HapLand: A Scalable Robust Emotion Regulation Haptic System Testbed

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Abstract

Emotion regulation is crucial for healthy adaptation [29, 16], while emotion dysregulation can lead to the development of mental health disorders such as anxiety or depression [6]. Everyone, one way or another, sometimes fails to effectively regulate their emotions, making this a challenging problem with broad potential impact. In our research, we are exploring three ways in which haptics-enabled wearables can facilitate effective emotion regulation, formulated based on Gross's model of emotion regulation [15]. We hypothesize that an individual-level biofeedback haptic could foster healthier and more effective patterns of emotion regulation. We have designed and implemented HapLand, a scalable, robust biofeedback haptic system testbed to facilitate research-based haptics-enabled wearables design for the purpose of emotion regulation. In this paper, we give an overview of HapLand and our plans for using HapLand for future research.

Author Keywords

Haptic; Emotion; Emotion Regulation; Accelerometer; Linear Resonant Actuators; Eccentric Rotating Mass; Wearable

ACM Classification Keywords

H.5.m. [Information Interfaces and Presentation (e.g. HCI)]: Miscellaneous. J.4 Social and Behavioral Sciences:Psychology.

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 [16]. To mitigate the risk of such harm, people engage in emotion regulation, using a variety of strategies to change the undesirable aspects of ongoing emotional response [15]. While emotion regulation behaviors are widespread and largely intuitive, people nevertheless sometimes fail to implement them effectively. For instance, they may fail to invoke regulatory skills when they are not cued with appropriate emotion regulation strategies [2, 24]. Such observations give rise to a more general question about *how* technology affordances can aid those who fail to self-regulate their emotions.

Haptic signals are simple, personal, and subtle, making them perfect candidates to be used in technological aids [10] to emotion regulation. Relying on the process model of emotion regulation [15], we identified three different ways in which haptic signals could aid emotion regulation (discussed in more detail in the Background section). HapLand is the result of our efforts to build a scalable, robust haptic system testbed with which to explore design parameters of wearable haptic devices aimed at aiding emotion regulation through these three identified mechanisms.

HapLand is a research testbed that allows researchers to create custom-made bio or non-biofeedback haptic effects, visualize them, and deploy experimental designs to study the effectiveness of those effects via self-report or physiological impact on the user.

Background

Here we present an overview of the process model of emotion regulation and provide the rationale for why we consider haptics a suitable technological aid for emotion regulation. We also consider relevant empirical work and highlight how HapLand differs from prior work.

Emotion Regulation Process Model

The process model [15] differentiates among emotion regulation strategies based on the point in the emotion generative process at which each strategy has its primary impact. According to the model, emotion generation begins with encountering a *situation*. Two groups of emotion regulation strategies work by intervening at this stage. *Situation selection* involves taking actions that make it more (or less) likely that one will end up in a situation that could give rise to a desirable (or undesirable) emotion. For example, one might take the stairs instead of the elevator to avoid a grumpy neighbor. Situation modification involves directly modifying a situation in order to alter its emotional impact. For example, one might step out of the elevator as soon as the grumpy neighbor enters it. The second stage of emotion generation involves paying *attention* to salient aspects of the situation. The strategy that intervenes at this stage is attentional deployment, which refers to re-directing attention within a given situation in order to influence one's emotion. The most common form of attentional deployment is distraction, which focuses attention on less emotional aspects of the situation or moves attention away from the situation altogether. One could employ distraction, for example, by thinking about vacation plans while standing next to the neighbor in the elevator. The third stage of emotion generation is *appraisal*, – i.e. the individual's interpretation of the situation. *Cognitive change* is the strategy that intervenes at the appraisal stage. It refers to modifying one's interpretation of the ongoing person-situation interaction in order to alter its emotional impact. A common cognitive change strategy is reappraisal, which involves modifying the meaning of the situation. The fourth stage of emotion generation is the point at which the *emotional response* generated

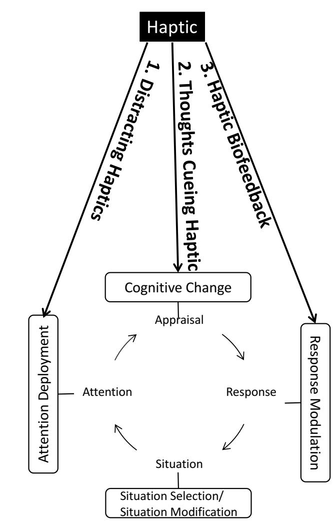

Figure 1: Three potential haptic augmentations for emotion regulation strategies drawing upon Gross' model [17].

by appraisals leads to changes in experiential, behavioral, and neurobiological response systems. *Response modulation* refers to strategies that directly influences experiential, behavioral, or physiological components of the emotional response after the emotion is well developed. Examples include using alcohol, cigarettes, and even food to alter one's feeling state, suppressing facial expressions of emotion, or using physical exercise and deep breathing to alter one's physiological response.

Haptic Augmentations of Emotion Regulation

The choice of haptics to implement a biofeedback emotion regulation system was informed by the findings of Benali-Khoudja et al. [5], Obrist et al. [25], and [18], supporting the idea that haptics can elicit an emotion, as well as by the contrary results of Swerdfeger [28] suggesting that a haptic pattern is meaningless in itself, but becomes interpretable and consequently gives rise to an emotional response after an association has been learned between an emotion and the haptic pattern.

Figure 1 illustrates our proposal for three broad ways that haptics can augment emotion regulation strategies. First, *haptics as an aid to attention deployment strategies* i.e., using haptics as a means of distraction to disengage from the environment. For instance, in an emotional situation, haptic patterns coupled with gamified tasks could provide engaging activities that people could employ as needed. As an example, consider a wearable device that initiates haptic patterns upon detecting increased arousal and asks the wearer to make mentally demanding judgments of the pattern (e.g. count how many clockwise versus counter-clockwise patterns were presented).

Second, *using haptics to aid cognitive change by cueing particular reappraisals*. This type of application requires user training to associate haptic patterns with specific thought patterns as well as algorithms to trigger appropriate cues in a context-sensitive manner. For example, individuals could learn to associate specific haptics with particular personally relevant reappraisal tactics (e.g. thinking about how encounters with unpleasant situations build resilience). A wearable device could then present the haptic upon detecting increased distress. Currently, this type of application is out of scope of HapLand's capabilities due to the need for prior training and context-specific algorithms.

Lastly, *haptics as an aid for response modulation* to directly influence the experiential, the behavioral, and particularly the physiological component of the emotional response after the unpleasant emotion is well developed. For instance, haptic signals could mimic bodily responses characteristic of low emotional arousal (e.g. slow heart rate or breathing rate) and thereby entrain physiological systems towards that state. Alternatively, haptic signals could mirror the current state of physiological systems (i.e. provide biofeedback) to facilitate awareness and thereby aid short- and long-term capabilities to regulate physiological systems. We hypothesized that those haptic patterns that simulate bodily signals such as heart rate and breathing rate are intuitively learnable and are more likely to give rise to an emotional response compared to haptic patterns that are perceived as meaningless.

Related Biofeedback Systems

Gevirtz et al. built a biofeedback system that presented heart rate variability (HRV) as visual biofeedback to participants to regulate emotion. The experimental procedure consisted of participants sitting in front of a computer screen looking at a visual moving object, and monitoring their physiology data as they perform focused breathing. [11, 12, 13, 14]. *Breathe* is a focused breathing app in WatchOS 3, with visual and haptic feedback [4]. The hap-

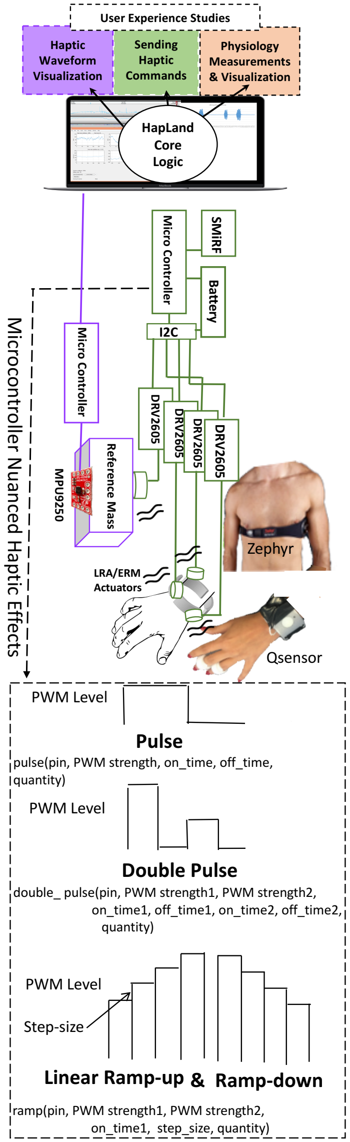

Figure 2: Top: Components of HapLand system. Bottom haptic effect building blocks.

tic feedback is a vibration that slowly increases in intensity during the inhalation. The animated visual provides feedback during both inhalation and exhalation. Just like Gevirtz et al.'s work, the biofeedback does not influence the visual display speed nor the haptic feedback. *MoodWings* is a truthful visual biofeedback system in the form of a flapping butterfly that reacts to a user's stress levels [21]. In this biofeedback device, a high state of arousal precipitates a large flap of the wings, while a calmer state results in gentle movement. The researchers concluded that truthful biofeedback to a nervous population is not very helpful. *EmotionCheck* is a biofeedback device that emulates slow heartbeat haptic signals and applies them via a watch on a person's wrist [7]. Choudhury et al. concluded [7] that haptic intervention, in the form of mimicked 60 bpm heartbeat, down-regulates self-reported anxiety level.

These solutions demonstrate the general feasibility of haptic signals for systems aimed at emotional well-being. However, there is a need for a flexible platform that would allow for systematic and conceptually grounded research of haptic aids to emotion regulation. HapLand was developed to meet this demand.

HapLand System

HapLand is a test-bed apparatus that allows us to explore design parameters – including body location, actuator type, and haptic effect intensity, duration, and pattern – to build an effective emotion regulation wearable system. HapLand provides a platform to create and visualize subtle, quiet, and individualized biofeedback or non-biofeedback haptic patterns. HapLand also allows for implementation of user experience studies in the lab in which the user does not need to sit in front of a screen while a haptic pattern is played on that person's body (i.e., the user may continue engagement with the environment), unless it is a requirement in the study. Figure 2 illustrates HapLand components, which include:

(1) Components to capture physiology measures during haptic use, via two sensors: Qsensor [1] and Zephyr Bioharness. Qsensor is a Bluetooth compatible device that collects electrodermal activity (EDA) with sampling rates of 8, 12, 16, or 32kHz and writes them into a file. Zephyr [23] is a Bluetooth compatible chest harness that logs cardiovascular and respiratory measures. Zephyr collects ECG data every 4 milliseconds, and R to R (the interval between peaks in a ECG waveform) and breathing waveform data every 56 milliseconds.[23]. There are theoretical and empirical rationale for the use of HRV and electrodermal activity (EDA) as an index of individual differences in emotion regulatory ability. Higher HRV reflects a greater capacity for regulated emotional responses [3, 19, 27] and higher EDA is correlated with higher difficulty in regulating negative emotions [8, 19]. For these reasons, HapLand is equipped with portable cardiovascular measures and EDA collector devices.

(2) Core logic of the system that decides which haptic actuator (eccentric rotating mass [ERM] or linear resonant actuators [LRA]) at which location on the body to activate; how to adjust a haptic pattern (tempo, duration, and intensity) based on collected physiology measures, and which commands to send to the haptic wearable wirelessly. The core logic is implemented in Matlab®.

(3) The wearable component that plays the haptic effects (shown in green in Figure 2): two wireless wearables are each equipped with four actuators (see Figure 3). The two wearables feature different types of actuators. The wearable devices receive haptic commands from the core logic of the system through wireless serial ports (Bluetooth Serial Port Protocol).

(4) Component to run experimental designs: Using Psychtoolbox [26], one can design user studies to explore the impact of haptic effects on emotion regulation (e.g., a user study to identify annoyance threshold of LRAs and ERMs).

(5) Component to visualize a haptic effect: While a haptic effect is being played, one or more accelerometers attached to the actuator(s) can collect data.

Why Use Two Different Types of Actuators?
The HapLand wearable component can use either of two types of electromechanical devices, ERM or LRA. Each system drives four actuators, all either LRA or ERM. ERMs are small DC motors with an off-center mass that vibrate in the x-y plane (parallel to the skin). Vibration amplitude is determined by applied voltage and vibration frequency increases with amplitude. LRAs must be driven by an AC signal at their resonant frequency. The resulting vibration is along the z-axis (perpendicular to the skin). Each actuator thus creates distinctly different sensations for the wearer, so using both in our testbed provides us with a broader potential palette for designing and testing haptic experiences.

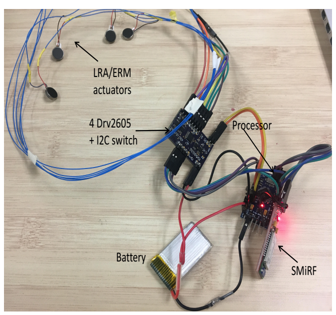

Figure 3: Wearable Components of HapLand system.

Why Use Four Actuators of each Type?
If tactors are placed too close together and each tactor is responsible for presenting a unique signal in the scheme of some complex tactile pattern, the observer will perceive it as one signal and will miss the underlying message generated with the use of two signals. Two-point discrimination acuity is 35mm to 38mm on the forearm [9, 22]. Therefore, 4 actuators are placed around the wrist, allowing for the maximum number of distinct, discernible touch points.

Creating Haptic Effects Based on Acoustic Waves
For creating biorhythm haptic effects, we use acoustic heartbeat and breathing waveforms to define the haptic parameters of duration and intensity. While heartbeat and breathing audio translate readily into recognizable sensations, ECG waveforms, the electrical representation of a heartbeat, do not. Laput et al. have observed that accelerometer data highly resembles audio signals captured via microphone [20] suggesting that compelling haptic sensations can be modeled on audio waveforms.

Scalable Nuanced and Complex Haptic Effects
HapLand is scalable in creating many completely independent effects, and sequences of effects, on the 4 actuators. Primitive effects of pulse, double pulse, and ramp are provided. All parameters can be specified including strength(s), duration(s) and number of repetitions. Ramps can either increase or decrease in intensity. A heartbeat effect is created using a double pulse, for example, while inhalation and exhalation are modeled using ramps with appropriate beginning and ending intensity. Combinations of the primitive effects can create a large variety of complex effects.

Examples of potential advanced haptic effects include: (1) Distributed (using multiple actuators to distribute a haptic effect): Consider a heartbeat signal with two pulses and a long delay simulated via one actuator versus two actuators. With two actuators, one can simulate the first pulse while the other, adjacent to the first, simulates the second pulse.

(2) Bundled: Consider heartbeat and mimicked breathing effects bundled together to allow for focused breathing; as well as feedback that the heart rate is slowing down by gradually decreasing of heart rate effect tempo and intensity. This haptic is richer in context and carries more meaning for a person than a heart rate or breathing rate alone.

(3) Gradually Decremented: The aspect of a haptic signal that is decreasing is embedded in amplitude, tempo, or both. Therefore, it is interesting to question whether one versus the other is more effective in communicating “your

body is calming down.” Our senses are good at tuning out continuous stimuli (i.e., threshold shift), so varying the amplitude (but not stopping it) makes it difficult to miss when an important event is happening. Therefore, we have hypothesized that the anxiety disorder population will benefit more from the gradually decremented than the static haptic.

(4) Truthful versus fabricated versus mixture of both haptic signals: The truthful haptic signal pattern is positively correlated with bodily signals such as HRV, breathing rate variability, and significant EDA changes. Truthful signals can be used as a training aid, helping people learn how to influence affective states in desired directions. Fabricated haptic signals, on the other hand, are those that do not reflect the true physiology state of a person. The signals reflect a desired state rather than the actual state.

Use of Accelerometer Data to Visualize Haptic Effects
HapLand allows for visualizing the acceleration produced by a haptic effect. We use a MPU9250 accelerometer attached to a 25g reference mass. The actuator is tightly coupled to and the entire setup suspended from the edge of a desk allowing acceleration in all directions to be measured.

Figure 4 allows us to compare a heartbeat audio waveform with the acceleration produced by both ERMs and LRAs.

Discussion
We have conducted preliminary tests with HapLand that demonstrate its readiness for systematic studies. As a next step, we intend to use the platform to systematically test conceptually designed haptic patterns. Following the conceptual framework presented here (see Figure 2), we seek to develop a response modulation haptic that combines entrainment and biofeedback. As a first step, we will identify desirable intensity and temporal characteristics of the haptic patterns by quantifying the thresholds of detection (when

Figure 4: Heartbeat audio (top) and acceleration of a reference mass produced along x axis by an ERM (middle) and long z axis by an LRA (bottom)

a sensation becomes noticeable) and “annoyance” (when a sensation becomes unpleasant), for each haptic pattern and actuator type. A more advanced research question focuses on the effectiveness of different haptic feedback regimes as a function of emotional intensity. Hapland provides all necessary requirements to launch such studies.

Conclusions
Haptic signals have desirable properties for designing technological aids to emotional well-being. We proposed a conceptual framework identifying different ways in which haptic signals could benefit emotion regulation. We also developed HapLand, a flexible hardware and software testbed to facilitate systematic research and development of haptic aids to emotion regulation.

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