Affective Haptic Vest for Facilitating Interpersonal Communication

By

JACAR BALDWIN

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APPROVED, THESIS COMMITTEE

Marcia O'Malley
Thomas Michael Panos Family Professor in
Mechanical Engineering, Electrical and
Computer Engineering, and Computer Science

Matthew Brake
Assistant Professor of Mechanical
Engineering

Akane Sano
Assistant Professor of Electrical and
Computer Engineering, Computer Science
and Bioengineering

HOUSTON, TEXAS
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ABSTRACT

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Jacar Baldwin

Touch plays an important role in deepening human connection. The emerging field of Affective Haptics seeks to analyze and design systems capable of processing human emotions through touch. There is an increasing focus on using the sense of touch to assist in communicating information: in entertainment, treatment procedures in social and developmental therapy, and social interaction. This thesis reports on the design of an Affective Haptic Vest, the design of vibrotactile cues displayed onto the back of the wearer of the vest, and an exploratory experiment to evaluate the ability of the vest and cues to facilitate communication of emotion. In particular, the goal of this experiment was to investigate if the vibrotactile cues displayed through the vest were capable of communicating four foundational human emotions: happiness, sadness, anger, and fear. The results were supportive of the hypothesis that the vest and cues could convey affect, and encourage us to explore the design of vibrotactile cues on the back as an affect area, and highlight areas to further consider when designing affective wearable devices.
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to the deep-dive of groundwork of which we’ve built ours distinct but similar areas of this field, to the looking out whenever this new venture may have cast doubt in my ability to successfully pursue this avenue, I thank you.

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Chapter 1

Introduction

Foundations of a successful relationship, be it professional, affectionate, or social, are rooted in effective communication. Relaying information is the catalyst in establishing trust with another person, accomplished intentionally through verbally speaking and physically touching them. However, underlying motivations are shown through a mix of conscious and subconscious acts. Examples are audible exasperation such as a groan or a sigh to show discontent and boredom respectively and through physical cues such as body language and facial expressions. Individuals utilize facial expressions to decipher attitudes towards something the giver of information said, to recognize shifts in conversational tones, and also in deliberately providing these same pieces of knowledge to people. 65% information given to a user is defined in their perception of nonverbal but person-to-person communication [11]. An issue arises however in perceiving nonverbal expressions in day-to-day conversations, thus a device is necessary to stimulate these attitudes, and effectively communicate them to the wearer of said device.

This thesis reports the hardware and vibrotactile design of an Affective Haptic vest, and an exploratory experiment in facilitating communications of affect. The goal of this experiment was to develop a wearable device capable of eliciting affective expressions and investigate if the vibrotactile cues stimulated through the vest were capable of communicating human emotion (happiness, sadness, anger, and fear). The results of the experiment seek to inform the design of vibrotactile cues of the back as
an affect area, and things to consider when designing affective wearable devices.

1.1 Kinesthetic and Cutaneous Feedback

Haptic interfaces are devices that stimulate the sense of touch through physical interaction with the skin, fingers, hands, limbs, or other body parts [1]. Because there are a range of sensory receptors in the skin and in the tendons around our joints, there are a range of types of haptic devices that target particular touch sensations. The two broad categories of haptic interfaces are kinesthetic-type devices and cutaneous-type devices. Kinesthetic haptic feedback utilizes sensory receptors in the body’s muscles and tendons to discern applied torques and forces applied to the user from the environment. Consider the action of picking up a baby - our proprioceptive sense allows us to understand where are limbs are in relation to our body. When we lift the baby up, we sense the effort from our muscles, and we perceive the forces by the motion and action in the tendons around the joints of our arms. This form of haptic feedback is beneficial in scenarios that employ the reliance of forces and torques, such as virtual object manipulation in virtual reality to enhance the user’s sense of immersion like in [12]. Cutaneous haptic feedback is applied to the surface of the body, with information provided through the skin. This type of haptic feedback is recognizable in modern day society with the newest age of mobile technology. Every time a notification comes to your phone, your skin’s mechanoreceptors (detailed in Table 1.1) sense the sensation, allowing your brain to perceive the interaction and make note of its roughness, duration, rhythm, etc., and derive at a conclusion of alert/priority category to decide when to respond to it.
<table>
<thead>
<tr>
<th>Receptor Type</th>
<th>Skin Type</th>
<th>Location</th>
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<tr>
<td>Merkel disks</td>
<td>Glabrous/Hairy</td>
<td>Basal layer of epidermis/</td>
<td>Indentation</td>
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<td></td>
<td></td>
<td>Around guard hair follicles</td>
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<tr>
<td>Ruffini ending</td>
<td>Glabrous/Hairy</td>
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<tr>
<td>Meissner corpuscle</td>
<td>Glabrous</td>
<td>Dermal papillae</td>
<td>Skin movement/</td>
</tr>
<tr>
<td>Pacinian corpuscle</td>
<td>Glabrous/Hairy</td>
<td>Deep dermis</td>
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<td>Longitudinal</td>
<td>Hairy</td>
<td>Awl-Auchene/Zigzag</td>
<td>Hair follicle deflection</td>
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<tr>
<td>lanceolate ending</td>
<td></td>
<td>hair follicles</td>
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</tbody>
</table>

Table 1.1: Summary of mechanoreceptors in the skin [10].

1.2 Types of Cutaneous Haptic Feedback

1.2.1 Normal Force

Normal force feedback devices produce forces perpendicular to the desired extremity. As such, these equipment are most commonly referred to as “squeeze” devices. Often, when this force is applied to the skin, a band is used to uniformly squeeze the surface of the appendage. Squeeze bands produce continuously varying normal forces, and on or more squeeze bands can be combined in a wearable device. An example of a cutaneous squeeze device can be seen in Fig. 1.1(a).

1.2.2 Shear Force

Shear force feedback devices produce forces tangential to the skin, typically realized through mechanism that either stretch or twist the skin surface. Stretch cues are realized by actuating a mechanism that makes contact with the skin and translates
Figure 1.1: (a) Cutaneous fingertip haptic device utilizing "squeeze" forces [1]. (b) Inclusion and depiction of Normal vs Shear Forces [1].

along the limb, or by a rotating mechanism with an axis or rotation parallel to the skin surface. Twist cues are recognizable as a rotation about an axis normal to the skin surface, maintaining contact as the rotation movement occurs. Shear and normal force cues can be combined to create a multimodal haptics devices, as shown in Fig. 1.1(b).

1.2.3 Vibration

While shear and normal force cue are defined by their “direction” of actuation, vibration cues are defined by the parameters of the actuation. Vibration type cutaneous cues are the most commonly used haptic actuation. One reason for their widespread use is the variety of cue types that can be actuated by manipulating parameters of the sensation such as amplitude, duration, location, and frequency [13]. Adjusting just one of these characteristics can lead to a multitude of cues, and adjusting a combination of them, and extending the number of vibrotactile actuators, multiplies the cue range tremendously. Another advantage of vibrotactile actuators for wearable haptic designs is that such devices do not require mechanical grounding like shear...
and normal cue devices. Vibrations can manipulate discrete, scaled actuation’s to convey information with an intensity marker, as well as displaying continuous information (such as navigational information through a mobile app [14]) with continuous or pseudo-continuous cues. Figure 1.2(a) and 1.2(b), display examples of some vibrotactile haptic devices.

(a) Missive                 (b) Poke

Figure 1.2: (a) MISSIVE multi-sensory haptic device, includes a band of vibrotactors around the arm [2]. (b) POKE haptic device used to deliver touches during phone conversations [3].

1.3 Affective Haptics

The current state of technology lies in the innovation of information technology. At your fingertips at any given time, is the ability to expand your knowledge, develop a new skill, or gain answers to questions of the world. While breakthroughs in communication are at an all-time high, the ability to sensibly discern and articulate emotions through technology hasn’t been created. The first attempt in accommodating this disparity of understanding is with the introduction of Affective computing; an interdisciplinary field of psychology, computer science, and cognitive science that seeks to study and develop emotional systems [15]. This catalyzed the bridging of the gap...
between emotion and technology, spawning subcategories like emotional intelligence, Human-Computer Interaction, and Affective Haptics.

1.3.1 Development

Affect is the underlying feeling of emotion or mood, Haptic is a Greek verb meaning “touch”. The field of Affective Haptics therefore is defined as “the acquisition of human emotions through the human touch sensory system, the processing of emotion-related haptic data to detect affect, and the display of emotional reactions via haptic interfaces. Emotions may be solely communicated through the sense of touch or coordinated/integrated with other sensory displays (such as audition or vision) in a multimedia system [16].” Research is far-reaching and plentiful and to better categorize this field, I group the overall applications into three groups:

- Extracting emotion
- Conveying emotions
- Manipulating emotions

In the extracting of emotions, the affect state of the user is derived through sensory instruments, typically through a collection of bodily and/or physiological parameters [4]. In [17], an imitation furry pet sensed heart rate, hand pressure, and gesture motions to describe user affect onto a tangible object. In the conveying of emotions, researchers seek to specifically evoke an affective state onto a user. In gaming, affective haptics is used to help enrich the player’s engagement [18]. The manipulation of emotions group is a combination of the above applications where the technology seeks to persuade or modify your current state of affect into another state. This is a common method in the remediation of the user’s emotional state like in therapeutic
touch [19]. For those who suffer from social disorders, affective sensory integration therapy extracts an unexpected state of negative affect, determines the best course of action, and typically will elicit a positive or effective affect to counterbalance it.

With the continued growth of the field, technologies have been created to effectively provide an apparatus applying one or a combination of these groups. When looking at affective haptic devices, I group the devices based on design aspects:

- Multi-modality
- Stimulation Modulators
- Tactile Network
- Tactile Mediums

*Multi-modality* is the choice or combination of modes of presenting affective information. From more prevalent modalities of audio and visual stimuli to underrepresented stimuli like thermal and tactile. *Stimulation modulators* is the parameters the affect device actuators modify to present information: intensity, velocity, shape, succession, etc. The *Tactile Network* is the sender/receiver combination that the affect information is being passed from and to. Examples include human-robot, robot-human, human-human, and human-illusion that describes the telepresence or imaginary receiver of cues, typically in the form of an object or middle-man of communication. Lastly are the *Tactile Mediums*, the tactile displays or aides that assist in presenting the affective cues. The most common examples are in wearable devices like a vest, sleeve, or wristband, to tangible objects like robots or animals.
1.3.2 Applications

The following subsections gives descriptions and examples of the common application areas in affective haptics.

Entertainment

Eid and Osman [16] define a category that summarizes the application area of entertainment and affective haptics: entertainment for affective haptics vs affective haptics for entertainment. Entertainment for Affective Haptics is the utilization of games or gaming environments to measure affective behaviors around game [20]. An example of this would be the analysis of character engagements within a game to measure situations that induce stress or anxiety for gamers. The more popular of the group is the utilization of affective haptics for entertainment. This focus is on the use of affective modalities to enhance the user experience and immersion in entertainment. Lemmens et al [21] develop a tactile jacket to deliver movie-specific tactile stimuli to the wearer to influence the viewer’s emotions to the movie. In gaming, affective haptic devices are created to provide realism for the gamer to enhance their participation. In [22], Lindeman et al. developed a spatialized vibrotactile feedback system that enhances user realism in a virtual game, with a focus on minimizing load and maximizing contact and collision information (realism in experiencing an opening of a door or shuffling through tall grass). The future of gaming is moving towards full immersion by placing the player as close to the environment as possible through virtual reality. Affective haptics applies its foundation of human affect to increase the virtual presence for the user through pseudo-mapping and vibration actuation [23].
Health

The development and strengthening of affective touch are important in the livelihood of humans, especially for children, the old, and the afflicted. The field of Affective Haptics creates means of providing valuable impact both in evoking and repressing affect in people. Within mental health, affective haptic devices have elicited soothing sensations that assist in grounding senses, complementary to current mental illness treatments [24]. In the repressing of affect state, the devices have been shown to provide help in the treatment of depression in ADD for relaxing [25]. Moving to the physical side of treatment, affective haptics has been shown to provide assistance in postural stability for the elderly. Through a noninvasive vibrotactile display of user body tilt, affective devices reduce body sway during testing for balance-impaired individuals [26]. In the more operative domain, there’s been research in the application of affective haptic in telesurgery, telerobotics, and teleoperation surgery [27].

Communication

The newest age of technology has conditioned the normalcy of haptics as a means of providing information to users. The most common example of this is with smartphones delivering notification and alert messages to our cellular devices. Affective haptics has valuable applications in providing information to individuals in multiple areas. In guidance navigation, the user experience is a common case in the implementation of affective foundations. The user experience is an integral part in relaying technological information, from personalization preferences to material property choices, these all play a role in the interaction process in navigation [28]. In navigation itself, similar to its application in healthcare [26], affective haptics is utilized in feedback information to aircraft pilots [29]. During long-term flights, heading per-
ception and subsequent spatial disorientation is common, which cause a decrease in
attention during aircraft transport. To mitigate that incident, affective haptic de-
vice senses the pilot’s postures and movement and produces affect-based orientation
corrective-actions to “realign” the pilot’s orientation, and provides a tool to improve
exhaustive flight conditions. In [30], a less-threatening situation of navigational aid
is presented and an affective vest is created to stimulate vibrotactile patterns across
the lower back. In intimate communication, a more robust system in [31] sought to
create a sense of presence between loved ones over distances.

1.3.3 Current State

The current state of research in affective haptics has highlighted a gap in under-
standing the complexities around the individuality of humans and in the vibrotactile
rendering of emotions. Between people, there are a number of anatomical features
that can influence affect. At surface level, body features like size, the toughness of
skin, hair, and more can impede the actuator’s ability, physically, in the localization
of actuation and slippage of vibrotactile motion. Internally, the affective response
to haptic stimulations has proven difficult to characterize. A comprehensive system
around user perception of responses will help the development of patterns signifying
levels of affect, using subjective ratings of pleasantness and arousal, to more wholly
provide universal affective stimuli [16]. In the same breadth, the creations of these
patterns needs to be thoroughly tested and expressed in repeatable and effective mea-
ures. The scale, size, method, and vibrational patterns of waveforms have, to date,
been exploratory in application but not conducive to the populace as we move to-
wards more complex affects. In the audible method of vibrations [13], an introduction
of rhythm was tested and proves a promising domain to explore. However, its lim-
its are derived culturally, where a temporal pattern recognized domestically will not have the same recognition across national lines. Research in more complex waveform criteria is needed to depict complicated emotions. In vibrotactile parameters, the use of localization within an affect area is also being researched heavily. Previously, the only difference in the location was a uniform vibration, across the entirety of an appendage. In research such as [32], spatial localization within an affect area is investigated to determine its efficacy in manipulating human emotions/perception.

1.4 Contributions

This thesis reports the hardware and vibrotactile design of an Affective Haptic vest, and an exploratory experiment in facilitating communications of affect. The goal of this experiment was to develop a wearable device capable of eliciting affective expressions and investigate if the vibrotactile cues stimulated through the vest were capable of communicating human emotion (happiness, sadness, anger, and fear). The results of the experiment seek to inform the design of vibrotactile cues of the back as an affect area, and things to consider when designing affective wearable devices. Chapter 2 presents the framework by which affect is implemented into wearable designs, including different designs across affect areas, actuators types, and vibrotactile parameters. Additionally, the design parameters chosen to create an Affective Haptic Vest for facilitating interpersonal communication are detailed. Chapter 3 describes the results of a pilot experiment to determine the efficacy of the design. Conclusions and future work are presented in Chapter 4.

The primary contributions of this thesis includes:

- A survey of the literature related to affective haptics
• A prototype wearable affective haptic vest comprised of an array of vibrotactile actuators

• The design of complex vibrotactile cues and a software for rendering affective haptic cues

• A pilot investigation of the efficacy of the vest and cues to elicit emotional responses from users
Chapter 2

Affective Haptic Design

In this chapter, we conduct a survey on affective haptic devices with important conclusions, describe the design of our Affective Haptic Vest and the accompanying vibrotactile cues used to facilitate communication of emotion. There are several design considerations for a wearable haptic device, including the location of the body where it will be worn and the configuration of haptic actuators; the type of haptic actuators to be used, and the method to drive the actuators. Once these are decided, the affective cues themselves need to be redesigned.

Figure 2.1 : (Left) 3D Print iterations. (Right) Hand sketch revision for Affective Haptic Vest.

(a) 3D Housing Iterations               (b) Vest Design Sketch
2.1 Survey of Affective Haptic Devices

In the implementation of affective haptics into communication, one of the first research areas were around the use of tactile interfaces. In its early stages, the medium for communicating affect was in tangible objects like with the Haptic Creature device shown in Figure 2.2.

![The Haptic Creature](image)

Figure 2.2: The Haptic Creature [4].

The device was created to perceive the world through touch and express itself through different human-like means like breathing or audible noises of purring [4], and adapted to sense human emotion through touch [17]. While it was found to be effective in the communication of affect via a tangible device, its anthropomorphic base proved to not be a good application in human-human communication.

The tactile interface of a wearable device created a new means of communicating emotions through a device. One of the earlier examples of this was the TapTap device [33]. The wearable haptic system allowed for a nurturing human touch to be recorded, broadcast and played back for use in emotional therapy. A full pilot study was conducted, and showed the effectiveness of actuators in recalling human touch. My takeaways from this were primarily in the decision of my tactile interface as a
body-focused wearable haptic device and design parameters I utilized.

The original TapTap design utilized four different types of actuators: 8x vibrating motors, 8x solenoids, air bladder and 4x peltier junctions (as seen in Figure 2.3(a)). Through different actuations like sequential vibrations, simultaneous actuations, and air and heat manipulation, the sought to reproduce human touch (press, stroke, contact and tap). The first design led to conclusions around how gender effect actuation perception, the importance of location and sequencing of actuation, and confirmed the ability for a body-brace device to convey human touch. A second prototype (depicted in Figure 2.3(b)) was developed to solve the design problems around the original brace. The brace was difficult to adjust the actuator positions and was perceived as un-sociable. The vibrations seemed more robot-like and a new garment was chosen to make it more personable. Their choice of a more modular, and user-friendly scarf provided a medium that was fashionable, secure, and user-friendly by giving the user the ability to activate the actuators when they desired.

While the device did prove to be highly customizable by allowing the wearer to choose the location of each actuation, for the purposes of ensuring consistent
affect communication across subjects and standardize emotional recognition, a more structured apparatus was necessary.

In the device and experiment by Bailenson et al. [5] at Stanford, a three-part experiment was conducted, of which I will be focusing on the first two. In the first experiment, they used a basic, two degrees-of-freedom, Virtual Interpersonal Touch (VIT) force feedback device, (Immersion Impulse Engine 200) to determine participants ability to represent various mental states and emotions through the joystick. In the second experiment, they sought to test people’s ability to recognize the haptic joystick representations rendered in experiment one.

![VIT Device for experiment one of the study [5].](image)

The affects of choice for experiment one were anger, disgust, interest, fear, joy, sadness, and surprise, most of which comprise what’s referred to as the “Big 7”. The goal of the experiment was for a user to communicate each of these mental states, via the joystick (depicted in Fig. 2.4), within 10 seconds, with the goal of another individual successfully identifying the same mental state given before their emotional conveyance. The results from the experiment two (depicted in Fig. 2.5), showed the effectiveness of conveying these 7 emotions from participants in experiment one.
Participants were correct on 33% of trials, scoring above chance, and the greatest emotion recognition in fear, joy, sadness, anger, and disgust. One of the more discernible and statistically significant motion parameter was in how speed of their interaction impacted their decision.

Figure 2.5: Average Response across all participants for the 7 emotions [5].

The criteria behind the design of these forms were created through research into affective haptic cues currently utilized in affective haptic devices. A model utilized in representing affect emotions is the circumplex model of affect [34]. This model is founded on the principle that all affects can be described through the combination of dimension of arousal and valence. In early devices, their affect areas focused on the elicitation of these two dimensions. A prototype by Salimnen et al [6] was developed to be used as a medium at which to interpret affective qualities of stimulus pairs of rotational motion properties: burst length, continuity, and direction.
The common dimensions of valence and arousal were incorporated in affect stimuli but a third and fourth dimension of approach-ability and dominance was included. The case around its inclusion was the underlying human motivation of emotions being linked to avoiding or approaching something. The stimuli consisted of three variables: four rotation style (Fig. 2.7) (forward, backward, forward-backward, and backward-forward), burst length (100ms, 50ms and 20ms), and continuity vs discontinuity. For the discontinuous stimuli interval, a 33ms, 100ms and 140ms burst was in between the stimuli.

The experiment began with a practice session focused on distinguishing between two cues as either the same or different of 15 sets of a combination of stimuli. The testing phase consisted of all 12 possible combinations being stimulated on the participants (132 of different, 132 of same) with the same task set described in the practice sessions. After the experimental trials, the participants were asked to rate their experience on a nine-point bipolar scale for each affective parameter: from pleasant to unpleasant, from relaxed to aroused, from avoidable to approachable, and from controlled to controlling. Results of the experiment show that rotation style, are a feasible tactile cue to distinguish affective parameters. The discontinuous stimuli
were rated as more pleasant and approachable, but less arousing and dominating than continuous stimuli. The reaction time analysis shows that the most significant variable was rotation style, while the error rate was significant by burst length. Design considerations from this experiment that was utilized in my design process is the incorporation of movement into my design parameter. Through the movement, or perceived movement of vibrotactor onto a person, you are able to introduce a new set of waveforms capable of achieving different emotional perceptions.

Switching focus to more recent prototypes around the Big 7 emotions, Krishna et al [7] developed a vibrotactile glove to assist in aiding delivery of facial expressions to visually impaired people. The device itself, pictured in Fig. 2.8, was developed for the hand and consisted of 14 vibration motors (one for each phalanges), mounted on the backs of finger.

Their affect expressions of choice were slightly outside the norm, consisting of six of the Big 7, with the addition of what I’d call a “control” group at which the par-
Participants could compare to the other cues (neutral affect). The vibrotactile cues were grouped into two sections based off of the “visual emoticon”, utilizing the mouth to prominently represent the emotion (Happy, sad, surprised and neutral), and “auxiliary icons” (angry, fear and disgust). In the visual emoticon category, the patterns of the vibrotactile cues were similar to the shape of the mouth in the haptic expressions (as seen on Fig. 2.8). For the second group, since the mouth wasn’t sufficient enough alone to convey the emotion through tactors, location and direction of vibrotactor patterns were prioritized. For the experiment, the goal was to determine how well participants could recognize the haptic patterns. They were given a familiarization phase where they were introduced to each pattern, with a confirmation correspondence from experimenter, and began actual experiment once participant deemed themselves “comfortable” in pattern recognition, and then until they had 100% recognition across random presentation of the patterns. Data points derived

Figure 2.8 : (a) Finalized design of Vibrotactile Glove. (b) Emotional Mapping for Vibrotactile Glove [7].
from this experiment were recognition accuracy and time response.

Figure 2.9: (a)Recognition rate across all 12 participants. (b) Average Response time across all 12 participants [7].

Results of this experiment showed an overall recognition rate of 89% and that Group 2, of the auxiliary icons, performed higher than visual emoticon parameters. Design consideration in this study I utilized in my vibrotactile design is the use of patterns in distinguishing emotional vibrotactile cues. Even with discernible choices of vibrotactile cues associated with common human emotion (happy being a U, sad being an upside-down U, etc), the patterns in group 2, still performed better. This suggests that location and sequence of actuations proves an important criterion, outside of replication of facial features patterns, that is worth considering when developing haptic cues.
2.2 The Affective Haptic Vest

The following subsection details the affect, mechanical and physical design and considerations of the Affective Haptic Vest, a wearable garment that combines functionality with vibrotactile feedback. The design spanned months of experimental iterations of mechanical drawings, 3D prints (Fig. 2.1(a)), commercial product research, and prototyping before finalizing on the design shown in Fig. 2.10.

Figure 2.10: Finalized design with vibrotactile actuators adhered to the Affective Haptic Vest.

2.2.1 Haptic Vest

The design process for the haptic vest (shown in Fig. 2.10) was driven by a primary goal producing a wearable garment that maximizes usability while ensuring maximum localized vibrotactile actuation. I selected a vest form factor for my wearable haptic
device. I chose a vest for its ease of wearability. Prior work has also shown the importance of applying affective cues to the body [30] [21].

There were multiple vests readily available to buyers but different types had different limitations that wouldn’t lend themselves to an affective experiment - weighted vests were too bulky and limited movement, fashion vests were too light, and workout vests were designed around solely accomplishing a singular physical task. Based on commercially available garments, a multi-sized sauna vest (Wonderience ASIN: B07ZVS792W) (Fig. 2.11) was chosen to allow comfort for the wearer, a modular design to accommodate different user physiques, and a zipper/adhesive strap combination for the security of tactors onto the wearer’s body.

With the accommodation of user physique came the design criteria around easy load-unload (LUL) of the tactors between sizes of vests. Due to the selection of the
sauna vest, the fabric style created a limitation of options for securing the tactors onto the vest. Tactors were secured in a 3D printed housing, shown in Figure 2.14(b) an adhesive was needed to bind the actuators. The adhesive needed to be double-sided to allow for LUL, strong enough to fasten to both the housing and the slick fabric of the inside of the vest, and capable of being sized to different vests and design changes. A Hook and Loop tape adhesive (Fig.2.12(a)) by Strenco (Model: VC215) fulfilled all of these criteria. The adhesive was cut into scaled, square sizes and arranged on the location on the back where the desired vibrations were.

Figure 2.12 : Detailed picture set of the hook and loop adhesive (Vest Side) utilized in securing tactors onto vest.

2.3 Vibration Actuators

Vibration and vibration motors have the largest, commercially sourced, readily available market among the list of actuators. Depending on scope and application, there are numerous sizes, shapes, and subsequent cost for vibration motors and its important to understand your options for these systems to effectively source for what you want. All Vibration motors create mechanical oscillations from electrical signals, for the user to feel. This section is meant to provide the decision matrix for the
vibrotactor used in the Affective Haptic Vest, and an overview of the most common vibration motors in the field.

2.3.1 Voice Coil Actuators

The actuator of choice for this haptic device was the voice coil actuator (VCA). VCAs were originally used for speakers in converting electrical energy into sound waves through a cone, to amplify a voice (hence its name). Voice-coil’s create vibrations through linear motion of a mass however they do not utilize a spring, but polarity of a magnet. The electrical current flowing through the coil, interacts with the magnetic field in the systems, and generates forces perpendicular to the direction of the input current and is modified by adjusting polarity of the current [35]. Vibration Actuator designs that led to the voice-coil among other actuators are:

- Larger displacement size
- Bi-directional movement
- Constant force across the bi-directional stroke travel length
- Higher force density (capable of achieving high forces over large distances)
- Complex motion profiles (Ex; accelerate and stop precisely, bi-directional force precision)

There are limitations with using voice coils, such as frequency response cap at smaller stroke sizes and price, but within the scope of Affective design, its advantages outweigh its shortcomings.

Because of the metallic backing of the Tectonic tactors (pictured in Fig. 2.14(a)), a 3D print design was created to house the tactor securely, while not limiting the
coils vibrating to its highest height. To the back of the housing, the male part of the adhesive was attached and finalized the LUL design for the Affective Haptic Vest.

Twenty actuators (four sets of five tactors) were used in creating the Affective vest. They were arranged in four areas of the back most commonly used in relaying information through touch: the left and right of the teres major and minor, and the left and right of the lower latissimus dorsi. Examples of touch, common in these areas are hugs, supportive pats on the back, and physical guidance. The 2-1-2 arrangement of the tactors (as seen in Fig. 2.15) was chosen to resemble a human hand, the center tactor being the palm and branching out equally from to each corner of the set.

Figure 2.13: Voice Coil Actuator section view

Figure 2.14: (a) The Metal Cup Exciter by Tectonic used as the vibrotactile actuator in the Affective Haptic Device. (b) Encapsulated Tectonic Exciter with 3D printed housing
2.3.2 Alternative Methods of Vibration

Alternative methods of providing vibration cues include eccentric mass rotating motors and linear resonant actuators.

Rotating Mass

The first vibration motors widely accepted and used in haptic are Eccentric Rotating Mass Actuators, or ERMs. They are the simplest of the vibration motor, and ideally are comparable to DC motors. The rotating mass is labeled "eccentric" because it is off-center from its point of rotation. ERMs rely on the off-center rotation to produce an unbalanced centripetal force, that cause the motor to move back and forth, and creates lateral vibration effects. Their initial popularity was with the introduction of
pagers, and to this day are still widely used in the cell phone industry because of its low-cost, accessibility and easy implementation.

![Eccentric Rotating Mass Actuator Internal Diagram](image)

Figure 2.16: Eccentric Rotating Mass Actuator Internal Diagram (exploded view).

**Linear Resonance**

The next step up from ERMs would be Linear resonance actuators, or LRAs. Similar in method to ERMs, LRAs use electrical current and magnetic fields to create force. A key difference here is that the voice coils are static, while the mass moves instead. They operate similar to a spring-mass system, at which the electromagnet is agitated by an oscillatory signal, the spring within an LRA pushes the mass back into the system, forcing the mass to oscillate up and down, which in turn creates a vibration force. Notable haptic performance advantages for LRAs over ERMs are that LRAs are more efficient at their resonance frequency (Fig. 2.17(b)), provide more design options for directional vibrations along axes as seen in Fig. 2.17(a), and provide faster response time. The primary limitation around LRAs is its necessity in being tuned.
to its resonant frequency to achieve its greatest performance and efficiency, as well as requiring an AC input to function correctly.

![LRA diagram](image1)

![Frequency Chart](image2)

**Figure 2.17**: (a) Z-axis, bi-directional LRA Internal Diagram explode. (b) Resonant Frequency Response Chart.

### 2.4 Audio Interface

With the number of tactors needed to actuate the haptic vest, there was a need for an audio device capable of vibrating Tactile cues with minimal noise and maximum flexibility of application around vibrotactile parameters. There’s also a need for a digital-to-analog converter that will transform our input, vibrational waveforms, to an analog signal that will be played through our actuators. Tactile cues were rendered in Syntacts, an audio-based haptics software, outputted through a Digital-to-Analog audio interface (MOTU 24Ao). A single MOTU has 24 output channels (12 tactors) and can be tethered to one another via an Audio Video Bridging (AVB) connection configuration. Signals were amplified with a Syntacts amplifier board [8]. The AES-59 DB25 linear amplifier can drive up to eight vibrotactors with little noise and requires a 5V power supply. Through the combination of five Syntacts amplifiers, and two
MOTU24Ao (as seen in Fig. 2.18) serving as a channel extender, this fulfills our design criteria for the hardware.

Figure 2.18 : The Audio interface and converter setup used as an audio-based control.

2.5 Vibrotactile Parameters

There are three primary components to a vibrotactile haptic cue. These are the duration that the cue persists, the frequency of the vibration, and the waveform that governs the variations in cue amplitude versus time.

2.5.1 Duration

Duration refers to the length of the vibration cue and is typically expressed in milliseconds or seconds. In deciding the length of vibrational cues, it is important to ensure the cue is stimulated long enough for the recipient to receive and process the affective information, but not too long to where the cue becomes lost or unpleasant. In affective haptics, this will create more negative perceptions of cues than elicited. Duration of cues can be stimulated either in a singular wave from start to finish, or a
sequence of waves with gaps in between them. Findings by Van Doren et al. [36] show the effect of gap size on the perception of audible waveforms. Results showed that the greater the gap duration, the required intensity of the stimulus decreased. This showed an important conclusion around how parameters can impact one another and leads to a decision on minimizing the complexity of vibrotactile dimensions. Because of this, my cue durations were kept consistent across vibrotactile actuation, at around 3.3 seconds.

2.5.2 Frequency

Frequency refers to the rate of vibration and is typically expressed in Hertz (Hz). In vibrotactile actuation, frequency typically shows itself in two forms: pulses per second and cycles per second. In both cases, the increase of these two forms leads to an increase in vibration. Limitations around frequency begin at the safety of participants. For audible vibrations, humans can hear up to a range of 20000Hz, but in affective haptics, with the vibrations being produced on human skin, the range is reduced to between 10 - 400Hz [37]. Brown et. al [13] designed an experiment focusing on the modulation of frequencies to determine the perception of smoothness and roughness of a sinusoidal wave. The variables of frequency were scaled from a 250Hz sine wave chosen due to device capabilities and skin sensitivity. The results showed that perception of roughness typically increased as frequency modulation decreased, and the un-modulated sine wave was perceived as smoothest. However, in the design of affective haptic devices, modulation of frequency alone isn’t sufficient measure outside of a variable for intensity. This leads to the constraint of input frequency to be 65Hz across vibrotactile actuations.
2.5.3 Waveform

Waveforms refer to the shape of the vibrational wave, the most common being a sinusoidal wave. Both when communication of touch was conceptualized by Geldard in the 1950’s [38], and in recent research in the current state of affective haptics [39], the parameter of waveforms has received little attention. When waveforms were manipulated, the focus was on how waveforms affect the perception of other vibrotactile parameters, but not in the distinguishability or identification of different waveforms [40]. It is for this reason, that this parameter was the focal point at which I designed my vibrotactile cues.

2.6 Vibrotactile Cue

2.6.1 Communication of Affect

There are numerous emotions that exist and are expressed in the world, but as outlined in section 1.3, there is a culturally acceptable 6 universal human emotions: happiness, sadness, anger, fear, surprise and disgust. Experiments in affective haptics seek to sense or convey a combination of these emotions through different means. Papers have shown variable levels of success in completing this task, even between emotions, and their has yet to be an absolute method of communicating these emotions through any means. I chose to design cues for four emotions: happiness, sadness, anger and fear (seen in Figure 2.19). Across research results, taking into account experiment design and procedure, these emotions were recognized most commonly and were deemed most distinguishable, two of which I referenced and will speak on.
2.6.2 Affective Cue Design

In affective haptic devices, after the decision on what emotions one would like to elicit, the larger field of parameters around how to convey/sense these emotions arise. The focus for my affective vibrotactile cues focused on the use of complex waveforms in eliciting emotions (depicted in Figures 2.20(a) - 2.20(d)). The criteria behind the design of these forms were created through research in vibrotactile cues currently used in vibrotactile devices across different modalities, devices, and mediums [40] [41] [9].

Consistent Design Considerations

Most commonly, vibrotactile cues focused on the manipulation of frequency, amplitude, and duration of sinusoidal and/or square input waves. The input duration and frequency were consistent across all affect cues in my design; 3.3s and 65Hz respectively. Amplitude was chosen an additional parameter in the experimental design due to its prevalence in effecting perception of affective vibrations, and served as a multiplier from 0.25x to 1.0x for all affects. From the study by [7], patterns were shown to distinguish emotional vibrotactile cues. Even with discernible choices of vi-
Figure 2.20: Overview of waveforms created for elicitation of affective haptics via the Syntacts software [8]. (a) Waveform eliciting Anger affect. (b) Waveform eliciting Fear affect. (c) Waveform eliciting Happy affect. (d) Waveform eliciting Sadness affect.

Vibrotactile cues associated with common human emotion (happy being a U, sad being an upside-down U, etc), the patterns in group 2 (focused around vibration patterns), still performed better. This suggests that location and sequence of actuations prove an important criterion, outside of replication of facial features patterns, that is worth considering when developing haptic cues. By manipulating the perceived direction of the tactile cues, you’re able to create different sets of affective perceptions of the cues. Across all parameters that I am utilizing, perception of the direction of the waveforms is manipulated similarly; localized across the middle tactor of each tactor set, and spatially scaled outwardly, exponentially, and concentrically (depicted in Fig. 2.21).

In further analysis of the experiment by Bailenson et al. [5], I’ve made considerations around affective parameter of motion in vibrotactile design. The data derived from the experiment depicted a set of patterns around the motion parameters (distance traveled, speed, etc) the participants used to convey these emotions (depicted in the table 2.1).

Design consideration in this study I utilized in my vibrotactile design was the
speed of the cues being presented and note of choice of affects. One of the more discernible and statistically significant motion parameters was in how the speed of their interaction impacted their decision.

**Anger and Sadness**

In table 2.1, there are commonalities across motion parameters (in particular between anger in comparison to sadness) that was considered in my design. Based on the descriptions in the table, I characterized the vibrotactile design around anger as abrasive in nature; an abrupt, but intense vibration that is rapid and long in actuation, and sadness as more timid; small scale, steady actuation across a short period. These were the foundations of which my vibrotactile cue was developed. Anger was intended to feel as more an intense interruption of a rising vibration [40], this was achieved by a growing amplitude and a multiplier of a Pulse Width Modulator (PWM). The PWM quickly creates a repeating cue train with an input frequency and duty cycles. In creating sadness, the intended feel was a low and slow intensity [40], minuscule falling
<table>
<thead>
<tr>
<th></th>
<th>Disgust</th>
<th>Anger</th>
<th>Sadness</th>
<th>Joy</th>
<th>Fear</th>
<th>Interest</th>
<th>Surprise</th>
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<tr>
<td>Distance</td>
<td>Short</td>
<td>Long</td>
<td>Short</td>
<td>Hold</td>
<td>Short</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (M)</td>
<td>Fast</td>
<td>Slow</td>
<td>Fast</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (SD)</td>
<td>Jerky</td>
<td>Steady</td>
<td>Jerky</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Accel (M)</td>
<td>Faster</td>
<td>Slower</td>
<td>Faster</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Accel</td>
<td>High</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Angle (SD)</td>
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<td>Position (SD)</td>
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<td>Major (SD)</td>
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<tr>
<td>Minor (SD)</td>
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<td>Narrow</td>
<td>Wide</td>
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<tr>
<td>Major (%)</td>
<td>Square</td>
<td>Rectangular</td>
<td>Square</td>
<td>Square</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: Summary of movement parameter differences in derived measures for 7 emotion. [5]

Vibration, achieve by a layering of sinusoidal waves and low input amplitude. By layering the amplitude, this sought to establish a familiar feel of a rub or caress, that slowly but subtly increased in size to a peak, and diminished at the end.

**Happiness and Fear**

In the creation of emotions of happiness and fear, literature [9] [41] often made note of their similarities to audible noises. Using words relating to the delivery of the sounds (loud, rough), the qualities of the sound (soft, deep, timbre), and more. My design around these complex waveform gathered the most common characteristics of musical and audible and created my vibrotactile cues around them.

For happy, it was often the loudest of the cues that presented as a baseline at which to gauge other cues. The Happy affect was often the hardest to distinguish across
<table>
<thead>
<tr>
<th>Emotion</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Happiness</td>
<td>Fast tempo, moderate variations in timing, moderate to loud sound level, tendency to (relatively) sharpen contrast between &quot;long&quot; and &quot;short&quot; notes (as in dotted patterns), mostly staccato articulation, fast tone attacks, bright timbre, light or no vibrato.</td>
</tr>
<tr>
<td>Sadness</td>
<td>Slow tempo, relatively large deviation in timing and low sound level, tendency to (relatively) soften contrasts between &quot;long&quot; and &quot;short&quot; notes, legato articulation, slow tone attacks, slow and deep vibrato, final ricard, soft timbre, flat intonation.</td>
</tr>
<tr>
<td>Anger</td>
<td>Fast tempo, high sound level, tendency to (relatively) sharpen contrast between &quot;long&quot; and &quot;short&quot; tones, no final ricard, mostly non legato articulation, very sharp tone attacks, sharp timbre, distorted tones.</td>
</tr>
<tr>
<td>Fear</td>
<td>Large tempo variations, large deviation in timing, very low sound level, large dynamic variation, mostly staccato articulation, fast and irregular vibrato, pauses between phrases, and soft spectrum.</td>
</tr>
<tr>
<td>Tenderness</td>
<td>Slow tempo, relatively large deviations in timing, low to moderate sound level, tendency to (relatively) soften contrast between &quot;long&quot; and &quot;short&quot; notes, legato articulation, slow tone attacks, soft timbre, and intense vibrato.</td>
</tr>
</tbody>
</table>

Figure 2.22 : Music Parameter settings for emotions [9].

literature [40]. The affect input contained a sinusoidal wave with an even, bright tempo, having a quick attack and remaining steady for the duration. This waveform served as close to the normalcy of vibrations and was most reflective of the current renditions of waveforms in affective haptics. With the fear affect, this was a more intricate waveform to design around because of the amount of sparse information around creating them. Of the Big 7 it has shown to be a difficult affect to create [7] discernibly, along with disgust, and hard to characterize outside of its relation to bodily functions. As such, the creation of this waveform sought to imitate the bodily response to this affect. The emotional cue contained the largest deviations containing multiple rises, falls, and plateaus by the Attack-Delay-Sustain-Release function [8], staccato in delivery (a prominent poking), with irregular patterns by use of the PWM with smaller duty cycles. To describe it via a scenario; the increasing of your heart rate in the climax of your favorite horror film.
Chapter 3

Affective Haptic Vest for Facilitating Interpersonal Communication

In this chapter, we outline the exploratory experiment used to evaluate the ability of the vest and cues to facilitate communication of emotion. In particular, the goal of this experiment was to investigate if the vibrotactile cues displayed through the vest were capable of communicating four foundations of human emotions: happiness, sadness, anger, and fear, by designing cues around complex waveforms and varying amplitudes defined by research in affective haptics.

3.1 Participants

Nineteen participants took part in this study (8 male, 11 female) and received a $15 gift card as compensation for their participation. All participants gave informed consent, and the protocol was approved by the Rice University Institutional Review Board (IRB-FY2022-7).

3.2 Experimental Procedure

The experiment was conducted in a single session lasting approximately 1 hour. Subjects provided their shirt size when scheduling their experiments, and upon arrival, they were fitted to the vest the corresponded to their shirt size (depicted in Fig. 3.1).

Subjects were seated in front of a computer monitor and used a mouse to interact
with a graphical user interface (GUI). To orient participants before the start of the experiment, the GUI presented an overview of the haptic vest hardware. The number and location of the tactors on the vest were explained.

Users could click a series of buttons in the GUI to try out pre-made haptic cues. Users were presented with a basic Attack-Sustain-Release sinusoidal vibrotactile cue (depicted in Fig.3.2) and could select buttons to play the cues at each tactor set location on the back (upper left, upper right, lower left, lower right, and whole back) to get acquainted with typical haptic sensations. Following the acclimation phase, a detailed explanation of the experiment, the goal of the experiment, and user instructions were provided via the GUI. At any time before the experimenting phase, users were permitted to ask questions for clarification on acclimation and instruction.
Once acclimated, users began the experiment. First, a pre-defined vibration cue, from the randomized emotional input set (happy, angry, sadness, or fear) with a randomized scaling factor (0.25x, 0.5x, 0.75x, 1.0x) was presented through the haptic vest. Users were prompted to click one of four labeled icons, representing one of the four emotions, on the screen. A replay button was available for users to repeat the haptic cue up to 3 times. Then, the user confirmed their selection by clicking “submit”. Once the counter reached 3, the replay button was disabled and the user was reminded to make their selection. The GUI was programmed to automatically save their data set. This process was repeated until 250 total trials were complete (Each participant received the same arrangement of four emotion and four scaling factors for each trial, across 15 sets, with 10 trials included for acclimation).

### 3.3 Data Analysis

Data from the experiment were analyzed to determine the following outcome measures:
• **Recognition Accuracy:** The percent of total responses where users correctly identified the presented cue.

• **Varied Emotional Recognition:** The percentage of user responses that matched scaled input emotional responses.

These two metrics allow us to test the efficacy of the vibrotactile cues conveyed by the wearable haptic vest. Confusion matrices are utilized to represent the ability of the participants to correctly identify the emotional cues. Chi-square test, likelihood ratio test and Cramer’s V are used to test for random selection, to ensure the results are not due to chance, and to determine the association between the two variables. A pictorial variation of the confusion matrix is used to depict the accuracy of responses across the varying amplitudes.

The Chi-square test was chosen because it is intended to test how likely it is that an observed distribution is due to chance, as well as it also measures how well
the observed distribution of data fits with the distribution that is expected if the variables are independent. In the Chi-square test, the null hypothesis suggests that the variables forming the table are independent. With the inclusion of a 4x4 variable set (Emotional input - Happy, Anger, Sadness, Fear vs Amplitude - 1x, 0.25x, 0.5x, 0.75x), a contingency table was formed to conduct a statistical test. The observed chi-square statistic value ($\chi^2$) for the contingency table analysis is determined by the critical value at the level of significance ($P<0.05$) and our degrees of freedom (as seen in Table 3.2). See equations 3.1 and 3.2, where $O_{i,j}$ represents the observed (correct user emotion), $E_{i,j}$ represents the expected value based on frequency, and $r$ and $c$ represent the variable count of the information.

$$\chi^2 = \sum_i \sum_j \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}}$$ (3.1)

$$k = (r - 1)(c - 1)$$ (3.2)

Being the experiment uses large sample sizes, an alternative approach called likelihood ratio “$G$” test was conducted as well. The input for the $G$ test is the same as the chi-square test and its calculation is shown in Equation 3.3.

$$\chi^2 = 2 \sum O_{i,j} \ln \left( \frac{O_{i,j}}{E_{i,j}} \right)$$ (3.3)

Before conducting in-depth analysis on the impact of the variability sets on one another, the Cramer value “$V$” was found to determine association between our variables. The calculation for $V$ is found in Equation 3.4.

$$V = \sqrt{\frac{\chi^2}{N \cdot \min(R - 1, C - 1)}} = \sqrt{\frac{\phi^2}{\min(R - 1, C - 1)}}$$ (3.4)

Cramer’s $V$ can heavily biased as it relates to its population, and often overestimates the strength of the association between variables. As such a bias correction was also
calculated for using Equations 3.5 - 3.8 including its input variables.

\[ \tilde{V} = \sqrt{\frac{\tilde{\phi}^2}{N \times \min(\tilde{R} - 1, \tilde{C} - 1)}} \]  
\[ \tilde{\phi}^2 = \max(0, \phi^2 - \frac{(C - 1)(R - 1)}{N - 1}) \]  
\[ \tilde{C} = C - \frac{(C - 1)^2}{N - 1} \]  
\[ \tilde{R} = R - \frac{(R - 1)^2}{N - 1} \]

Some subject data sets were excluded from the analyses. Data from Subjects 1 and 2 were not included due to the experimental code not correctly randomize the amplitude factor. Data from Subjects 8 and 9 were excluded due to malfunction of hardware and non-compliance with instructions related to the vest. Due to the inability to secure the haptic vest onto the participant, Subjects 3 and 17 were unable to complete the experiment. Subject 19 was unable to complete the experiment due to a malfunction of the hardware. To account for learning effect, the 18 trials of each data set were excluded from analysis. The first four sets of input/amplitude combination (16 trials) were not analyzed due to participant exposure to each combination. An additional 2 trials were not analyzed so that an equal number of repetitions of each combination of cue and amplitude were included in the data to be analyzed.

### 3.4 Results

Based on user responses, fear was most commonly perceived reliably at 36.2% accuracy, and anger was least perceived reliably at 28.6% accuracy. Table 3.1 shows the percentage of times all our emotion inputs (Happy, Sadness, Fear, and Anger) were correctly recognized across all amplitudes. The overall results are shown in Fig. 3.4. Because our statistic value ($\chi^2 = 137.83$) is greater than the critical value (d.f. = 9,
P<0.05 = 16.919) we reject the null hypothesis and conclude that the user responses were not chosen by chance. The G statistic value ($\chi^2_G = 157.79$) solidifies our rejection of the null hypothesis. Amplitude variability and the emotion input showed to have a significant result and have a medium to large level of association ($V=0.238$ and $\tilde{V} = 0.2315$) as defined in table 3.3.

When analyzing the design of vibrotactile affective cues, this experiment derived
Table 3.1: Emotion Recognition Percentage Table. **Bold** lettering across the diagonals signify the emotional recognition rate where input matched response. The cells highlighted blue signify the highest *perception* percentage of input emotion regardless of recognition.

<table>
<thead>
<tr>
<th>Emotion</th>
<th>User Response - Amplitudes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sadness</td>
</tr>
<tr>
<td>Input</td>
<td></td>
</tr>
<tr>
<td>Sadness</td>
<td><strong>33.8%</strong></td>
</tr>
<tr>
<td>Fear</td>
<td>31.2%</td>
</tr>
<tr>
<td>Anger</td>
<td>23.4%</td>
</tr>
<tr>
<td>Happy</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

Table 3.2: Chi-Square Probabilities across degrees of freedom and significance levels

<table>
<thead>
<tr>
<th>df</th>
<th>0.995</th>
<th>0.99</th>
<th>0.975</th>
<th>0.95</th>
<th>0.90</th>
<th>0.10</th>
<th>0.05</th>
<th>0.025</th>
<th>0.01</th>
<th>0.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>—</td>
<td>—</td>
<td>0.001</td>
<td>0.004</td>
<td>0.02</td>
<td>2.71</td>
<td>3.84</td>
<td>5.02</td>
<td>6.64</td>
<td>7.88</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
<td>0.10</td>
<td>0.21</td>
<td>4.61</td>
<td>5.99</td>
<td>7.38</td>
<td>9.21</td>
<td>10.6</td>
</tr>
<tr>
<td>...</td>
<td>(...)</td>
<td>(...)</td>
<td>(...)</td>
<td>(...)</td>
<td>(...)</td>
<td>(...)</td>
<td>(...)</td>
<td>(...)</td>
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<td>(...)</td>
</tr>
<tr>
<td>9</td>
<td>1.74</td>
<td>2.09</td>
<td>2.70</td>
<td>3.33</td>
<td>4.17</td>
<td>14.68</td>
<td>16.92</td>
<td>19.02</td>
<td>21.67</td>
<td>23.59</td>
</tr>
</tbody>
</table>

Table 3.2: Chi-Square Probabilities across degrees of freedom and significance levels.

conclusions to better elicit emotions to a user via the back. The detailed results for emotion recognition between amplitudes are shown in Fig. 3.6. Looking at the stacked bar chart, users recognition of anger increased as the amplitude increased (4% at 0.25x, to 43% at 1.0x), and user perception of anger increased across majority of emotions (Fear: 4% at 0.25x, to 45% at 1.0x, Happy: 18% at 0.25x, to 67% at 1.0x). This leads to a conclusion that when eliciting anger as an emotion, users interpret higher amplitudes of waveforms as more negative. When analyzing user
emotion recognition to both sadness and happiness, the inverse applied whereas the scaled amplitude decreased, the recognition increased (Sadness: 1.0x = 21% to 0.25x = 66%, Happy = 1.0x = 25% to 0.25x = 51%).

<table>
<thead>
<tr>
<th>D.f.*</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.07</td>
<td>0.21</td>
<td>0.35</td>
</tr>
<tr>
<td>3</td>
<td>0.06</td>
<td>0.17</td>
<td>0.29</td>
</tr>
<tr>
<td>4</td>
<td>0.05</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>0.04</td>
<td>0.13</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Table 3.3 : Cramer’s V Effect Size Table

3.5 Discussion

Researchers have commonly found the effect amplitude plays on perception and recognition of affective cues across differing vibrotactile mediums (earcons [40], gloves [7], and animalistic displays [4]), across locations of presentations be it in a lab or travelling [42], and in recognition across vibrotactile patterns [43], and the findings here come to the similar conclusions. When analyzing the design of vibrotactile affective cues, this experiment derived conclusions to better elicit emotions to a user via the back. The detailed results for emotion recognition between amplitudes are shown in Fig. 3.6. Looking at the stacked bar chart, users recognition of anger increased as the amplitude increased (4% at 0.25x, to 43% at 1.0x), and user perception of anger increased across majority of emotions (Fear: 4% at 0.25x, to 45% at 1.0x, Happy: 18% at 0.25x, to 67% at 1.0x). This leads to a conclusion that when eliciting anger as
Figure 3.6: Stacked Bar chart with detailed user response inputs across input emotion and amplitude variability. The values bordered in black signify the user emotion recognition that matches the input emotion, across the variability markers. The underlined numbers signify the highest recognized user response, regardless of input emotion, corresponding to each input emotion-amplitude variability combination.
an emotion, users interpret higher amplitudes of waveforms as more negative. When analyzing user emotion recognition to both sadness and happiness, the inverse applied whereas the scaled amplitude decreased, the recognition increased (Sadness: 1.0x = 21% to 0.25x = 66%, Happy = 1.0x = 25% to 0.25x = 51%). When eliciting fear, though peaking at 41% with a 0.5x amplitude, across the amplitudes the user perception is relatively consistent. With fear being an affect commonly understood as harder to interpret as outlined in [44], this was an expected result of the experiment. When attempting to elicit more complex emotions such as fear, disgust, gratitude, etc, more research needs to be done to increase distinguishability.

An important aspect to consider when presenting users with affective cues, I’m calling Affect priming. Affect priming is where the presentation, perception, and response of the previous cue, has an effect on the perception of the proceeding cue. For instance, referencing values from Fig. 3.6, if a user was first presented with a fear or anger waveform at 1x amplitude, and then presented with the happy cue at 0.25x amplitude, it may be easier to perceive happy. However, if a user was presented with sadness at 1x amplitude first, they may be equally inclined to choose happy or sadness. From this, participants, especially when being blindly introduced to these vibrotactile cues, can develop patterns around their perception of these cues naturally. This is a current field of interest in affective haptics focused on learning behavior and patterns of affective cues [13].

In the experimentation and presentation of affective cues through verbal communication, a substantial amount of time should be spent on what I’m calling affective vernacular. Affective vernacular is your word choice and meaning when conveying information around the affective wearable device. In this experiment, when giving participants the instructions, some perceived the meaning of affect vernaculars
differently. Often times the goal tasks of the user were misunderstood, where the participants were requested to “to the best of your ability, is to select the emotion that corresponds to one of the four emotions.”, they were often confused as to the focus point of their correspondence. In other words, participants didn’t know if they should respond with the affect that the vest made them feel (I felt angry after this cue), or if they should choose the affect that the affective cue felt like (the vibrations felt angry). In changing the vernacular, the perception of the cues may have influenced user responses.

In the design of Affective haptic wearable devices, ability to modulate effectively should be heavily considered. An attempt at accommodating for this was implemented into this experiment through the selection and procurement of vest (details can be found in section 2.2). Most vest are capable of accommodating for the width and circumference of the torso but few offer the capability of tightening the upper body. For participants with smaller stature, during the experiment you could see them trying to manipulate the vest to have uniform tightness: either by using their free hand to constrict the loose fabric, or by pressing against the back of the seat. This looseness in fit led to the actuations from upper set of tactors not stimulating consistently across participants. This led to the removal of participants’ data (see section 3.1) and may have influenced perception in other users. In the same breadth of properly actuating vibrotactors, with differing shapes of human bodies, through either muscle or skin, the ability to locally vibrate these cues consistently between participants was also unattainable. A garment capable of tightening around the upper torso would also provide a solution here.

In the design of the vibrotactile cues for my Affective Haptic Vest, the finalized design was a complex process around the combination of the envelopes, processes and
oscillators available on the Syntacts software [8]. However the original waveforms in the design consisted of minimally modulated but distinct patterns focused on the rise and falls of the input waves at certain time intervals. However, there were an unforeseen issues around the Polybezier function, function that connect points at set distances, with bezier curves. When implementing into the waveforms, you’re able to adjust the slope of lines to create specific vibrational wave patterns, an example I created is in Figure 3.7(a). Once the vibration was created and saved, it would export properly in whatever signal style one would want, but the error occurs when importing the signal back into the software. As seen in Figure 3.7(b), after a certain point the waveform function is snipped and eridactes the patterns originally stimulated. An attempt was made at fixing this issue internally but for the sake of time, the rest of the Syntacts input functions were adapted to be used in experimentation.

The findings of this hardware and tactor design encourage us to further explore the design of vibrotactile cues on the back as an affect area and highlight things to further consider when designing affective wearable devices.
Figure 3.7: (a) Example of Polybezier waveform before error. (b) The same Polybezier waveform after error occurred.
Chapter 4

Conclusion

The long-term goal of affective haptics is to effectively convey emotional information through haptics; the sense of touch. This is beneficial in serving as a new modality to convey and perceive information when other senses may be overstimulated or unavailable and provide benefits to those who may be deprived of these senses. To accomplish this goal, a device capable of perceptibly eliciting affect to a user is needed.

Through a thorough survey of research in affective haptics, the commonalities around affect parameters were established with the understanding of means and methods. Areas of improvement were relayed and kept in mind during the creation of the affective device described in this paper. This also defined a realistic success rate across disciplines, that the device sought to achieve. Through the survey of the design of affective haptic devices, a criterion was created that led the decisions around affect area of the back, localization of vibration actuations, and means of actuating affect.

A prototype wearable affective haptic device was developed through iterations of design processes around wear usability, to allow for maximum comfort and tactile vibration while minimizing movement restriction. A vest was chosen that satisfied these parameters and introduced modular sizing for body types and tacter security through an adjustable strap. In tandem with the vest, 3D prints were created to house the tacters effectively, maximizing the actuations onto the user while remaining stable onto the vest. Voice coil actuators were chosen as the method of creating vibration due to their range of frequency, complex motion profile, ability to achieve high forces.
of large distances and constant forces across their entire travel length. This was compared against additional methods of vibrations defined in the understanding of their tactile design, electrical design, and mechanical capabilities.

The design of complex vibrotactile cues and software for rendering affective haptic cues was achieved through the use of Syntacts. These cues were defined through research in psychology, musical arts, biology, and engineering, with attention to affective perception and consistency. These affect cues focused on the complexities of waveforms to explore their usability in relaying emotional information to users through the rise and falls, stutters, and patterns. A pilot investigation was conducted to determine the efficacy of the vest and cues to elicit emotional responses to users. Categorical statistical measures were defined, introduced, and utilized in establishing perceptibly of these designs to participants. Bias corrections were conducted to account for size.

The overall results indicate that individuals were able to recognize the affective vibrotactile cues, via the affective haptic vest, greater than chance. These findings support the variation of waveforms in eliciting affective responses through the affect area of the back. Furthermore, it solidified the importance and continuity of amplitude in vibrotactile parameters, as a prominent motivator in recognizing emotional cues. Anger and Fear were most recognizable at higher amplitudes while happiness and sadness were most recognized at lower amplitudes.

Overall this thesis contributes to the establishment of complex waveforms as a means of conveying emotional information along the back. The findings can provide insight into affective haptic device designs, as well as vibrotactile affective cue designs.
Bibliography


ACM, Apr 2010.


