdomen is because it would interfere with the accelerometer-measured breathing pattern.

Their approach assumes the baseline breathing is the ideal, which is not obviously true absent any education on how to breathe correctly. The researchers found that the type of feedback was not intuitive for all participants to interpret, but the participants were motivated to continue improving their breathing patterns. It would be interesting to see followup studies that report on the lasting effect of using the affordance.

WEHAB FRAMEWORK FOR DESIGNING AFFORDANCES

There is more to designing affordances for emotion regulation in the wild than understanding the WEHAB space. In this section, we describe a WEHAB framework that gives a general approach for designing such affordances. We also present a set of research and development challenges that are suggested by the framework. These challenges are multidisciplinary in nature, and include both the WEHAB solution space as well as other disciplines, such as artificial intelligence.

The WEHAB framework is based on the temporal PM by Gross. As noted in the earlier section on the emotion regulation space, Gross's PM describes how the emotion regulation process unfolds: an emotion is generated, a strategy is selected, the chosen strategy is implemented, and then by monitoring, the strategy is maintained, stopped, or switched. Each point in this model can be augmented with interventions that can involve the user of an affordance (see Figure 2). In the WEHAB framework, we considered three types of haptic interventions: (1) cueing, which is used to direct a user towards some strategy; (2) involvement, which guides a user through a tactic; (3) biofeedback, which is used as part of a biofeedback process.

For the identification stage, the haptic intervention is cueing: notifying the user of the need for emotion regulation. For example, imagine a device that, based on environmental information (e.g., GPS coordinates, sentiment analysis of the latest email or text message, calendar schedule, etc.) and physiology measures (e.g., heart rate, breathing pattern, etc.), detects a person experiencing negative emotions and notifies the person that they need to regulate. The key developmental problem is how can one detect a person's unhelpful emotional state in the wild. What are the biomarkers and environmental data sources one can use, how can the information be captured, and how can one make use of them to ensure a timely intervention?

Cueing is also used for the haptic intervention at the strategy selection: once a strategy is selected, it needs to be communicated to the user. The problem here is implementing haptic-based communications. Such communication can be a haptic encoding that represents a particular strategy. Depending on the number of available strategies or tactics, distinct easy-to-memorize haptic effects will need to be defined. Communicating this way will require some training for the user to learn the representations, and could be quite simple or as complex as using an encoding like Braille or Morse Code.

Of course, determining which strategy to communicate is needed as well. Designing an algorithm for recommending a strategy is not easy, in part because it depends on the individual skills, self-efficacy beliefs, and on the situation. For example, when in a demanding interpersonal situation, some people increase their anger to achieve power, while others increase their calmness to achieve the same goal. Rumination might be a good strategy for someone in the first group because it increases anger, while reappraisal might be a good strategy for someone in the second group because it increases calmness. Tamir el. al. [97] have suggested understanding the relation between motives (e.g., being powerful) and emotion goals (e.g., being angry) and the relation between emotion goals and emotion regulation strategies (e.g., rumination). These relations appear to be determined by culture and by by personal factors. Using these relations as the basis of emotion regulation strategy selection seems feasible. This line of research, which combines motivational science and emotion regulation science, could lead to effective methods of selecting emotion regulation strategies in the wild. Open research and development problems include being able to capture the relations for an individual and understanding how they change, and using information such as environmental factors to determine how to go from desired motives to supporting emotion regulation strategies. In addition, it is plausible that a wearable affordance might be useful to capture the data in the wild that would be needed to further develop this model.

At the strategy implementation stage, the device will use haptics to implement a tactic supporting the selected strategy. The haptic intervention at this stage is in the form of involvement. Depending on the tactic, the involvement haptic can be used as an aid for response modulation such as a breathing pacer or a muscle contraction and release pacer, or, as an aid to attention deployment (e.g., to help with distraction). For example, haptic patterns coupled with gamified tasks could provide engaging activities that request the user to pay attention to a task (e.g. counting the number of clockwise and counterclockwise patterns that the device generates). Some challenging problems at this stage are what are the characteristics of a haptic effect that makes it suitable as an involvement intervention, and what are useful body sites to place a haptic wearable? In the next section, we further describe some of the development questions with respect to a haptic breathing pacer in the context of an emotion regulation affordance that we are building.

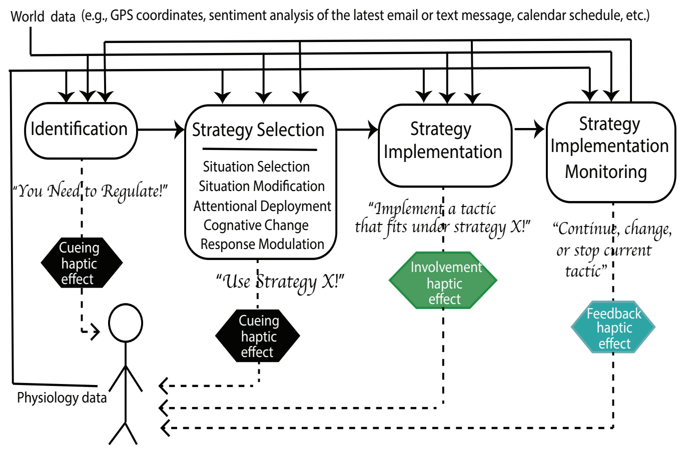

Figure 2. WEHAB framework of haptic interventions for emotion regulation drawing upon Gross' extended process model [36].

At the strategy implementation monitoring stage, haptic biofeedback intervention is needed. As shown in Figure 2, such feedback informs the user to continue with the selected tactic, or to change something, or to stop. More precisely, we have identified seven ways that biofeedback can assist here. Two of these indicate that the user should continue with the current tactic, and indicate how well the user is doing in terms of attaining the desired emotion goal or motive. For example, it may indicate how well the user, using the tactic of EDA-based biofeedback, is attaining the emotion goal of feeling less angry. Or, it may indicate how well the user is attaining a motive, such as the hedonic motive of feeling pleasure or the instrumental motive of getting better at swimming despite being afraid of water [27].

Three of the ways biofeedback can assist have to do with the user changing something. One communicates whether the user is meeting the required conditions before attending to an involvement haptic (e.g., erect posture, loose clothing, etc. before attending a paced breathing haptic [2, 72, 74]). A second is how well the user is attending to the involvement haptic (e.g., detecting symptoms indicating incorrect breathing when attempting diaphragmatic breathing [46]). The third gives recommendations on how to attend the involvement intervention better (e.g., increasing the exhalation time by slowly pushing the air through pursed lips [46]).

The remaining two have to do with stopping the current tactic. This can include switching to another strategy, or just stopping emotion regulation process altogether either because the desired emotion goal or motives are met or no longer valid [35].

Providing all seven forms of assistance would require significant research and development problems to be solved, including determining appropriate biomarkers, unobtrusively instrumenting the user in the wild for collecting the biomarkers, and communicating the biofeedback in an effective manner.

EXAMPLE OF USING WEHAB SPACE AND FRAMEWORK

In this section, we illustrate the utility of the multidisciplinary WEHAB space and framework by describing a use case of designing a wearable for emotion regulation. We argue that the design is better informed by including the biofeedback, wearables, and haptics spaces together, and in doing so we may influence the field of biofeedback as well as wearables.

The situation we consider here is the design of a breathing pacer. In term of the WEHAB framework, we are intervening at the strategy implementation stage using an involvement haptic effect and at the strategy implementation monitoring stage with monitoring that is used to generate a biofeedback haptic effect when the user is breathing incorrectly.

Our implementation of this tactic is informed by biofeedback practice. As we have described previously, research and practice has shown that people are capable of voluntarily producing a very large respiratory sinus arrhythmia (RSA) through resonance frequency [75] abdominal breathing, and a large RSA correlates with enhanced self-regulation and a more positive mood. HRVB practitioners commonly train people to breathe at their individual RF by having them attend a visual breathing pacer. A HRVB practitioner encourages proper diaphragmatic breathing by touching the patient's abdomen with their fingers. The patient's breathing pattern is captured using surface electromyography (sEMG) recording electrodes, and this pattern is used to detect habit of breathing incorrectly and/or effortfully. These electrodes are placed on the two Spinal Iliac Anterior Superior (SIAS) locations [72] on the body, which are low on the abdomen. It is also near these locations that the practitioner touches to encourage diaphragmatic breathing [73]. Practitioners often use thoracic and abdomen gauges to monitor breathing, and use a capnometer to determine whether the patient is overbreathing. While we may consider using such devices as well, we don't consider them further in this paper.

While useful for HRVB training, this arrangement is not useful for emotion regulation in the wild. A visual pacer is obtrusive in a real-life setting, and using surface EMGs involves wearing electrode pads on a day-to-day basis that can cause adverse skin reactions such as redness and skin irritations. And, of course, there is no technician to monitor the breathing pattern and to encourage proper breathing.

For the involvement haptic intervention, we chose C-2 tactors [1] because they are optimized for use against the skin: they minimize wave propagation on the body surface. For monitoring breathing, we decided to use accelerometers for two reasons. First, the results by Roshan Ferk et al. [27] support the feasibility of using accelerometers for classifying breathing disorders from breathing patterns. Second, we have observed that when a user is stationary and is not speaking, the resolutions of breathing patterns captured by accelerometers with data sampling rate of 20Hz suffices for detecting the following, which are common during hyperventilation with diaphragmatic breathing: breath holding, proportion of inhalation to exhalation (in healthy breathing, exhalation should be longer than the inhalation), the depth of breathing, the consistency of breathing, the transition time between exhalation and inhalation, and the over-breathing recovery rate.

We placed the accelerometers and tactors near the SIAS positions. However, this placement of resulted in it being difficult for the user to breathe effortlessly, perhaps because of the weight of the actuators on the abdomen. This caused us to go back to HRVB practice for further insights on the design of the wearable. We found that HVRB technicians often find it effective to encourage abdominal breathing by asking the patient to envision a balloon in their abdomen, and inhalation being caused by this balloon inflating [46]. Such a balloon would put pressure on the immobile parts of the user's abdomen, such as the dorsal side. This suggests that the C-2 tactors could be placed on the back, for example directly opposite of the SIAS locations, with the haptic sensation suggesting the pressure caused by the imaginary balloon. In addition, one biofeedback practitioner observed that placing haptic actuators strategically on the lower part of the body trunk will assist awareness of abdominal breathing, and symmetric haptic effects might be more effective in terms of encouraging breathing with the full diaphragm [73]. These observations give further support for using two tactors placed low on the trunk and symmetrically on the body.

We are currently conducting studies to determine which of these two placements–at the SIAS locations or on the dorsal locations opposite of the SIAS locations–is more effective. If, in fact, we find the dorsal locations to be better, this could have an effect on HVRB practice. Indeed, we have subsequently learned that some practitioners have independently begun considering using touch on the back to encourage proper breathing.

CONCLUSIONS

Failures of emotion regulation are both common and costly. This paper emphasizes the importance of a multidisciplinary approach for designing affordances that assist people to regulate their emotions in the wild. We identified four disciplines—two technical (wearables and haptics) and two psychological (emotion regulation and biofeedback) and reviewed the parts of these that are important to the problem at hand. We call these parts of the four disciplines the WEHAB solution space. By exploring this multidisciplinary solution space, designers can deploy tradeoffs across all four disciplines, as compared to optimizing along a smaller set of disciplines.

After reviewing existing work in the context of the WEHAB solution space, we presented a conceptual framework that provides structure for exploring the use of haptic-based technology for emotion regulation. This WEHAB framework pinpoints common failures in emotion regulation and identifies different kinds of haptic interventions to facilitate emotion regulation. We concluded with an example of using the WEHAB approach that illustrates the value of multidisciplinarity. Our hope is that the WEHAB approach will enable more effective research and development in the area of wearables for emotion regulation in the wild.

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