HapLand: A Scalable Robust Emotion Regulation Haptic System Testbed

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ABSTRACT

Emotion regulation is crucial for healthy adaptation [47, 24], while emotion dysregulation can lead to the development of mental health disorders such as anxiety or depression [7]. 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 [23]. 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; Haptic Data Visualization; Pulse Width Modulation

ACM Classification Keywords

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

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 [24]. 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 [23]. 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 [3, 39]. 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 [18] to emotion regulation. Relying on the process model of emotion regulation [23], 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 why people may fail to regulate their emotions 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 [23] 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 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.

Why People Fail to Regulate their Emotions

Gross [24] identified three major reasons to explain why people fail to regulate their emotions. The first is lack of emotional awareness or an inability to track emotion dynamics; The second is an inability to correctly tradeoff between multiple active competing goals. Even after a person has become aware of an emotion and activated a goal to regulate that emotion, there remain tradeoffs between this currently active goal and other competing active goals. For example, there may be a tradeoff between a short-term relief (If I skip the cocktail party, I can avoid feeling anxious) and a substantial long-term price tag (If I skip the cocktail party, I may miss out on developing helpful professional contacts). Third, a person may be unable to correctly select an emotion regulation strategy. For example, people prefer reappraisal to distraction when emotion intensity is low, but prefer distraction to reappraisal when emotion intensity is high, because at high-intensity lev-

els, reappraisal is often no longer effective. Gross further specified how perception of emotion may influence regulation ability; for example 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 more effective.

Related Work on Haptics for Emotion Regulation

From situation awareness for pilots [37, 18] to body posture awareness for yogis [40], from partial weight bearing awareness in patients [16, 9, 48], to movie watching [30, 36, 41] and gaming [54, 49] enhanced emotional experience, from tracking time, to intuitive navigation [10] and guided breathing [2], researches have explored meaningful characteristics of haptics in different use contexts by building various haptic wearable systems. In the context of emotion expression and emotional information communication, the choice of haptics has been driven by the perception that haptics can be a low fidelity substitute of the sense of touch [8]. Therefore, touch-emotion related studies – including findings on calming effects of touch by Coan [11] and other scholars [13, 53, 26], as well as Keltner's [28, 27] work, conveying that six distinct emotions could be communicated via touch – play a role in shaping haptic-emotion research studies.

Researchers have looked into characteristics of a haptic stimuli that can best elicit, reduce, aggravate or transform a specific emotion. For example, Lemmens et al. [33] looked into tactile patterns based on "butterflies in stomach" for love by sequentially firing motors in the stomach area in a circular manner or "a shiver down your spine" for fear and anxiety applied on an arm or other parts of the body with certain duration and intensity with goal to enhance the emotional experience while watching a movie. McDaniel et al. [36] described six motion patterns (such as wave, spiral, shoulder tap, rain, etc) to elicit emotional response 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. [6] described haptic patterns including "divergent wave", a "vertical shutter", a "horizontal line sweep", etc., inspired from hand writing and voice recognition.

Examples of haptic devices that researchers built in the context of emotion expression and emotional information communication include a mid-air haptic device by Obrist et al. [43], HaptiHug, HaptiHeart, HaptiButterfly, HaptiShiver, HaptiTemper and HaptiTickler by Tsetserukou et al. [51], a 6x4 grid of haptic motors by McDaniel et al. [36]. Furthermore, Benali-Khoudja et al.[6] made an attempt to build a vibrotactile system (the VITAL), and describe the fundamentals of a tactile "language". Rehman et al. [30] built a vibrotactile chair to enhance visually impaired individuals' experience by conveying online affective information in tactile form.

Technologies and research studies developed to improve emotion expression and emotional information communication, including those that employ haptics [43, 30, 6, 36, 33, 29, 52], may be useful to facilitate extrinsic emotion regulation (i.e., someone else has the goal of regulating your emotions or you reach out to someone else to get help with reg-

ulating your emotions). However, with the barriers posed by current lifestyles and working conditions, extrinsic regulation of emotions through touch in traditional face-to-face communication is not always an option. For that reason, people often need to choose among the various communication media options available today to socially regulate their emotions. After choosing a medium, people still have the challenge to produce and maximize "readability"(easy-to-understand representation of emotional information) [55]. In aural and visual communications, readability may come from clear, verbal and salient social cues (e.g., facial expression, voice tone, and body gestures). In text-based communications, readability may be achieved through use of emoticons, capital letters, letter repetition, multiplication of exclamation marks, etc. Yet, extrinsic emotion regulation practicality is limited as today's communication media are not designed with the primary goal of accommodating extrinsic regulation of emotion. Furthermore, the people we often rely on for extrinsic emotion regulation are not always available. In sum, we observed that a large portion of haptic investigations were focused on extrinsic emotion regulation, yet haptics for intrinsic (self) emotion regulation (in particular via biofeedback) has been relatively less well researched.

Only recently, to the best of our knowledge, several startups and tech companies, have begun to develop various limited or no biofeedback haptic wearable technologies explicitly designed for intrinsic emotion regulation, referred to as calming technologies, to facilitate self emotion regulation, in particular by aiding response modulation [50, 42, 2, 14, 10]. An example of visual and haptic wearable with no biofeedback as an aid for response modulation is *Breathe*. *Breathe* is a focused breathing app for WatchOS 3, with visual and haptic feedback [5]. The haptic feedback is a vibration that slowly increases in intensity during the inhalation. The animated visual provides feedback during both inhalation and exhalation. An example of individual-based haptic wearable with biofeedback as an aid for response modulation is *Doppel* [14]. *Doppel* is a Kickstarter wearable wristband with pre-built haptic effects in forms of rhythm of music, heartbeat, and breathing designed to up-regulate positive emotion and down-regulate negative emotion. The device allows for change of intensity and speed of the pre-built haptic effects. It also incorporates resting state heart-rate (computed by placing the pad of a finger over phone's camera and sitting quietly for a minute) in adjusting the haptic effects.

All these approaches have made important contributions, but none of these has fully addressed the important characteristics of a haptic effect that may regulate an emotion. A significant challenge is the substantial dimensionality of the problem, which arises from the existence of numerous possible combinations of the factors (such as tactile sensor types, sizes, vibrotactile strengths, durations, location on the skin, etc.) that could play a part in defining the key characteristics of a haptic effect that may or may not have a significant impact on an on-going emotion. Consequently, it seems infeasible to launch a study to evaluate each one of the haptic effects because the operation is considered to be resource-hungry in terms of time, cost, and necessity of having a large sample size. In addition, researches are looking into haptics for variety of contexts including use of haptics as technological aid for enhancing emotional experience while watching a movie or improving visual or hearing impaired population experiences. With these constraints, each of the earlier studies was forced to choose a limited set of combinations in a particular context resulting in a sparsely populated dataset compared to the entire universe of possible combinations.

It might be expected that the problem will resolve itself eventually, as techcompanies are looking into wearable haptic devices and soon will open their wearable devices for creation and communication of more complex individual-based haptic effects. Through their API platforms, people will create haptic effects for different purposes, and following Darwin's grand idea ofevolutionbynatural selection, the effective haptic effects will thrive and the rest will perish. Until then, we follow the path that other scholars have pursued; building a haptic testbed and presenting a systematic approach for using haptics as technological aid for emotion regulation.

We think that there is a need for a flexible platform that would allow for systematic and conceptually grounded research of haptic aids to intrinsic emotion regulation as autonomic signals historically have been presented to people in visual or auditorial biofeedback modalities rather than haptics. HapLand was developed to meet this demand.

Related Biofeedback Systems for Intrinsic Emotion Regulation
Two examples of visual biofeedback and one example of haptic biofeedback systems as an aid for response modulation is as follows: 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 performed focused breathing. [19, 20, 21, 22]. *MoodWings* is a truthful visual biofeedback system in the form of a flapping butterfly that reacts to a users stress levels [34]. 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 [12]. Choudhury et al. concluded [12] that haptic intervention, in the form of mimicked 60 bpm heartbeat, down-regulates self-reported anxiety level.

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. [6], Obrist et al. [43], and [29], supporting the idea that haptics can elicit an emotion, as well as by the contrary results of Swerdfeger [46] 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 counterclockwise 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 bio-feedback) 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.

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 EDA with sampling rates of 8, 12, 16, or 32kHz in realtime and writes them into a file using QLive software. Zephyr [38] is
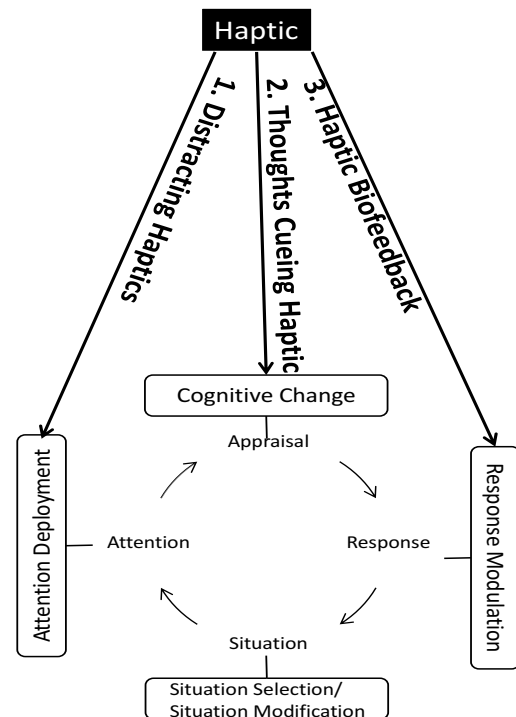

Figure 1. Three potential haptic augmentations for emotion regulation strategies drawing upon Gross' model [25].

a Bluetooth compatible chest harness that logs cardiovascular and respiratory measures. Zephyr sends an ECG packet every 252 milliseconds. Every ECG packet has 63 ECG samples spaced 4 milliseconds apart. Zephyr also sends an R to R (the interval between peaks in a ECG waveform) packet and a Summary packet (heart rate, heart rate confidence, and breathing waveform, etc.) every 1008 milliseconds. Every R to R packet has 18 R to R samples spaced 56 milliseconds apart [38].

Based on Gross's reasoning as to why people fail to regulate their emotions, we concluded that use of physiology measurements could help with not only efficacy assessment of haptic effects in emotion regulation (i.e., how well a haptic effect can help regulating an emotion), but also could facilitate drawing awareness to emotion dynamics tracking (e.g., biofeedback haptic effects) as well as correctly selecting an emotion regulation strategy (e.g., distraction versus reappraisal when arousal level is high). Furthermore, 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 [4, 31, 45] and higher EDA is correlated with higher difficulty in regulating negative emotions [15, 31]. 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
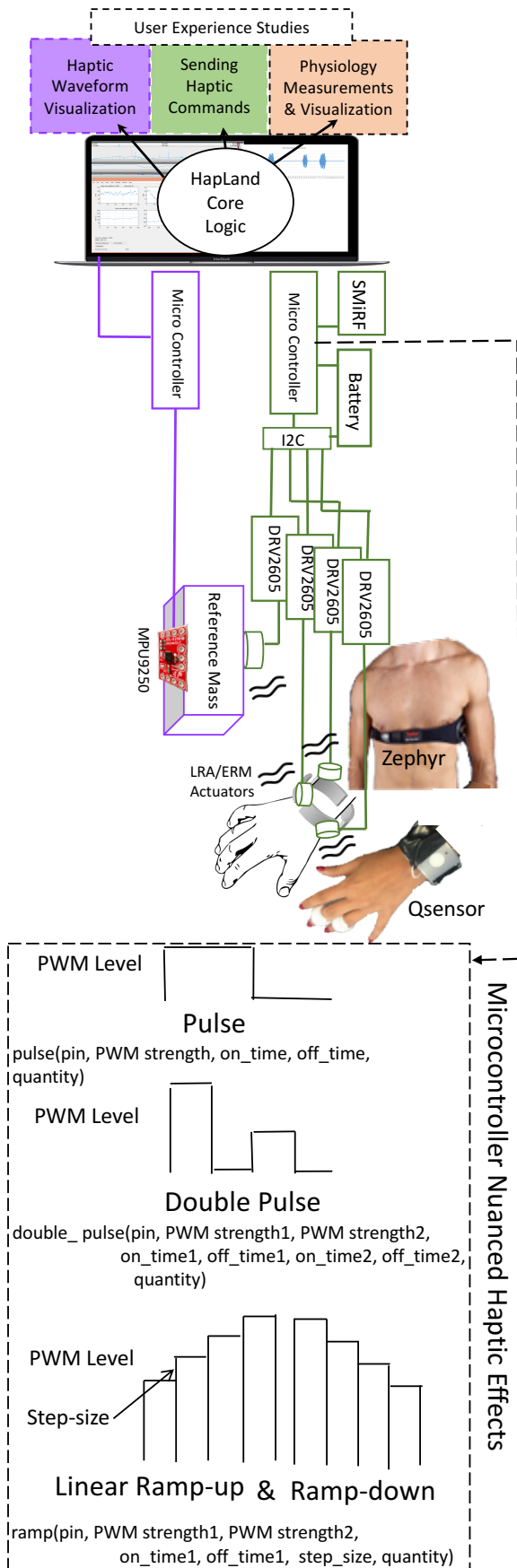
Figure 2. Top: Components of HapLand system. Bottom haptic effect building blocks.

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 [44], 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. LRAs have a lower vibration strength compared to ERMs (0.75G~2G for LRAs and 1G~3G for ERMS). 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.
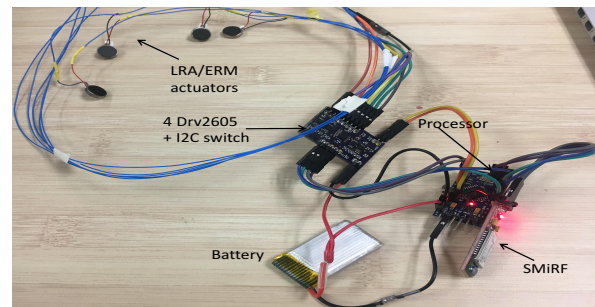

Figure 3. Wearable Components of HapLand system.

DRV2605 Haptic Driver and PWM

Haptic motors require a driver. The DRV2605 chip from Texas Instruments will drive either an ERM or an LRA. It features a library with 123 built-in effects including clicks, ramps and buzzes, but these are intended to create notifications and alerts, such as in cell phones, and are not suitable for creating biorhythm sensations. Instead, we use the pulse width modulation (PWM) input of the DRV2605 to compose our own effects. This requires a microcontroller capable of producing adequate PWM signals and we chose the

ATmega328p made by Atmel. Using PWM we are able to precisely control haptic strength, duration, location, and can build concurrent multi-actuator haptic effects. In the case of LRAs use of the DRV2605 was essential since it detects the resonant frequency of the LRA and converts the PWM signal to an AC drive signal at that frequency. For ERMs it is possible to apply a current buffered PWM signal directly to the actuator, however using the DRV2605 in closed-loop mode allows for overdrive at start-up and braking at stop, producing more precise effects. Since each DRV2605 can only drive a single actuator, we use 4 of them in each system.

Tradeoffs and Limitations of Using ATmega328p
To drive LRAs, the DRV2605 requires a PWM frequency of at least 10kHz. Curie micro controller (mounted on Arduino 101) was not suitable because it did not drive PWM signal at the required frequency base. The Atmel ATmega328p micro controller (used by Arduino Uno, Pro Mini, and Nano), on the other hand, provides PWM frequencies up to 31250Hz which was more than enough to drive the LRAs. Also, using the Pro Mini or Nano, we could power on the wearable using a single lithium ion battery. However, this decision came with the following tradeoffs. (1) Atmel ATmega328p microcontroller provides limited RAM space for local variables and thus the number of haptic effects we can queue up. (2) No more than 4 actuators can be driven because Atmel ATmega328p microcontroller provides 6 PWM pins. We used four of which (pins 9,10,11, and 3) to drive the actuators and the other two (pin 5 and 6) for internal timekeeping. Haptic control signals were transmitted wirelessly to the microcontroller using a Blue SMiRF Gold module which implements a Bluetooth serial port.

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 less than 1 mm on the fingers, 35mm to 38mm on the forearm, 15 mm on the forehead, 39 mm for the back, and 45 mm for the calf [17, 35]. Therefore, choice of 4 actuators is about right assuming that tactors are be placed around the wrist.

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 [32] 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. It is interesting to ask 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 an important event occurance.

(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. 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)

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 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. Should this paper be accepted, will bring the system to the conference for demonstration.

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REFERENCES

1. *Affectiva*. `http://qsensor-support.affectiva.com/`.

2. 2breathe. `http://2breathe.com/how-it-works/`.

3. Amstadter, A. Emotion regulation and anxiety disorders. *Journal of anxiety disorders 22*, 2 (2008), 211–221.

4. Appelhans, B. M., and Luecken, L. J. Heart rate variability as an index of regulated emotional responding. *Review of general psychology 10*, 3 (2006), 229.

5. Appleinsider. `http://bit.ly/28WTd78`.

6. Benali-Khoudja, M., Hafez, M., Sautour, A., and Jumpertz, S. Towards a new tactile language to communicate emotions. In *IEEE International Conference Mechatronics and Automation, 2005*, vol. 1, IEEE (2005), 286–291.

7. Berking, M., and Wupperman, P. Emotion regulation and mental health: recent findings, current challenges, and future directions. *Current Opinion in Psychiatry 25*, 2 (2012), 128–134.

8. Bonanni, L., Vaucelle, C., Lieberman, J., and Zuckerman, O. Taptap: a haptic wearable for asynchronous distributed touch therapy. In *CHI'06 extended abstracts on Human factors in computing systems*, ACM (2006), 580–585.

9. Bril, A. T., David, V., Scherer, M., Jagos, H., Kafka, P., and Sabo, A. Development of a wearable live-feedback system to support partial weight-bearing while recovering from lower extremity injuries. *Procedia Engineering 147* (2016), 157–162.

10. by Somatic Labs, M. `http://wearmoment.com//`.

11. Coan, J. A., Schaefer, H. S., and Davidson, R. J. Lending a hand social regulation of the neural response to threat. *Psychological science 17*, 12 (2006), 1032–1039.

12. Costa, J., Adams, A. T., Jung, M. F., Guimbetiere, F., and Choudhury, T. Emotioncheck: leveraging bodily signals and false feedback to regulate our emotions. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, ACM (2016), 758–769.

13. Debrot, A., Schoebi, D., Perrez, M., and Horn, A. B. Touch as an interpersonal emotion regulation process in couples daily lives: the mediating role of psychological intimacy. *Personality and Social Psychology Bulletin 39*, 10 (2013), 1373–1385.

14. Doppel. `http://www.doppel.london/`.

15. Fabes, R. A., Eisenberg, N., and Eisenbud, L. Behavioral and physiological correlates of children's reactions to others in distress. *Developmental Psychology 29*, 4 (1993), 655.

16. Fu, M. C., DeLuke, L., Buerba, R. A., Fan, R. E., Zheng, Y. J., Leslie, M. P., Baumgaertner, M. R., and Grauer, J. N. Haptic biofeedback for improving compliance with lower-extremity partial weight bearing. *Orthopedics 37*, 11 (2014), e993–e998.

17. Gemperle, F., Hirsch, T., Goode, A., Pearce, J., Siewiorek, D., and Smailigic, A. Wearable vibro-tactile display. *Carnegie Mellon Wearable Group, Carnegie Mellon University, Tech. Rep.* (2003).

18. Gemperle, F., Ota, N., and Siewiorek, D. Design of a wearable tactile display. In *Wearable Computers, 2001. Proceedings. Fifth International Symposium on*, IEEE (2001), 5–12.

19. Gevirtz, R. Resonant frequency training to restore homeostasis for treatment of psychophysiological disorders. *Biofeedback 27* (2000), 7–9.

20. Gevirtz, R. Psychophysiological perspectives on stress-related and anxiety disorders. *Principles and practice of stress management* (2007), 209–226.

21. Gevirtz, R., Gordon, E., and Koslow, S. Autonomic nervous system markers for psychophysiological, anxiety, and physical disorders. *EK Gordon, S.(Ed.), Integrative neuroscience and personalized medicine* (2011), 164–180.

22. Gevirtz, R., and Lehrer, P. Resonant frequency heart rate biofeedback. *Biofeedback: A practitioners guide 3* (2003), 245–250.

23. Gross, J. J. The emerging field of emotion regulation: an integrative review. *Review of general psychology 2*, 3 (1998), 271.

24. Gross, J. J. *Handbook of emotion regulation*. Guilford publications, 2013.

25. Gross, J. J., and Levenson, R. W. Hiding feelings: the acute effects of inhibiting negative and positive emotion. *Journal of abnormal psychology 106*, 1 (1997), 95.

26. Hertenstein, M. J., and Campos, J. J. Emotion regulation via maternal touch. *Infancy 2*, 4 (2001), 549–566.

27. Hertenstein, M. J., Holmes, R., McCullough, M., and Keltner, D. The communication of emotion via touch. *Emotion 9*, 4 (2009), 566.

28. Hertenstein, M. J., Keltner, D., App, B., Bulleit, B. A., and Jaskolka, A. R. Touch communicates distinct emotions. *Emotion 6*, 3 (2006), 528.

29. Huisman, G., and Darriba Frederiks, A. Towards tactile expressions of emotion through mediated touch. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, ACM (2013), 1575–1580.

30. Kim, M., Lee, S., and Choi, S. Saliency-driven real-time video-to-tactile translation. *IEEE transactions on haptics 7*, 3 (2014), 394–404.

31. Kreibig, S. D. Autonomic nervous system activity in emotion: A review. *Biological psychology 84*, 3 (2010), 394–421.

32. Laput, G., Xiao, R., and Harrison, C. Viband: High-fidelity bio-acoustic sensing using commodity smartwatch accelerometers. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, ACM (2016), 321–333.

33. Lemmens, P., Crompvoets, F., Brokken, D., Van Den Eerenbeemd, J., and de Vries, G.-J. A body-conforming tactile jacket to enrich movie viewing. In *EuroHaptics conference, 2009 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics 2009. Third Joint*, IEEE (2009), 7–12.

34. MacLean, D., Roseway, A., and Czerwinski, M. Moodwings: a wearable biofeedback device for real-time stress intervention. In *Proceedings of the 6th international conference on PErvasive Technologies Related to Assistive Environments*, ACM (2013), 66.

35. Matscheko, M., Ferscha, A., Riener, A., and Lehner, M. Tactor placement in wrist worn wearables. In *Wearable Computers (ISWC), 2010 International Symposium on*, IEEE (2010), 1–8.

36. McDaniel, T., Bala, S., Rosenthal, J., Tadayon, R., Tadayon, A., and Panchanathan, S. Affective haptics for enhancing access to social interactions for individuals who are blind. In *International Conference on Universal Access in Human-Computer Interaction*, Springer (2014), 419–429.

37. McGrath, B. Tactile situation awareness system.

38. Medtronic. **http://qsensor-support.affectiva.com/**.

39. Mennin, D. S. Emotion regulation therapy for generalized anxiety disorder. *Clinical Psychology & Psychotherapy 11*, 1 (2004), 17–29.

40. NadiX. **http://wearablex.com/nadix/**.

41. Nanayakkara, S. C., Wyse, L., Ong, S. H., and Taylor, E. A. Enhancing musical experience for the hearing-impaired using visual and haptic displays. *Human–Computer Interaction 28*, 2 (2013), 115–160.

42. NuCalm. **http://www.nucalm.com//**.

43. Obrist, M., Subramanian, S., Gatti, E., Long, B., and Carter, T. Emotions mediated through mid-air haptics. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ACM (2015), 2053–2062.

44. Psychtoolbox. **http://psychtoolbox.org/**.

45. Reynard, A., Gevirtz, R., Berlow, R., Brown, M., and Boutelle, K. Heart rate variability as a marker of self-regulation. *Applied psychophysiology and biofeedback 36*, 3 (2011), 209.

46. Swerdfger, B. A. *A First and Second Longitudinal Study of Haptic Icon Learnability*. PhD thesis, University of British Columbia (Vancouver, 2009.

47. Szczurek, L., Monin, B., and Gross, J. J. The stranger effect the rejection of affective deviants. *Psychological science 23*, 10 (2012), 1105–1111.

48. Tech, L. B. **http://www.lumobodytech.com/**.

49. Thumbsticks, V. S. C. W. N. **http://engt.co/2iT09Ys**.

50. Thync. **http://www.thync.com/**.

51. Tsetserukou, D., and Neviarouskaya, A. ifeel_im!: augmenting emotions during online communication. *IEEE Computer Graphics and Applications 5*, 30 (2010), 72–80.

52. Ur Réhman, S., Liu, L., and Li, H. Manifold of facial expressions for tactile perception. In *Multimedia Signal Processing, 2007. MMSP 2007. IEEE 9th Workshop on*, IEEE (2007), 239–242.

53. Weller, A., and Feldman, R. Emotion regulation and touch in infants: the role of cholecystokinin and opioids. *Peptides 24*, 5 (2003), 779–788.

54. Withana, A., Koyama, S., Saakes, D., Minamizawa, K., Inami, M., and Nanayakkara, S. Rippletouch: initial exploration of a wave resonant based full body haptic interface. In *Proceedings of the 6th Augmented Human International Conference*, ACM (2015), 61–68.

55. Zaki, J., Weber, J., and Ochsner, K. Task-dependent neural bases of perceiving emotionally expressive targets. *Frontiers in human neuroscience 6* (2012).