Towards a Haptic Taxonomy of Emotions: Exploring Vibrotactile Stimulation in the Dorsal Region

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ABSTRACT

The implicit communication of emotional states between persons is a key use case for novel assistive and augmentation technologies. It can serve to expand individuals' perceptual capabilities and assist neurodivergent individuals. Notably, vibrotactile rendering is a promising method for delivering emotional information with minimal interference with visual or auditory perception. To date, the subjective individual association between vibrotactile properties and emotional states remains unclear. Previous approaches relied on analogies or arbitrary variations, limiting generalization. To address this, we conducted a study with 40 participants, analyzing associations between attributes of self-generated vibrotactile patterns (AMPLITUDE, FREQUENCY, SPATIAL LOCATION of stimulation) and four emotional states (ANGER, HAPPINESS, NEUTRAL, SADNESS). We fin a preference for symmetrically arranged patterns, as well as distinct amplitude and frequency profiles for different emotions.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**; **Haptic devices**.

KEYWORDS

Affective Haptics, Vibrotactile Encoding, Haptics, Haptic Rendering

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1 INTRODUCTION

The seamless transfer of complex information between a computer and one or more individuals is becoming increasingly important as computing becomes more integrated into daily life through innovative concepts like Human Augmentation [27, 34] and Human-Computer Integration [14]. Emotions are a complex type of information that has attracted the interest of researchers in these fields [7, 30] and beyond, because communicating emotions has proven useful for online communication [12, 15, 32], storytelling [9], and assisting neurodivergent individuals [5].

A major challenge in communicating emotions through vibrotactile encoding that they are a non-homogeneous category of information [26]. This means the psychophysiological effects of emotions can highly vary [4] and can differ depending on the body location of the vibrotactile stimulation [1]. A number of approaches have explored encoding across locations such as the wrist [25], forearm [22], hands [19, 33], and the back [1, 8, 23, 39]. Predominantly, pattern creation strategies involve arbitrarily combining vibrotactile dimensions and then asking users to rate valence and arousal [23, 25, 28, 37], rating the locations users assume an emotion is represented in the body [2], mapping facial expressions to vibration intensities [33], or user-generated patterns [8, 36]. These patterns are typically created as analogies from vision or are created based on a non-generalizable individual basis.

This approach to pattern creation restricts our understanding of the fundamental elements that contribute to subjectively associating emotions with specific vibrotactile patterns. As a result, the practicality of these insights for researchers and designers is limited, not extending beyond the demonstration of emotional communication capabilities.

In this paper, we present a study with 40 participants to examine the associations between emotions and vibrotactile patterns

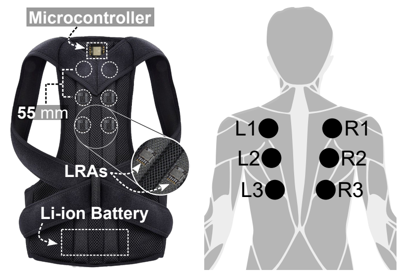

Figure 1: (Left) The vibrotactile vest uses a posture corrector as the base, an ESP32 FireBeetle micro-controller, six Linear Resonant Actuators (LRAs) and one Li-Ion Battery with a charging circuit. (Right) The LRAs' locations on the back.

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presented in the dorsal region of the body. This work aims to advance the development of intuitive vibrotactile patterns capable of conveying information about emotional states. We focus on three fundamental dimensions of vibrotactile feedback, namely Amplitude, Frequency, and Spatial Location, and explore their correlations with emotional states. The choice of the dorsal region aligns with Chandra et al. [8], as this area is less commonly utilized for environmental sensing in everyday applications. Consequently, utilizing this region for communication minimizes the occlusion effect commonly observed with visual, auditory, or haptic feedback in other regions (e.g., wrist or hand). While Chandra et al. [8] use a stationary chair design, we provide the first wearable solution in the form of a vest. This is the next step toward an unobtrusive design that can be used in the wild. Additionally, we differentiate our work by using films to elicit emotions, as they have been shown to be reliable for stimulating discrete emotions [18], and to outperform other stimuli such as music [31].

2 TOWARDS A HAPTIC TAXONOMY OF HAPTIC EMOTIONS

To investigate a haptic taxonomy of emotions, we developed a prototype consisting of a vibrotactile vest and a pattern creation interface, which was connected to the vest via Bluetooth Low Energy (BLE). In this section, we describe the specifics of this prototype.

The **haptic vest** was constructed by integrating a commercial posture corrector to ensure ergonomic contact with the user's back. Six Pimoroni DRV2605L breakouts were strategically positioned in the dorsal region inside the vest, maintaining an approximate spacing of 55 millimeters between each actuator as illustrated in Figure 1. Actuators were placed in pairs along the left and right scapular lines of the back: L1 and R1 in the suprascapular, L2 and R2 in the intrascapular, and L3 and R3 in the infrascapular region.

Each breakout integrated a Texas Instruments DRV2605L driver, which offered built-in auto-resonance control. Each breakout also featured an ELV1411A Linear Resonant Actuators with a resonant frequency of approximately 150 Hz and amplitude of $14.7m/s^2 (1.5g@100g)$. Notably, the upper back region exhibits lower sensitivity to tactile stimulation compared to other areas [11, 13], requiring meticulous calibration of resonant frequencies, intensities, and spatial resolution for effective tactile rendering. Considering this low tactile sensitivity, we spaced the actuators slightly above the just noticeable difference (JND) thresholds for tactile stimulation on the back (at approximately 55 millimeters, see Figure 1), estimated to be between 45 and 50 millimeters [35]. This spacing enables both optimal discrimination of individual stimulations and the ability to interpolate stimulation between adjacent actuators.

The **pattern creation interface** was developed using Python and the Kivy UI framework[1]. This interface incorporated controls to enable the customization of tactile patterns. Specifically, it featured two sliders responsible for adjusting the continuous variables of Amplitude and Frequency, i.e., to increase or decrease their intensity. To govern the activation of the actuators, six buttons were arranged in a 2x3 layout, emulating the Spatial Locations of the haptic vest. Two extra buttons were implemented; one for rendering the selected pattern and the second for submitting the pattern and progressing to the next phase. The submit button remained inactive until the render button was pressed, ensuring participants were aware of the stimulation before submitting. Upon submitting the pattern, all input values were automatically reset to their default settings. Additionally, the interface served as a proxy for the experimenter by providing instruction screens, playing the emotion elicitation videos, and displaying the emotion assessment questions.

[1] https://kivy.org/

3 USER STUDY

We conducted a between-subject study with one independent variable Assigned Emotion with four levels: Angry, Happy, Neutral, and Sad, manipulated using video emotion elicitation (Figure 3.4). Three dependent variables that constitute the building blocks of the vibrotactile patterns were measured: Amplitude, Frequency, and Spatial Location, while maintaining a constant duration of stimulation of 2 seconds. Participants were randomly assigned to one of the levels of Assigned Emotion and asked to develop ten vibrotactile patterns describing the elicited emotional state.

3.1 Measures

First, we analysed *vibrotactile patterns* in detail. As a standard haptic technique, vibrotactile rendering allows a wide number of dimensions that can influence the perceptual attributes of haptic patterns [3, 10]. Yet, in this study, we focused on three key aspects [20]: Amplitude, Frequency, and Spatial Location of the stimuli.

Amplitude is the intensity of the stimulation applied to the user, ranging from $0m/s^2$ to $14.7m/s^2$. Frequency, in this study, refers to the envelope frequency of the stimulation, ranging from $1Hz$ to $60Hz$, while the underlying frequency is set to the resonant frequency of the actuator ($150Hz$). Lastly, Spatial Location refers to the regions on the dorsal region where stimuli are delivered (see Figure 1 for visualization of the vest and the stimulated regions).

The Big Five questionnaire encompasses the personality traits Conscientiousness, Agreeableness, Neuroticism, Openness to Experience, and Extraversion. These traits can be linked to the experience of positive and negative emotions. We used this measure to perform a group allocation check. This screening ensured that the distribution of participants across conditions was balanced for their personality traits, thus reinforcing the validity of the findings.

To measure *emotion classification*, we quantified the effectiveness of the emotion elicitation process by comparing the Classified Emotion and the Assigned Emotion. After every emotion elicitation video, we asked participants:"How did this video make you feel?", with four possible answers: Angry, Happy, Neutral, and, Sad.

The Self-Assessment Manikin (SAM) scale [6] measures Arousal, Valence, and Dominance. In the current study we collected SAM data, however it was not analyzed.

3.2 Emotion Elicitation

Empirical evidence suggests that emotions play a role in people's decision-making processes [26]. In fact, some researchers argue that decision-making would be impossible or suboptimal without emotional involvement [26]. In line with this perspective, Damasio's Somatic Marker Hypothesis (SMH), suggests that emotions implicitly bias human behavior. Based on this theoretical framework, we aimed to induce an emotionally congruent state in participants prior to each pattern creation stage, i.e., aligning their current emotional

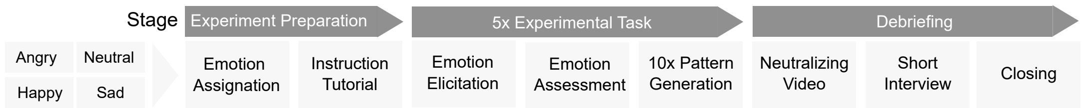


Figure 2: A between-subject experiment was conducted; participants were randomly assigned to one of four conditions. Participants classified the induced emotion and subsequently generated ten vibrotactile patterns.

experience with the intended category of patterns to be created. In other words, we wanted to increase the likelihood of generating patterns that reflect the target emotional qualities. We used the video emotion elicitation method over alternatives, as it has been shown to have a comparatively superior performance [18, 31, 38]. We collected videos from different datasets and selected five per emotion [24, 29]. The videos reported in these datasets are mostly scenes from movies (see Gilman et al. [17], Jurásová and Spajdel [21] for details).

3.3 Participants

We recruited 41 participants using the university's mailing list. One was excluded due to a technical problem. From the 40 remaining participants, 24 self-identified as male, 15 as female, and 1 as non-binary. The mean age of our participants was 23 years old (M = 23.77, SD = 2.91). They were compensated with 10 Euros/hour for their participation.

3.4 Task and Procedure

Participants were informed of the experiment's details, risks, and benefits, and asked for consent. Emotions were randomly assigned without the participants' knowledge. The prototype and interface were explained and a tutorial round of pattern generation was conducted. Then the experimenter left the room and communication was limited to text to avoid influencing emotions. Participants performed the experimental task five times. They watched an emotion elicitation video (Figure 3.4) and assessed the induced emotion using the SAM scale and emotion classification. They created 10 vibrotactile patterns using combinations of: (1) Amplitude, (2) Frequency, and (3) Spatial Location and asked to render each pattern before submitting it. Once a set of 10 patterns were submitted, the next elicitation video would play, participants were allowed to submit the same pattern multiple times. This process was repeated 5 times using distinct videos eliciting the same emotion, resulting in a total of 50 patterns per participant. At the end, a neutralizing video was shown to counter emotional carry-over effects. The experimenter returned, conducted a brief interview, and concluded the study (refer to Figure 2 for a graphical overview).

4 FINDINGS AND DISCUSSION

This section presents an analysis and discussion of the key features exhibited in the generated vibrotactile patterns. An examination of the pattern profiles Amplitude and Frequency profiles is followed by an investigation of the influence of Spatial Location. Lastly, we explore the significance of each feature in effectively describing the Assigned Emotion.

First, we assess the data's validity by conducting a group allocation and emotion elicitation check. To address potential group allocation imbalances, we conducted an analysis of variance (ANOVA) on the factor Assigned Emotion for each subscale of the Big Five questionnaire. The results indicated no significant differences. in personality traits between the allocated groups, thereby confirming the validity of the group allocation procedure.

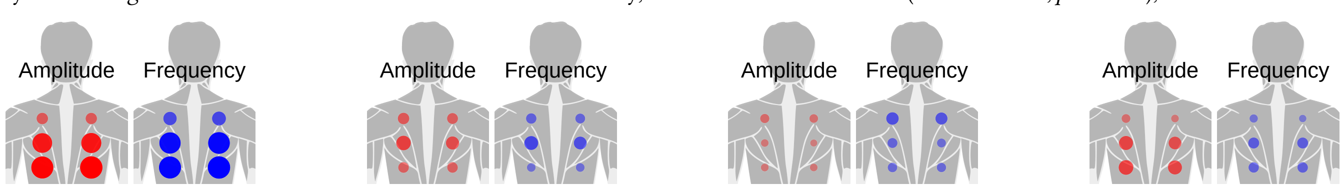
Further, participants were asked to classify the emotion induced by the elicitation video, in the following sections, we call this classification made by the participants "Classified Emotion". We compared this Classified Emotion to the Assigned Emotion. The results revealed that participants accurately classified the emotion in 68.23% of cases (chance level 25%). Further computations were exclusively performed using data from instances where the emotions were correctly classified.

4.1 Amplitude and Frequency

To study the impact of the Assigned Emotion on Amplitude and Frequency, we computed a Multivariate analysis of variance (MANOVA) using Assigned Emotion as a predictor. The MANOVA yielded a significant overall effect of Assigned Emotion on Amplitude and Frequency ($F(6, 2312) = 47.704, p < 0.005$). We then performed one Tukey Honest Significant Differences (HSD) per variable.

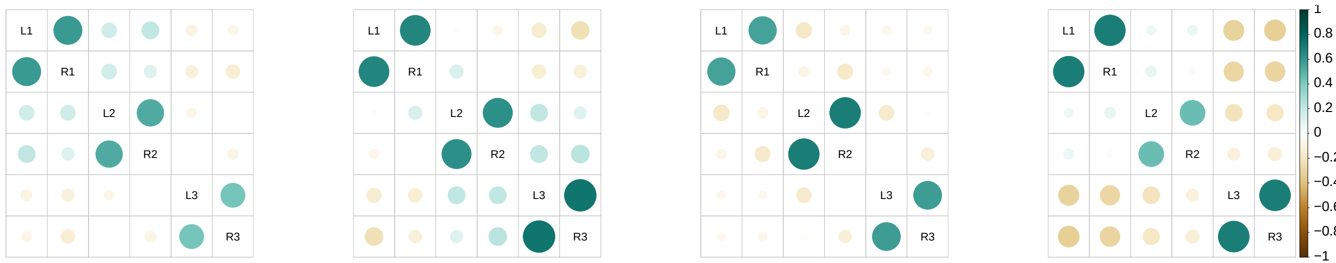
For Amplitude we found significant differences for all pairs of Assigned Emotion. Specifically, when compared to the Angry emotion, the Happy emotion showed a lower amplitude (diff = $-2.955 m/s^2$, $p < 0.001$), this was also true for the Neutral (diff = $-5.202 m/s^2$, $p < 0.001$), and the Sad emotion (diff = $-2.002 m/s^2$, $p < 0.001$). Likewise, the Neutral emotion showed a lower amplitude compared to the Happy emotion (diff = $-2.246 m/s^2, p < 0.001$), and the Sad emotion showed a higher amplitude compared to the Happy emotion (diff = $0.952 m/s^2$, $p = 0.004$). Finally, the Sad emotion showed a higher amplitude compared to the Neutral emotion (diff = $3.199 m/s^2$, $p < 0.001$).

For Frequency we found significant differences for the Happy, Neutral, and Sad emotions compared to the Angry emotion; In detail, the Happy (diff = $-9.869 Hz, p < 0.001$), Neutral (diff = $-8.672 Hz, p < 0.001$), and Sad emotions showed a lower frequency (diff = $-8.370 Hz, p < 0.001$) compared to the Angry emotion. However, no significant differences were observed between the Neutral and Happy emotions (diff = $1.197 Hz, p = 0.722$), the Sad and Happy



(a) Angry **(b) Happy** **(c) Neutral** **(d) Sad**

Figure 3: Predominant Spatial Location per Assigned Emotion in terms of Amplitude and Frequency. A bigger circle size represents a higher predominance in an specific location



(a) Angry **(b) Happy** **(c) Neutral** **(d) Sad**

Figure 4: Correlation matrices among SPATIAL LOCATIONS: Symmetrical patterns observed across all measured emotions. A value closer to 1 represents possitive correlations, while a value closer to -1 represents a negative correlation

emotions (diff = $1.499Hz, p = 0.505$), or the SAD and NEUTRAL emotions (diff = $0.302Hz, p = 0.993$).

The findings indicate that AMPLITUDE is the primary property with greater descriptive power for emotion communication. FREQUENCY, in constrast, exhibits descriptive capabilities for a variety of emotions, although some emotions exhibit frequencies that are not distinct enough for effective classification. ***Consequently, we recommend that designers prioritize maintaining consistent intensity (Amplitude) between the desired emotion to be communicated and the suggested ranges outlined in this section.***

4.2 Locations

To evaluate the impact of Assigned Emotion on SPATIAL LOCATION, we computed a weighed average calculation across all locations. The results are displayed in Figure 3 where it can be observed that Anger had a higher intensity than the other emotions, mostly in the intra and infrascapular region. Similar locations were relevant for sadness, but with a lower intensity. Happiness was mostly assigned to the interscapular region with lower intensities in the supra and infrascapular regions, and Neutral to the suprascapular region for amplitude, with a lower frequency intensity in the same regions. To further understand the correlation among SPATIAL LOCATION and Assigned Emotion We computed correlation matrices for each level of Assigned Emotion. The result show a correspondence between scapular regions. This is between L1 & R1 (suprascapular), L2 & R2 (intrascapular), and, L3 & R3 (infrascapular). Suggesting that participants preferred symmetrical over unbalanced patterns.

The findings indicate that specific locations can also contribute to the descriptive nature of the intended communicated emotion, predominantly in terms of vertical rather than horizontal location. This has implications for the quantity and placement of actuators in prototypes. ***Based on these results, we recommend that designers exploit the descriptive capacity of the back's location, particularly emphasizing the infra and suprascapular regions, which exhibit the highest potential to discern between emotions among all the locations.***

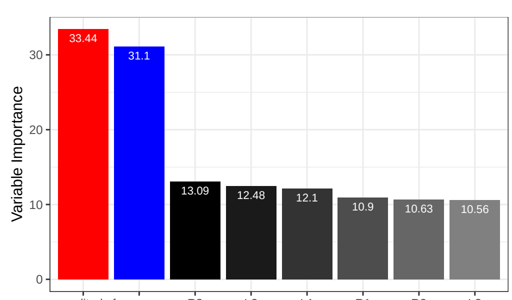


Figure 5: Feature relevance chart: AMPLITUDE and FREQUENCY have higher contribution to pattern classification.

4.3 Feature Importance

To determine the relevance of each feature, we perform a recursive elimination of features for variable importance [16]. Results are displayed in Figure 5. AMPLITUDE and FREQUENCY were identified as the primary discriminating properties for distinguishing between emotions based on the generated patterns, followed by the SPATIAL LOCATION. It is noteworthy that the less descriptive features are associated with complementary locations that are categorized as more descriptive, indicating redundancy due to high correlations between actuators within the same region.

Therefore, we recommend that designers prioritize Amplitude and Frequency as the primary factors and utilize the available locations whenever feasible to enhance the clarity of the communicated emotion.

5 CONCLUSION

We explored the initial steps towards establishing a taxonomy of emotional states using vibrotactile rendering, specifically focusing on the spontaneous associations individuals have with the properties of Amplitude, Frequency, and Spatial location in vibrotactile feedback. We found that all these properties contribute to the differentiation of the basic emotions. While we examined the primary features of vibrotactile encoding, we acknowledge the existence of alternative avenues for exploration, such as spatiotemporal rendering, waveform type, and onset time, which can contribute to the descriptive capabilities of vibrotactile patterns. Future steps towards a complete taxonomy of haptic emotions using vibrotactile feedback should explore a bigger set of emotions, as within the scope of this paper we explored only four basis emotions. Furthermore, cultural differences may influence individual associations with stimuli. Thus, conducting detailed investigations on cross-cultural associations can aid in developing a more universally applicable taxonomy.

OPEN SCIENCE STATEMENT

Supplementary data can be found at the following URL: https://osf.io/ycfhp/

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