Tactile Symbols with Continuous and Motion-Coupled Vibration: An Exploration of using Embodied Experiences for Hermeneutic Design

Nihar Sabnis
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
nsabnis@mpi-inf.mpg.de

Dennis Wittchen
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
dwittche@mpi-inf.mpg.de

Gabriela Vega
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
gabriela@latinxinai.org

Courtney N. Reed
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
creed@mpi-inf.mpg.de

Paul Strohmeier
Sensorimotor Interaction,
Max Planck Institute for Informatics,
Saarland Informatics Campus
Saarbrücken, Germany
paul.strohmeier@mpi-inf.mpg.de

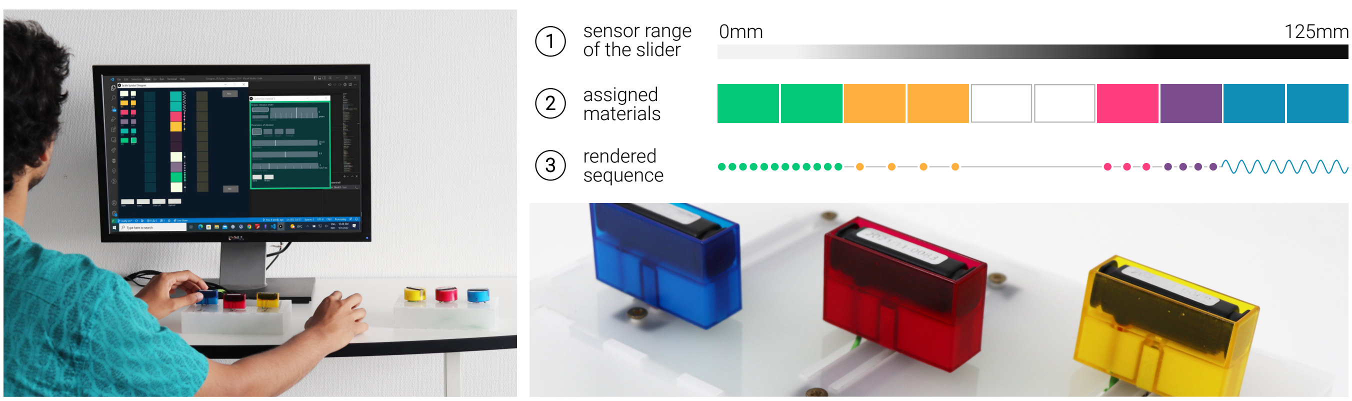

Figure 1: Users create vibrotactile effects using a custom application. These effects are rendered to tangible user interfaces (TUIs) like sliders to explore the symbols throughout the design process (left). A TUI consists of three sensors, each coupled with a dedicated haptic actuator (bottom right). A symbol is designed in a sensor range (1) by assigning vibrotactile effects to certain sensor regions (2). These effects are created as motion-coupled vibration (consisting of discrete grains, denoted as dots) or a continuous vibration for the specified sensor range (denoted as sine waveform). The rendered sequences can be a single symbol or multiple symbols separated by a non-augmented sensor range (3).

ABSTRACT

With most digital devices, vibrotactile feedback consists of rhythmic patterns of continuous vibration. In contrast, when interacting with physical objects, we experience many of their material properties through vibration which is not continuous, but dynamically coupled to our actions. We assume the first style of vibration to lead to hermeneutic mediation, while the second style leads to embodied mediation. What if both types of mediation could be used to design tactile symbols? To investigate this, five haptic experts designed tactile symbols using continuous and motion-coupled vibration. Experts were interviewed to understand their symbols and design approach. A thematic analysis revealed themes showing that lived experience and affective qualities shaped design choices, that experts optimized for passive or active symbols, and that they considered context as part of the design. Our study suggests that adding embodied experiences as a design resource changes how participants think of tactile symbol design, thus broadening the scope of the symbol by design for context, and expanding their affective repertoire as changing the type of vibration influences perceived valence and arousal.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**; *Haptic devices*; *User studies.*

KEYWORDS

embodied interaction, vibrotactile feedback, tactons, symbol design, postphenomenology

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1 INTRODUCTION

Tactile symbols communicate information through the sense of touch. These symbols typically use vibrotactile patterns to convey information, alerts, or task-based cues. Such symbols can be given additional expressivity by fine-tuning the vibration parameters (such as frequency, amplitude, rhythm, or envelope) to ease their interpretation or memorability [8]. However, compared to the complex interactions we have with the physical world and with one another through the sense of touch, their expressivity is relatively poor. Thus, providing meaningful and realistic sensations in computer mediated interactions remains a major challenge in the field of haptics [36, 48]. In this paper, we suggest that as an alternative to diving deeper into details of vibrotactile signal parameters, we might instead expand the design space of tactile symbols, by incorporating embodied experiences in their design.

Generally speaking, vibrotactile stimuli in HCI are used in two different ways. The first is as *symbol*. For example, a phone might vibrate to acknowledge user input, or indicate that new information is available. Here, vibration is used in an abstract way to represent information which the user must consciously interpret. The second is as *simulation*, that is the vibration is not used as representation, but is designed to feel like the object of interest. For example, vibration can be used to simulate the experience of friction or compliance or other material properties. In this case, vibration is used to create an experience that the user is familiar with from their day-to-day life. The user need not attend the stimulus to interpret it; rather, there is a pre-reflective understanding based on lived experience of the world.

According to Don Ihde, we can classify these two ways of using vibrotactile feedback according to how they mediate information. The first case, where vibration is used as a symbol representing something else, might be called *hermeneutic mediation* while the second case, where vibration is used to encode the target experience itself, might be thought of as *embodied mediation*. In HCI applications, we typically encounter vibration used for only one type of mediation, but seldom a combination of both approaches. In fact, it is often implicitly assumed that they are at odds with one another. In this paper, we therefore present an exploration demonstrating how these design approaches might be combined, showing that embodied haptic feedback can be used as a tool for hermeneutic mediation.

Here, we explore how embodied experiences can become design elements for hermeneutic mediation. More specifically, we explore how tactile symbols or tactons might benefit from integrating embodied experiences in their design. To do so, we created a design tool which supports two different modes of generating vibrotactile signals (from here on referred to simply as GUI). The two modes are designed to correspond to hermeneutic and embodied mediation. The first mode corresponds to hermeneutic mediation and provides tools to modify parameters of *continuous vibration*. This supports designers to shape the experience of the buzzing sensations we are familiar with from tactile symbols used in phones; for example, to alert a user that a text message is received. The second mode corresponds to embodied mediation and provides tools to modify parameters of *motion-coupled vibration*. Here the designer is given control over parameters of vibration, where the pulse frequency is coupled to the dynamics of a user motion. This enables creating the day-to-day experiences people are familiar with in the material world; for example, properties such as friction, compliance, texture, bending, or torsion. In addition to the GUI, we designed two tangible user interfaces (TUIs). Once a symbol is designed in the GUI, these symbols can be deployed in the TUI, where designers can experience them and compare and contrast design variations.

In a case study with five haptic design experts, we show how embodied experiences can be used in the design of tactile symbols. Experts were invited to design tactile symbols with the option to incorporate embodied experiences in their design. We instructed them to create four symbols which were chosen in such a way that they combined both positive and negative valence and high and low arousal, similar to a 2x2 factorial design. We then interviewed each expert to understand their design approach and the specific symbols they created. The thematic analysis of the interviews revealed insights on how haptic experts design tactile symbols. Four underlying themes were uncovered. In particular, highlighting how vibration was associated to previous lived experiences, both in designing and reflecting on symbols. Additionally, we found that experts had clear affective associations with the symbols and that these associations introduced consistency in the designs. Designs also appeared shaped around the idea of symbols which actively communicate information, as opposed to symbols which are passive and require the user to discover them. Finally, experts typically created symbols which considered the context in which they were experienced, including what users perceived prior to or after experiencing the symbol, as part of their designs.

We found that symbols created using continuous vibration were preferred for symbols with high arousal or negative valence (for example, warnings), while embodied experiences created using motion-coupled vibration were preferred for designing symbols with low arousal and positive valence (for example, reassurance). Finally, we also present a set of designs which were provided by the experts when they were given the opportunity to freely create new designs, after the main study was completed. Hence, we introduce the idea of using motion-coupled and continuous vibration to design tactile symbols, thus expanding the tactile vocabulary. We also reflect on the design process used by the experts to implement motion-coupled and continuous vibration based on the design context.

2 CONTEXT AND RELATED WORK

The work presented here applies directly to the design of tactile symbols; however, in doing so also explores more fundamental themes around the design of tactile interactions, and information representation in general. Therefore, this section starts with a broad overview of touch and experience in general, to better position our work within this larger discourse. This is followed by presenting related work of the specific example we are using for this exploration, that is tactile symbol design and vibrotactile rendering of material properties. We conclude by providing an overview of how vibrotactile designs are commonly evaluated, justifying our own evaluation choice.

2.1 Ways of Touching

Intuitively, most people will agree that there is a qualitative difference between the vibration of a phone, and a material's texture. This is remarkable, as both are mediated by vibration. What exactly this difference is, however, is difficult to grasp. In this and the following section, we discuss ways in which these stimuli might differ.

In the literature, there are a number of ways of distinguishing between different ways of touching. For example, a common distinction made in haptics is that touch can be either **active** or **passive**. The general idea is that experiencing a material property, requires action. To feel a texture, one must scan it with one's finger, to experience the softness of an object, one must apply force to it. This is considered *active touch*, possibly first used by Katz [29] in the context of texture exploration, and later popularized by Gibson, who describes a breadth of exploratory actions we use to understand the world [21]. Naturally, it is not always we who touch things, sometimes other things touch us. If another object touches us, this is considered *passive touch.* While we are able to infer information about objects through passive touch, studies have shown that our acuity in interpreting such information is substantially lower than for active touch [23].

Returning to the qualitative distinction between a vibrating phone and a material texture, active and passive touch might be useful terms. The vibration of the phone is clearly related to passive touch, as the vibration we experience is indifferent of our actions. However, we can also passively experience a texture; for example, when someone pulls a piece of paper from underneath our fingers. So while active and passive touch are related to the qualitative difference between the vibrating phone and a material texture, it does not fully explain the qualitative difference we care about.

Another set of terms commonly used for when distinguishing between types of vibrotactile stimuli is **proximal** and **distal**. Katz [29] suggests that there are multiple ways in which tactile information can be experienced. He suggests that, with respect to a sensory organ, stimuli can be *proximal* or *distal* [29]. He suggests that the ears and eyes, for example, allow us to perceive distal stimuli; to hear thunder from miles away, or even see stars in the sky. The tongue, on the other hand, is responsive to proximal stimuli. To taste the flavor of a drink, the tongue must be in contact with that drink. Tactile perception, according to Katz, is capable of both. When scanning a texture, it acts as a proximal sense. When we feel the rumbling of a far-away avalanche, or the vibration of the spin-cycle of a washing machine, it acts as a distal sense.

The distinction between proximal and distal already is closer to this qualitative difference we are searching to describe. For instance, we consider the vibration of a phone a distal stimulus, while the vibrations through which we feel a material texture are proximal. However, this still does not fully capture the way in which a material experience and the phone's vibration are different. For example, when we probe a sheet of ice with a stick, vibrations travelling through the stick help us understand the material properties of the ice. These vibrations are distal, yet intuitively the resulting experience is more like touching a texture than feeling a vibrating phone.

It appears that the qualitative difference we care about lies not in how we touch, nor in the properties of the stimulus. Instead, we need to look at the experience itself.

2.2 Ways of Experiencing

Here we find it useful to draw on the vocabulary suggested by Ihde [28] as it does not focus on the specifics of the stimulus, nor the methods of how we acquire it, but instead describes the ways in which we make sense of it. Ihde's taxonomy, often presented through the lens of Verbeek [50] describes different ways in which technology shapes our experience of the world. This taxonomy has found use in the Human Computer Interaction community, where it has been expanded upon [22, 51].

To describe the difference between vibration caused by a buzzing phone and touching a material texture, we need to concern ourselves with mediation. We experience the world through mediation whenever we access the world *through* a technology or medium; for example, when seeing through spectacles, or experiencing information encoded in vibration. Verbeek and Ihde distinguish between two types of mediation, *Hermeneutic* and *Embodied.* To Verbeek, a hermeneutic mediation occurs when information requires an interpretive step to understand, for example presenting the following numbers (255,0,0) to represent the color red. Alternatively, we might also directly display the color, which need not be interpreted for us to understand the redness in a pre-reflective manner. Verbeek refers to this as embodied mediation.

Looking towards the tactile domain, we find many ways in which vibration acts as a medium for **embodied mediation**. For example, when we touch different textures, the frequency spectrum of the resulting vibrotactile signals provide the primary cue which enables us to identify materials [4]. This occurs pre-reflectively; we are not consciously aware of the role vibration has in this understanding, and we do not even think of vibration. Instead, we directly understand what the texture feels like and make pre-reflective judgments such as "this must be a brick" or "this fabric feels a little bit like satin". The haptics research community has found many ways of using vibrotactile feedback for creating such embodied mediation systems, providing users with pre-reflective understanding of material consistency [44], texture [39], compliance [30], torsion [25], and force [24]. The shared mechanism in all these natural and digital vibrotactile mediation mechanisms is that the frequency at which tactile cues are provided to the user is proportional to the dynamics of the exploratory movement the user performs — we call this motion-coupled vibration. We learn to interpret these cues as babies and have perfected this skill throughout our sensory development.

Tactile symbols behave very differently. Their very purpose is for **hermeneutic mediation**; they are iconic placeholders which refer to some other concept. Users need to perform an interpretive step after perceiving them to understand what they represent. That is, the meaning of a tactile symbol only reveals itself upon reflection. It is this difference between embodied, pre-reflective sensemaking and hermeneutic interpretive sensemaking of the vibrotactile signal which best captures the distinction between the buzzing phone and the experience of the material texture we care about.

2.3 Hermeneutic Mediation: Tactile Symbols

Tactile symbols can be defined as the vibrational cues provided to the tactile modality of the user, with the aim of conveying a familiar idea, experience or construct in a predefined context [8]. The creation of tactile symbols to encode information has revolved around identifying, modulating and combining physical parameters of vibration such as frequency, duration, amplitude, waveform, body location, rhythmic patterns, and spatio-temporal patterns [7, 9, 26]. Researchers have attempted to optimize these parameters to create tactile symbols which maximize the rate of information transfer; for example, by studying how parameter dimensions relate to human perception [18] or by providing vibrotactile signals designed as metaphors of real world experiences [13]. Another approach to design tactile symbols is inspired from the principles of icon and earcon design [6, 11, 20].

Tactile symbols have been investigated unidimensionally [7], multidimensionally (modulating more than one vibrotactile parameter simultaneously to convey more complex information) [2, 9], and in cross-modal contexts in combination with audio feedback [26, 27]. These approaches of creating and evaluating tactile symbols have been fundamental to optimize the tactile symbols. However, intuitively designing for the user's perceptions of the vibrotactile symbol to the information it represents is still a challenge, and mismatches often lead to confusion in the interpretations of tactile symbols [18]. Also, the mapping from sensation to meaning is often abstract, and hence users need to learn the meanings, identify and interpret the tactile symbols which may cause delay in the user's response [16]. Moreover, tactile symbol design sometimes leads to unstructured vibrotactile patterns without any clear salience [13].

In this research, we explore how the design space of tactile symbols might be expanded by integrating embodied experiences in the symbolic design. By means of a qualitative study, we wish to address if doing so might address some of the shortcomings of existing vibrotactile symbol design.

2.4 Embodied Mediation: Material Experiences

An orthogonal research direction to tactile symbol design, is work that attempts to better understand how experiences unfold when we touch objects in the physical world. Here the elementary role of action on experiences cannot be understated: Touching an object can give an impression of temperature or reveal shape features if they are prominent enough to distort the skin, but, to experience the texture, one must move relative to the object one is touching [29]. This relative movement of the finger over a surface produces vibration, which is used to infer properties of the material [4, 5, 32]. There has been growing interest in coupling vibration with user movement to generate an experience of texture and other material properties. This vibration has been provided in research using three popular actuation methods, namely: vibrotactile, electrostatic and ultrasonic [3].

Focusing on vibrotactile actuation, Romano and Kuchenbecker coupled the movement of a probe, which acted as a texture recording device, to an actuated stylus. The stylus is then vibrated as it moves over a flat and smooth surface, providing users a sensation of moving the device over recorded materials [39]. This idea of coupling vibration with motion has also been explored by Kildal to provide an experience of compliance based on the pressure applied by the users [30]. Strohmeier et al. presented a flexible device which couples pulse frequency to the amount by which the device is bent, resulting in an experience of changing material composition [44]. Moreover, Heo et al. coupled changes in force and torque applied to a device by the user to generate the experiences of bending, twisting, and stretching of the device [25] and also created a haptic illusion of compliance based on tangential force provided by the user [24]. Furthermore, Ahmaniemi described a method to create dynamic virtual textures by using vibration coupled to user's hand movements driven based on wavetable synthesis [1].

The underlying principle of all these research is: when coupling vibrotactile feedback with user action, the vibration and action are perceptually combined, leading to a holistic experience of a dynamic system rather than a vibrating actuator (cf., [41, 47]). Although extensive research has been conducted in the use of motion-coupled vibration to generate material experiences, to our best knowledge, this is the first study that explores using such vibration for designing tactile symbols.

2.5 Evaluating the Tactile Symbol Design Process

The evaluation of tactile symbols primarily focuses on the dimensions for their design, investigation of the parameter space, information transfer rate, and the effectiveness of designed symbols to communicate the desired information [2, 8, 26]. Understanding these factors provides limited value in the overall understanding of this design process from a human-centered design perspective. Instead, behavioral studies that investigate how tactile symbols can be used to convey data efficiently are preferred [10, 18]. However, these studies do not provide insight and reasoning about the design approach and resultant symbols.

When research does report on the subjective experience of user interactions with haptic systems, it is often done briefly or as a collection of responses to questionnaires [12, 44]. Notable exceptions include an interview study done by Obrist et al. [37], which presented in-depth interviews comparing haptic feedback designed to target either Meissner or Pacinian corpuscles, structured interviews done by Schneider et al. [42] to understand what hapticians do and the challenges they face when working with haptics, and interviews used by Strohmeier et al. [43] to elicit descriptions of introspective, subjective experiences. Since we are interested in the

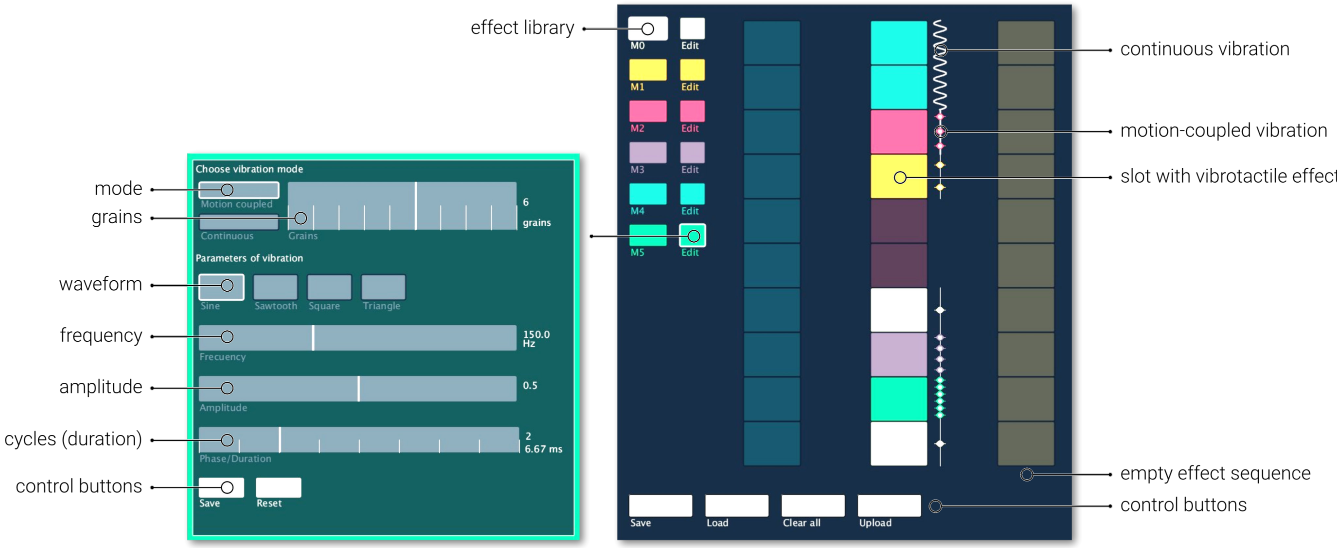


Figure 2: The GUI used for this study has two windows – one to parameterize vibrotactile effects: *Effect Designer* (left), and another to create sequences of these effects: *Effect Sequencer* (right).

design approach and reasoning behind the design of tactile symbols, we also focused on qualitative methodology in this research.

3 STUDY RATIONALE

Both in the literature [50] and casual discourse, hermeneutic and embodied mediation are often presented as opposites, almost incommensurable. We wish to highlight how these concepts can be blurred. We wish to understand *if and how embodied material experiences might be used as a design element to create a hermeneutic, tactile symbol*. For the same, we use motion-coupled vibration capable of creating embodied material experiences and traditionally used continuous vibration, to design hermeneutic tactile symbols.

We conducted in depth interviews with expert haptic designers, who were provided with a system that allows them to combine continuous vibration and motion-coupled vibration for designing haptic symbols. We chose to work with experts, as we wish to minimize reactions due to the novelty effects of designing haptic systems in the first place, and instead focus on how material experiences might be used within the context of traditional tactile symbol design. We intentionally do not explore symbols related to materiality (for example, we do not ask participants to design experiences such as *roughness* or *concrete-like*) but instead observe tasks which might require the designers to use the experience of *roughness* or *concrete-like* as a part of a symbol that refers to something immaterial, abstract.

Other studies present how one might create material experiences through vibration. Our study therefore does not aim to assess the quality of a particular tactile rendering approach or vibrotactile material experience, rather, we explore how such material experiences might be used for symbolic design.

After concluding our study, we intend to report *if* experts were able to use embodied experiences in hermeneutic design. Through analysis of the resulting designs, we wish to talk about *how* this was done in practice. Based on our interviews, we report on *why* this was done. Finally, based on all data we collect, we intend to highlight potential *benefits* this blurring of mediation types has for future design.

4 IMPLEMENTATION

The study uses two systems, a GUI for designing tactile symbols (Figure 2) and TUI for experiencing them (Figure 3). Tactile symbols designed in the GUI are rendered on the TUI, where the user can experience their design in real time with two basic interactions: a linear motion using a slider and a rotary motion using a knob. Since the vibration is motion-coupled, the user can explore their tactile symbols at varying movement speeds within a designated region, which might change the experience.

4.1 Graphical User Interface

A multi-window GUI was developed using Processing (v4.0) and run on a laptop (Lenovo ThinkPad - AMD Ryzen 7 PRO, Windows 10) throughout the study (Figure 2). Participants used the first window of the GUI to design a sequence of vibrotactile effects – *Effect Sequencer*. The other window of the GUI – the *Effect Designer* – provided control over a set of vibration parameters (Table 1).

The design parameters were chosen for the GUI screen in a way that would help designers to understand and assist them in designing motion-coupled as well as continuous vibrations effectively. The selection was initially inspired by work which explored such parameters [30, 46] and then optimized for the experiment. Parameters which we implemented but excluded for sake of simplicity in the GUI include an envelope (attack, decay, sustain, release) a filter (cutoff frequencies) and the ability to add noise.

Once the user creates their vibrotactile effects, they can switch to the *Effect Sequencer* to assign these effects to slot(s) in the sequences (Figure 2, left). Each sequence represents the sensor range of a

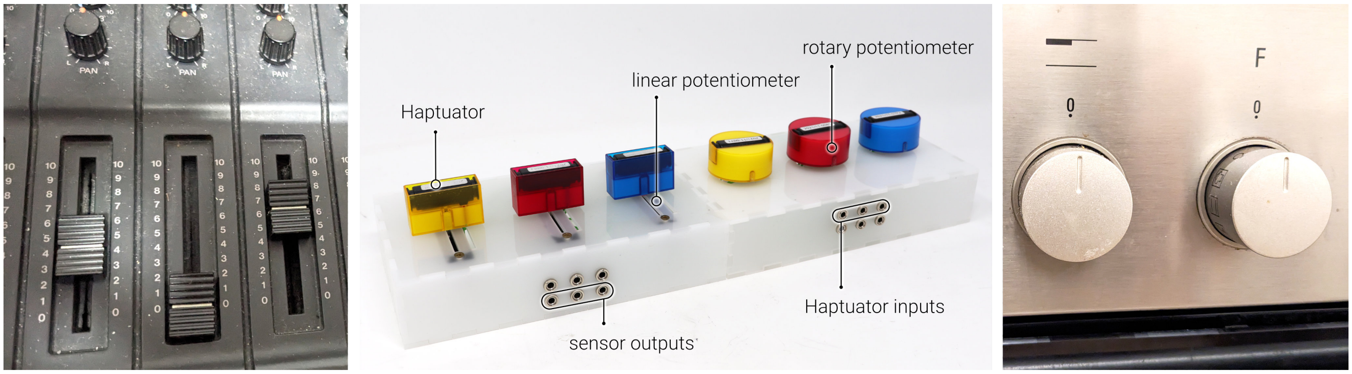


Figure 3: Middle: Participants explored their rendered vibrotactile effects with two types of physical elements: sliders (left) and knobs (right). Sides: similar UI elements found "in the wild".

physical element (e.g., a slider). The *Effect Sequencer* allows for the designing of three sequences simultaneously, where each sequence refers to one of the physical elements (Figure 2, right). These are connected through the central controller to the PC. When a tactile sequence design is ready to be experienced, the user uploads the design to the corresponding physical element and can explore the experience. Sequences, as well as the vibrotactile effects, can be edited at any time and re-uploaded to the TUI. Users can also export their designs as JSON files and load them later into the GUI. This enables users to expand their design beyond the three TUI slots, create fast design iterations, and share their designs with collaborators in co-located or remote setups.

4.2 Physical Elements

Two types of physical interfaces were used for experiencing the designs rendered by participants – linear sliders and rotary knobs (Figure 3). These two devices were selected after a pilot study, and were selected to support the scenarios we wished to explore. Moreover, linear sliders and rotary knobs nicely demo some of the hand motions often used to interact with tools and gadgets in the physical space/world. Their counterparts in the digital world are also known and commonly used in GUIs. For our purposes, functionally and in terms of haptic experiences, they are sufficiently similar to be interchangeable. The first interface consisted of a set of three 200k ohm slider potentiometers, the second a set of three 100k rotary knob potentiometers. The change in the resistance of the physical elements indicates the physical angular and linear movement made by the user on the knobs and sliders, respectively. The system is agnostic to potentiometers of any physical size, as all the calculations are done based on the sensor range. Each physical element is connected to one peripheral microcontroller (Figure 4). Based on the position of the physical element (sensor value) and the vibrotactile effect designed at the corresponding location using the GUI, the designated vibrotactile effect is played. The tactile signal generation is based on customized implementation of Haptic Servos [41]. The signal is generated using the Teensy Audio Library[1] and then converted to an analog signal using a PT8211 DAC shield. This analog signal is amplified using a Visaton 2.2LN amplifier and then fed into a Haptuator Mark 2D (Actronika). The Haptuators were placed in custom-made housings over the knobs and sliders. The housings were made to suppress the audio cues and constrain the propagation of the vibration along the length of the Haptuator. This GUI implementation and TUI housing designs are all open-source[2] and accessible for use with other TUI setups.

4.3 System Setup and Communication

The system consists of a cascade of physically connected hardware (Figure 4). The GUI, running on a PC, is connected via USB-serial with the TUIs central control unit – a Teensy 3.5 (Figure 4). This unit receives messages from the GUI via a serial interface and forwards them via an I2C-interface to the peripheral devices. These messages are ASCII strings, including control-messages to modify the system's state and data-messages to transfer the vibrotactile effects and effect sequences to the corresponding physical elements (Figure 4, bottom). Both message types include the I2C-address, which enables sending messages to a single device or all devices (unicast or broadcast, respectively). The peripheral devices (three Teensy 3.5s) receive the messages and update their state accordingly. To augment the physical elements, the peripheral devices read analog values from the sensors (slider or knob) and render vibrotactile pulses according to the selected effect sequence and parameters that were assigned for the current sensor position or region.

4.4 Design Justification

For this study to be valid, the motion coupled vibration must indeed be experienced as embodied mediation. We therefore base our design on previous work: It is well understood that vibration, when coupled in frequency to pressure changes [24, 30, 31, 46] or movement speed [15, 17, 39, 47] creates material experiences.

This study was implemented based on *Haptic Servos*, an open source vibrotactile rendering system, capable of implementing the above described experiences [41]. In a previous study, we tested if signals created with Haptic Servos lead to embodied mediation: Six participants were provided with either motion-coupled or continuous vibration and asked to describe their experience.

[1] https://www.pjrc.com/teensy/td_libs_Audio.html

[2] https://github.com/sensint/Haptic_Material_Designer

	Vibration Parameter	Description	Value / Range
Type	**Mode**	Refers to the types of vibration discussed in Section 2.	motion-coupled, continuous
	Grains	The number of grains (pulses) spread across a single effect slot (motion-coupled only).	1 to 10
Waveform Parameters	**Waveform**	The waveform of the vibration/pulse	sine, sawtooth, square, triangle
	Frequency	The frequency of the vibration/pulse	10 to 400 Hz
	Amplitude	The amplitude of the vibration/pulse	0.0 to 1.0
	Cycles	The number of cycles (periods) of the vibration/pulse. (motion-coupled only).	1 to 8

Table 1: The controllable vibration parameters in the *Effect Designer* by the haptic users. These include vibration type (mode and number of grains) and waveform parameters (waveform, frequency, amplitude, and cycles).

We found that the *continuous vibration* was often experienced as somewhat startling, or confusing. Often participants wondered if there might be a problem with the system, as the continuous vibration stood out from the other experiences. The *motion coupled vibration* on the other hand elicit curiosity and made the UI elements feel more interactive. Participants described their experience in terms of material metaphors, such as *"like moving it over a rough surface"* or *"Like peeling a sticker off"*. These experiences appeared to work equally well for both linear sliders and rotary knobs, and the difference of motion type did not appear to have any systematic effect on how the stimuli were experienced [41].

We therefore concluded that our system performs as desired and that we can use the tangible UI elements interchangeably.

5 STUDY: DESIGN OF TACTILE SYMBOLS

This section describes the participants and their background in haptics who designed the tactile symbols, the experiment design and the analysis methodology used to analyze the results of the study.

5.1 Participants

The inclusion criteria required that the participants have a minimal experience of 4 years and are active researchers contributing to the field of vibrotactile haptics in HCI. Five haptic experts (4 male, 1 female) were recruited through our research networks in Germany to participate in our study (referred as participants or designers). The participant group represented four countries and had between 4 and 7 years of experience in haptic design. Each participant received financial compensation for their time. The following are each participant's years of experience in the field of haptics and current research areas:

- **P1:** 7 years; Vibrotactile feedback in virtual reality to design haptic experiences.
- **P2:** 7 years; Designing for haptic interaction, tactile displays and wearable technology.
- **P3:** 5 years; On skin interfaces and vibrotactile feedback in wearable technology.
- **P4:** 4 years; Fabrication and designing of novel vibrotactile feedback devices.
- **P5:** 6 years; Designing haptic feedback for communicating emotion, soft robotics.

To demonstrate that one can use material experiences to support traditional haptic symbol design, one does not need a large sample. A single example would have been sufficient. However, we chose to add additional participants, so that we can make claims beyond the mere fact that it is possible, and can also report on patterns we found in observing experts designing symbols which included such material properties. We stopped conducting interviews, once we felt that observed themes started repeating. Any further claims, especially those aimed at generalization, will require follow-up studies, beyond the scope of this paper.

5.2 Experiment Design

As soon as the participants arrived, they were introduced to the apparatus and given a tutorial on the design process and the GUI/TUI setup so that they could render their desired effect sequence with the vibrotactile effects they want. This tutorial is provided in the Supplementary Material. After the initial exploration with the tutorial, the experiment was explained to them. The experiment involved three phases: a context-defined tactile symbol design phase, a forced choice selection of pre-designed tactile symbols for both knobs and sliders, and an optional creative exploration phase (sliders only). The tactile symbol design and the creative exploration phases were followed by a semi-structured interview in order to understand the design approach of the participants, their reasoning behind the symbols they designed, and the qualitative experiences they associated their designed symbol with. Interviews lasted 30-50 minutes per participant. Interviews with the participants were audio-video recorded with consent for later analysis.

5.2.1 Tactile Symbol Design. The haptic experts were asked to design symbols for warning, reassurance, ecstasy, and disengagement. To ensure that the symbols are different from one another, in multiple dimensions, we reference Russell's Circumplex Model of Affect, which maps emotions to a two-dimensional space according to the arousal (high or low energy) and valence (pleasure or displeasure) of an affective state [40]. The model is expressed as a two-dimensional space, with the horizontal axis as *valence*, and the vertical as *arousal*. The tactile symbols to be designed were chosen based on their positions in the valence-arousal space, as follows: 1) warning - negative valence, high arousal; 2) reassurance - positive valence, low arousal; 3) ecstasy - positive valence, high arousal; 4) disengagement - negative valence, low arousal. The tasks were designed in order to design symbols covering the valence-arousal space, however, the words valence and arousal were not conveyed to the participants at any point.

For the knobs, the task was to design tactile symbols for *warning* and *reassurance*. The context for the knobs was that the steering wheel has been replaced by a knob in a futuristic car. The participants needed to design a tactile symbol for *warning*, which indicated the driver should stay out of a lane where an accident has occurred. They also needed to design a symbol for *reassurance* to assure the driver that it is safe to switch to another lane. We selected these tactile symbols to be designed for the knobs. Here, the knob acts as a metaphor of a steering wheel of a car.

For the sliders, the designers were asked to design a feedback system for a fictional mood jockey (someone who sets the mood for an event, as a DJ would control the music for an event) which indicates the mood of the event. The task was to design tactile symbols for *ecstasy*, to indicate that everyone is enjoying the event, and *disengagement* to indicate that people are not enjoying the event. The important distinction between the two tasks was that there was no urgent call to action for the slider task. This distinction was made in order to keep the symbol design space versatile and fit into different contexts. For this task, we chose to use the sliders, as they are reminiscent of the UI elements a traditional DJ or audio-engineer uses for controlling music. Each tactile symbol was a pattern spanning 1 to 4 slots in the event sequencer. Participants were asked to narrate aloud their thought process as they designed the tactile symbols. The design prompts as given to the participants can be found in the Supplemental Material.

5.2.2 Forced Choice Selection. Following each design task, participants completed a forced-choice evaluation in which they had to select the suitable out of two presented symbols to better indicate warning, reassurance, ecstasy and disengagement. These presented symbols were preset and loaded using the GUI and presented to the designers using the same physical knobs and sliders. For each symbol, four comparisons were made. The comparison was always between a continuous and motion-coupled vibration The tactile symbols were preset and presented to the designers using the same physical knobs and sliders.

5.2.3 Creative Exploration. Finally, the participants were provided with time for creative exploration, to go back and try any other designs they wished to render without being constrained. Again, participants were asked to narrate their design process aloud.

5.3 Analysis

We used a qualitative approach to focus on this group of haptic experts. We conducted a reflexive inductive thematic analysis [14] of the interviews with the designers to provide a narrative of the preference over the type of vibration used, design decisions, approach to design each tactile symbol, and reasoning for the final designs of the symbols. The initial coding of the interviews was done by N. Sabnis. Further coding and theme organization was completed jointly by N. Sabnis and C. Reed, who approached the data through their own design experience and dialogue with the designers during the study. We use an inductive approach to ground these themes within the design context while applying the design experience of the researchers doing the analysis. N. Sabnis and C. Reed first familiarized themselves over a two-week period with the data during transcription and highlighting an initial code set of salient points relating to the design choices made and described in the interviews. N. Sabnis and C. Reed then coded together while recursively reviewing the interviews and the objective, parameterized aspects of the vibrations themselves. We also determined the design approach for each of the symbols based on the parameters used in the context-oriented design phase and forced choice evaluation. After reviewing the symbols and their designed parameters, we constructed and then iteratively refined a series of themes. The themes were constructed around the designers' perspectives and choices of vibration for the provided contexts, focusing how each symbol matched the designers' expectations and priorities in the design.

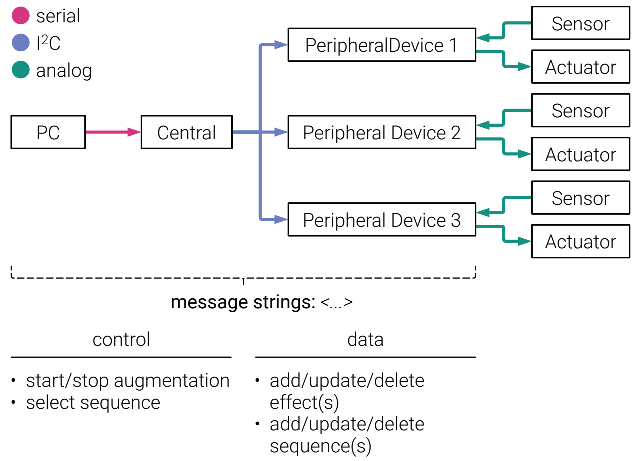


Figure 4: The PC and the central controller uni-directionally communicate via USB-serial. Each peripheral device is connected to the master using an I2C, and the communication is uni-directional from the central device to the peripheral devices. USB-serial and I2C communication is done with formatted message strings. The messages are used to modify the system's state (e.g., start/stop augmentation) and transfer data to the peripheral devices (e.g., send effects and effect sequences).

6 RESULTS

In this section, we describe the process of the participants to design tactile symbols using both types of vibration. Furthermore, we elaborate on the spanning of the type of vibration in the valence-arousal space as well as the qualitative associations of the type of vibration and their parameters. We present the results of the reflexive thematic analysis in which we explored four themes pertaining to the haptic experts' symbol designs, through which we investigate the use of continuous and motion-coupled vibration in the design of tactile symbols. Finally, we depict the free-form designs made by the participants during the creative exploration task.

6.1 Tactile Symbol Design Process

Participants followed a five-step process for designing Tactile Symbols. Below, we summarize the participants' thought process as they were designing the symbols thus highlight the commonalities and differences in their approach of designing the symbols.

6.1.1 Exploration of both types of vibration. After explaining the task to the participants, they first explored both types of vibrations. This exploration was done within the capabilities and constraints of the system in order to determine the parameters available for manipulation. P1 first wanted to 'get a feel for the material properties'. P5 described the initial interaction with motion coupled vibration to be 'just ticks' rather than a material experience, whereas P2 described motion-coupled vibration as 'something which feels easier to overcome and which wants me to be at a spot'. P3 described continuous vibration to be 'more expressive' than the motion-coupled vibration in their exploration phase. The participants also explored the vibration parameters for both types of vibration. The exploration phase helped the participants understand the potential design space for both types of vibration.

6.1.2 Association of the types of vibration to qualities conveyed using the symbol. Exploration phase was followed by association of both vibration types to the properties which need to conveyed using the tactile symbol. Overall, continuous vibration was associated with urgent, actionable and extreme symbols. P1 and P4 associated continuous vibration to raise awareness and convey different warning and disengagement levels. P1 and P3 also associated continuous vibration with high energy and high levels of ecstasy in the mood jockey task. On the other hand, all the participants associated the motion-coupled vibration to encouragement in the car turning task. While designing for disengagement, P1 and P3 associated motion-coupled vibration with low grains with higher disengagement. Hence, associations made by the participants with the type of vibration while designing the symbol were based on the context of the symbol.

6.1.3 Creating a pattern of multiple blocks to generate a symbol. After qualitative associations for both types of vibration in the given context, the participants designed a symbol iteratively, by combining multiple blocks in a pattern. P1 switched from motion-coupled vibration to continuous vibration to convey an increase in the level of warning. Moreover, in their pattern, P3 switched from motion-coupled to continuous vibration to indicate higher intensity of the emotion to be conveyed. The participants got creative and also designed a less intese state leading up to a final burst of the emotion to be conveyed. For instance, in their pattern, P1 indicated pre-warning as the user would approach the final warning state. No standard patterns amongst participants were observed but, patterns between a single participant were noticeable. For example, less number of grains throughout the pattern is associated to an ecstatic state by P5, whereas P2 increased the number of grains to indicate an increase in the level of ecstasy. P4 in their pattern made a gradient by increasing the number of grains for high levels of reassurance.

6.1.4 Fine-tuning the parameters of the symbol. The next step of designing the symbol was the fine-tuning of the selected vibration type. For instance, P5 noticed that they did not perceive the higher frequency vibration as an instance in the symbol for warning. Moreover, P1 increased the amplitude and reduced the frequency of the continuous vibration as the intensity of warning increased in their designed symbol. Moreover, they further optimized their design by using a square wave as it felt more assertive to indicate a strong warning. P4 described triangle waves to be more assertive and sine waves to be smoother compared to other waveforms. After playing around in the parameter space for motion-coupled vibration, they finalized on using a square wave with high amplitude and frequency. The fine-tuning was done by exploring the parameter space till the participants found parameters to suit their concept of how the symbol should feel.

6.1.5 Evaluating the symbol in the context. Finally, the participants evaluated their designed symbol in the context of the task which was given to them. This evaluation was done by experiencing the symbol on the TUI. After experiencing their symbol, P1 commented, 'the continuous increase in the parameters for warning will make the driver aware of pre-warning, and different stages of the warning symbol'. P5 evaluated their symbol for ecstasy by moving the slider over the designed symbol and feeling if the movement over the symbol is able to experience ecstasy. Similarly, the reassurance symbol was evaluated by P1 and P4 by imagining themselves in the place of the automobile driver and how rotating the knobs with vibration coupled to their rotation feels like they are being encouraged to turn in that direction. Thus, after iteratively designing the tactile symbol, it was evaluated by experts in the context of its intended use.

6.2 Mapping Vibration to Affective Qualities

The tasks for which the participants designed symbols for, namely - warning (negative valence, high arousal), disengagement (negative valence, low arousal), reassurance (positive valence, low arousal), ecstasy (positive valence, high arousal), were based on the Circumplex Model of Affect. Without any knowledge about the selection of tasks as well as the qualities for which the symbols were designed, there was a pattern in how motion-coupled and continuous vibration spanned the valence arousal space in the participant designs. Moreover, the associations made by the experts of vibration type and properties to subjective qualities is depicted in Table 2.

6.2.1 Valence. A trend of using continuous vibration to indicate negative valence whereas using motion-coupled vibration for positive valence was observed in the designed symbols. Negative valence was usually associated with irritation, annoyance or sadness. Continuous vibration with increasing amplitude, and frequency was preferred to design symbols in order to convey these qualities. Moreover, sawtooth, square and triangle waveforms were associated with negative valence. In contrast, positive valence is indicative of qualities like comfort, gentleness and encouragement. Motion-coupled vibration was associated with these qualities. For instance, P3 who used motion-coupled vibration to indicate positive valence qualities mentions, "for ecstasy, I'm thinking in terms of visceral experience, as it needs to be something comfortable." Sine waveform was perceived to be pleasant and gentle, thus associating it with positive valence. Figure 5a demonstrates P2's design of the

Vibration			Qualitative Associations
Type	**Vibration Type**	Continuous	Non-enticing (P4), Expressive (P2), Obstructive (P1), Urgent (P5) Recognizable (P2), Annoying (P1),
		Motion-Coupled	Exploratory (P4), Guiding (P4), Subtle (P2, P3), Soft (P5), Encouraging (P5), Nudging (P2, P4, P5), Sticky (P5), Resistive (P5)
	No. of Grains	High (>5)	Intense (P4), Strong (P4), Intrusive (P3), Ecstatic (P2)
		Low (<5)	Comforting (P1), Encouraging (P5), Low Information-Dense (P4, P5)
Vibration Parameters	**Waveform**	Sine	Smooth (P4), Soft (P4)
		Sawtooth	Hard (P4), Funky (P1), Disengaging (P5), Strong (P4)
		Square	Harsh (P4)
		Triangle	Aggressive (P4), Strong (P4) Noticeable (P4)
	Frequency	High (>200)	Urgent (P1), Ecstatic (P2), Enjoyable (P5), Alarming (P5), Intense (P5), Annoying (P4)
		Low (<200)	Low-Energy (P2, P5), Comforting (P1), Alarming (P1), Sad (P2), Unsafe (P1)
	Amplitude	High (>0.5)	Alarming (P1), Pronounced (P2), Engaging (P3), Enjoyable (P5), Harsh (P4), Unsafe (P1, P2, P3, P4)
		Low (<0.5)	Subtle (P1), Comforting (P1), Quiet (P4), Low-Energy (P2, P5), Negative (P1)
	Duration	Long (>4 cycles)	Ecstatic (P2)
		Short (<4 cycles)	Harsh (P4)

Table 2: Vibration types and parameters mapped to qualitative associations by the haptic experts.

symbols for reassurance (positive valence) using motion-coupled, whereas warning (negative valence) using continuous vibration.

6.2.2 Arousal. Experts preferred to use continuous vibration for indicating high level of arousal. High arousal was associated with strong, rough, and energetic, thus making continuous vibration a preferred choice. P5 used continuous vibration for designing the symbol for ecstasy and mentions, "continuous vibration indicate high energy and a vibrant mood." On the other hand, motion-coupled vibration is preferred to indicate low level of arousal. Low level of arousal is associated with qualities like soft, subtle and gentle. These qualities were similar to what the experts observed when rendering symbols using motion-coupled vibration. Figure 5b demonstrates how P1 designed the symbol for disengagement (low arousal) and ecstasy (high arousal), starting with motion-coupled vibration for low arousal and shifting towards continuous vibration for high levels of arousal.

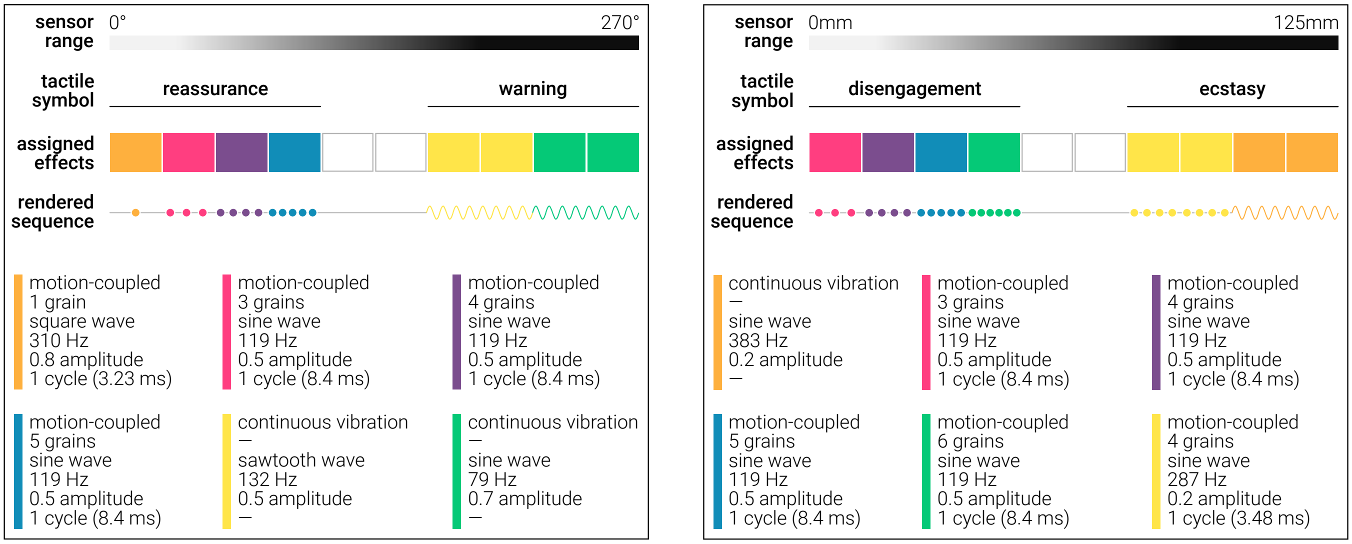
Summarizing, as the valence shifted from negative to positive, experts preferred using motion-coupled vibration over continuous vibration. And, as the level of arousal increases, experts preferred the use of continuous vibration to design the symbol. Thus, if we were to map continuous and motion-coupled vibration to the circumplex model, with increasing in arousal, continuous vibration is preferred whereas with increase in positivity of valence, motion-coupled vibration is preferred. Hence, a clear distinction of preferred type of vibration is seen with the high arousal, negative valence quadrant represented by warning, and low arousal, positive valence quadrant represented by reassurance, where, continuous and motion-coupled vibration has been preferred for the two quadrants respectively. On the other hand, for high arousal, positive valence represented by ecstasy, and low arousal, negative valence, represented by disengagement, no clear trend in the preferred type of vibration within the participant's design was found. These findings are concurrent with the results of the two alternative forced choice test described below.

6.2.3 Two Alternative Forced Choice. The results of the 2 alternative forced choice test show that the 4 out of 5 participants in our study preferred continuous vibration to motion-coupled vibration to indicate *warning*. On the other hand, motion-coupled vibration was preferred over continuous vibration to indicate *reassurance*. However, for *ecstasy* and *disengagement*, no particular vibration type preference was noticed. Note that we do not endeavor to prove any statistical significance in these results, but rather to examine this particular group of designers and speculate the reasoning for the correlation between the type of vibration and the emotion to be conveyed.

6.3 Thematic Analysis

The participants' design process can be outlined through four themes, presented in Table 3. These themes provide insights on how designers connect both types of vibration to their lived experiences, and how the vibration is selected based on the information which needs to be conveyed with the symbol. Then the designers define the affective qualities of the symbols, which are innately mapped to valence and arousal characteristics and designed around a reference state designated by the context or by the designer themselves.

6.3.1 All Vibration is Associated with Lived Experiences. We claim that the difference between embodied experiences and hermeneutic experiences is that embodied stimuli reveal their meaning in a



(a) P2's reassurance and warning symbols (knob). **(b) P1's disengagement and ecstasy symbols (slider).**

Figure 5: Example tactile symbols designed by two participants are shown with the rendered sequence and the parameter values for each vibrotactile effects in those rendered sequences.

pre-reflective manner, while hermeneutic stimuli require conscious reflection to interpret them. However, when approaching a design task, or when reflecting on a design, both hermeneutic and embodied experiences are discussed in the context of participants' lived experiences. Participants also reference familiar stimuli from other modalities to make sure that the symbol will be understandable and consistent with what the user already knows.

Participants suggested that symbols should be designed around experiences that users are familiar with from their day-to-day life, rather than requiring them to learn new mappings: safety especially can be maintained if "There are like standard symbols, not new generated ones, otherwise people first ignore them." (P4) For example, road warnings such as painted lines and rumble strips were associated with motion-coupled vibration and referenced when deciding to convey haptic pre-warnings in a futuristic car. P2 intends to "have like something equivalent to the [road] stripes, and then you actually enter the danger zone." P1 references the shock and negativity they feel with alerts on their phone, which inspires them to use continuous vibration: "My phone for example does continuous vibrations... whatever is annoying on my phone, I have experienced it there. I tried to deal with the warning this way." In iterating their design using continuous vibration, P4 is pleased when "It actually sounds like those warning beeps on some devices, and I think a lot of people might associate it with that."

The ability to use motion-coupled and continuous vibration enabled designing haptic equivalents of alerts in other modalities. For example, motion-coupled vibration when rotating a knob was associated with "the indicator (beeper) in the automobile while turning" (P2), whereas continuous vibration is connected creating shock or annoyance. Thus, the expert intends that the user will not have to think very hard about what they experience. In the disengagement case, P2 reflects on auditory stimuli they know from paragliding, which "uses an audio system that gives beeps when you dip, that beeps for your vertical velocity" to notify and encourage the glider to pull upwards. These beeps are similar to going over bumps created by the motion-coupled vibration, where each bump corresponds to a higher level of disengagement. Thus, *designing and reflecting on symbols and signal parameters with both motion-coupled and continuous vibration is done within the context of one's lived experiences.*

6.3.2 Symbols have Affective Qualities. Symbols were not only designed within the context of previous experiences, but also in reference to symbols affective properties. Without mentioning valence and arousal, designers had an intuitive understanding of the symbols' affective qualities. This was expressed through qualitative descriptors, which consistently place the symbols in an affective space. Symbols for warning (designated negative valence, high arousal by us) were designed to be "aggressive" and "stressful" (P4) while reassurances (positive valence, low arousal) were "comfortable" (P3) and "pleasant" (P1). Symbols for ecstasy (positive valence, high arousal) were intended to be "energetic" (P1) and "vibrant" (P5), while disengagement (negative valence, low arousal) was "depressed" and "unhappy" (P4).

This, in turn, led to consistency in the use of vibrotactile patterns. For example, P4 stated "I'm thinking in terms of visceral experience, as it needs to be something comfortable." when designing with motion coupled vibration and P5 describes that "my initial thought for the ecstatic [symbol] is like the vibration is umph-umph-umph full of energy." P5 then designed a signal based on continuous vibration structured in the same way, providing an energetic beat and resembling the experience of a lively club environment. Our analysis showed that these choices were not only made based on

Theme	Description
Vibration is Associated with Lived Experiences	Both motion-coupled and continuous signals are used in reference to lived experiences which provide a frame of reference for the designs: *"The strips on the side of the road [are] painted in a way that when you go with your car, you feel it"* (P5)
Symbols have Affective Qualities	Participants agreed on affictive qualities of symbols such as valence and arousal. This supports creating consistant designs, both with respect to lived experiences referenced, vibration type, and vibration parameters: *"With less energy you would show it with less number of grains, lower frequency, and lower amplitude"* (P2)
Symbols can be Active or Passive	Continuous vibration was preferred to evoke immediate action (e.g., warnings), while motion-coupled vibration was preferred for passive background information (e.g., reassurance): *"A warning should be recognizable and you should feel it right away so continuous vibration makes more sense"* (P1)
Context is Part of the Symbol	Participants did not only design the target symbol (e.g., "Danger") but also the context of that symbol. Here the context is what the user experiences before or after the primary symbol, or gradients between symbols: *"We're going from engaged to disengaged. We show this by reducing the haptic feedback"* (P2)

Table 3: Four themes which emerged during the design process. These show how designers used vibration types and parameters when creating tactile symbols.

real-world experiences, but that the experiences were also chosen to align with the affective qualities of the symbol. These *affective qualities provide guidance in selecting vibration parameters.*

6.3.3 Symbols can be Active or Passive. The designers decide on the use of motion-coupled or continuous vibration based on how urgently a user may need to take action and potential repercussions of the situation. Here, P1 and P4 explicitly differentiated between *Active Symbols* which the user can experience even if they do not move the TUI element or *Passive Symbols* which the user would only feel when moving the TUI element. In practice, this means active always is designed with continuous vibration, while passive refers to symbols using only motion coupled vibration. Using an active symbol, the user might be informed to not explore beyond a certain point. For instance, in the case of futuristic driving, the information that there has been an accident in the adjacent lane needs to be provided actively to the user and hence the experts preferred to use continuous vibration. The information and potential repercussions conveyed by the vibration should act as a barrier to discourage the user: "It immediately needs to be continuous [vibration], because it wants you to go back." (P1) "The driver needs to be alert as lives can depend on it." (P3) The expert's intention is to convey this information in an urgent fashion, without the driver needing to seek it out. To convey active symbols, high urgency and disruptive qualities are prioritized: "I would use continuous vibration... to actually alert the person not to turn. You don't want people to explore that region." (P4) It should be a "more noticeable, louder" (P2) and "stronger" vibration (P3). Thus, for conveying information actively, experts tend to use continuous vibration.

On the other hand, the information that it is safe to switch lanes can be provided as the driver turns; because there is no danger, it can be given as the driver moves into the space. Experts used motion-coupled vibration to convey passive symbols, because - "It was important to encourage the drivers gently that they are doing the right thing." (P2), "... as you are turning more, you get an indication like yup, it's okay, it's okay" (P5) wherein each grain of the motion-coupled vibration feels like, "there's this sort of nudge" (P1). Motion-coupled vibration might also be used for exploration, where the information is passively provided in case the user needs it; for instance, the mood jockey must seek out the emotional state, which is only provided if they move into the corresponding region on the slider: "What I imagine is that the mood jockey is playing around with the sliders... the urgency is low." Motion-coupled vibration was used to convey gentle feedback where the user needs to fetch passive information: "Grains make me feel that I can notice the vibration, but it doesn't appear too strong to me. I won't get too intrusive signals, but I will still know that I'm on the right way." (P3) As these systems are in constant use, continuous vibration is not used to convey the system state: "You do not want the vibration to be distracting or be vibrating even when you don't need it." (P5) For passive symbols, vibration is often intended to be slower, shorter and qualities like softness, gentleness and being non-disruptive are prioritized: "[I] just want to give you a notification in a gentle way." (P3). Thus, motion-coupled vibration was preferred for conveying information passively. *The designation of active or passive information in the designer's intention conveyed using continuous and motion-coupled vibration, respectively, makes subjective qualities of the symbol clearer.*

6.3.4 Context is part of the Symbol. Typically, a symbol is something binary: A warning that it is not safe to change lanes is either provided to the user or not provided to the user. However, in our study, experts embedded such symbols in a continuous context.

Here, the active warning symbol, designed using continuous vibration, is embedded within a larger passive symbol. This way, feedback might be given as a driver begins to approach a zone of danger. Once it is reached, the designers indicate this by switching from motion-coupled vibration to continuous. This contextual part would gradually fade in, for instance "the closer you get, the amplitude is more," (P5) and "three increasing incremental feeling designs [so] that the further you go, the more it warns you" (P1). This approach was taken by four out of five participants in designing the warning: they indicated a "pre-warning" stage with a softer vibration leading up to the strongest vibration, the final warning symbol.

In other cases, the active element of the symbol was not well-defined. The designer wanted to designate an end point; here, motion-coupled vibration was used to design the approach as well as indicate the end point. For instance, "for the reassurance you kind of had a pattern but then had a virtual stopping point, which indicated that you actually changed lanes... the shift was from many grains to one grain that gives them [a] click. So you have a definite endpoint" (P2). This is like creating a "barrier" (P1) which tells the user they have received all the information. In the case of ecstasy and disengagement, designers view them as emotional states and approach from either side with motion-coupled vibration. The surrounding vibrations describe "a gradient where you go down in levels" to finally reach that key piece of information (disengagement), in this case described by P5. P2 describes their design made with motion-coupled vibration like a ratchet when designing the reassurance symbol to let the driver know they had gone far enough into the next lane: "the idea is that if you are in the end position, you don't keep on doing it [turning]" (P2). *Provided with the ability to add motion-coupled vibration to the design of tactile symbols, designers started considering the context of the symbol, what users would feel before or after, as part of the design.*

6.4 Free-form Designs

The following are two of the designs of the creative exploration task, which was performed by four out of the five participants. Without constraints of the design space, the participants used a combination of motion-coupled and continuous vibration to render vibrotactile effects, for four out of the six designs. All the free-form designs were only done on the sliders to investigate how participants use the design space (provided by the system) of a single TUI, rather than comparing their approaches between different TUIs. In this section, we depict a visual representation of two free-form design they explored and describe their thought process in brief:

Lane Assist: Participant 4 designed a lane assist using one of the slider as shown in Figure 6a. The idea of the participant behind this design was that - "The user needs to find this sweet spot. How can we inform them where the sweet spot is. This sweet spot can be a lane assist or something to stay in the same lane while driving" For the same, a symmetric pattern of a combination of continuous and motion-coupled vibration was used. The continuous vibrations at the end are made rough to avoid the user from going there, whereas the motion-coupled vibrations are rendered in a way that the user gets encouraged to move in the direction of more grains if they are in the region which has fewer grains. The center region has no vibration and is the lane where the user is encouraged to be in.

Light Switch: 2 Participants (by co-incidence) designed a light switch with haptic feedback. The design by participant 4 is shown in Figure 6b. The switch is designed as a combination of continuous and motion-coupled vibration, where the number of increasing number of grains indicate the increase of light intensity. Excerpt from the participant - "I am trying to use a considerably lower frequency and lower amplitude because you don't want to hear the light switch. Plus, lower frequencies and amplitudes are less distracting when using the light switch. The reason of choosing a sawtooth signal was to have distinct clicks and a gentle continuous vibration was used at the end to indicate the maximum light intensity" (P4).

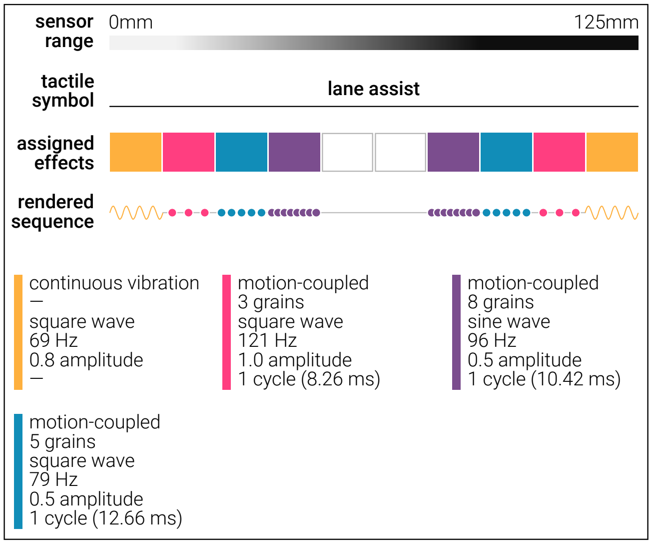
The design of a light switch by P1 can be found in the Figure 9c. Other designs include typewriter's key press effect by P1 in Figure 9a, the design of virtual hill and valley by P5 in Figure 9b, and the design of alternating roughness and softness regions described by P2 as 'hiccups' in Figure 9d.

7 DISCUSSION

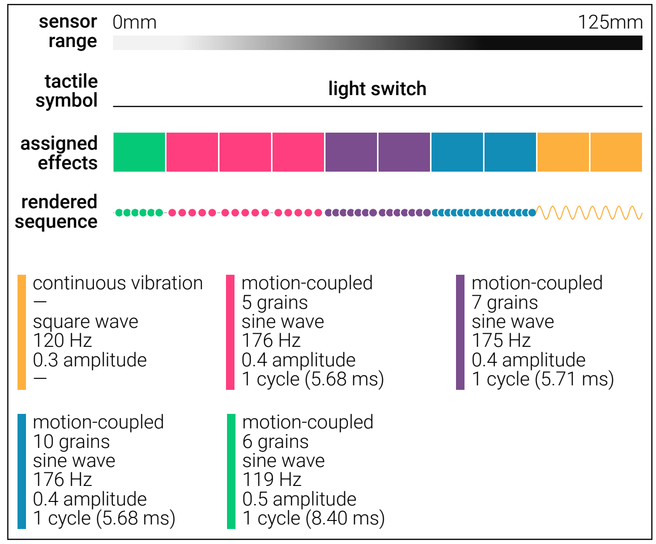
Our results demonstrate that haptic experts are able to explore the design space using motion-coupled and continuous vibration effectively to design tactile symbols. Combining continuous and motion-coupled vibrotactile cues was done effortlessly. For participants, the two types of vibrotactile signal simply became part of the repertoire they had at their availability to create symbols.

We did not instruct participants on how they might use motion-coupled vibration or continuous vibration, there was no explicit requirement to use one or the other, or to combine them. However, for almost all symbols, participants opted to use both types of vibration. Generally, while symbols typically used both types of vibration, motion-coupled vibration was used more often than continuous vibration; often continuous vibration was used to highlight a certain element of a larger motion-coupled symbol.For example, participants often used motion-coupled vibration as a feed-forward mechanism, which users would experience before they were exposed to the main part of the symbol. In our analysis, we describe this as designers considering not only the symbol itself, but the context of the symbol as part of the design. However, one might also frame this within the context of feedback and feedforward mechanisms (cf., [19]). Here the continuous vibration elements can be seen as a mechanism for feedback, whereas motion-coupled vibration as a tool for feed-forward, as a way to communicate the intention of the message to be conveyed prior to the actual message conveyance. The way in which designers in our study expanded the scope of the symbols was remarkable to us, as we had hosted previous studies and workshops on tactile symbol design using continuous vibration only [52, 53], where such topics never came up, nor are we familiar with this being observed in other studies of symbol design [13, 34, 54].

We found that participants actively adapted their design based on the type of information it represented, for example, information which did not require immediate attention from the user was often represented using motion-coupled vibration, so as not to disrupt



(a) P4's design of a lane assist.



(b) P4's design of a light switch. P1's light switch is in the appendix.

Figure 6: Example tactile symbols created by participants during the free-form design task (both rendered on a slider).

the activity of the user, but allowing them to attend to the information as they chose to. On the other hand, information which required immediate attention, such as warnings, was represented using continuous vibration, to nudge people to take direct action. Participants spoke of these as *active* or *passive* symbols. This distinction between actively and passively providing information was one of the first considerations people made when designing a symbol. Here, again, adding embodied experiences to the design space made participants reflect on the symbols in new ways, resulting in more diverse designs. It should be noted here that active and passive refers to the symbols, not to the user. Compared to discussion of active and passive touch [33, 35, 49], subject and object are switched. Active symbols have an affinity to passive touch; they can be perceived even when the hand is just resting on the TUI element. Passive symbols have an affinity with active touch, they typically require the user to actively engage with the TUI element to experience them.

We also found that participants tended to present symbols with a positive valence using motion coupled vibration, and in a negative valence using continuous vibration – possibly a consequence of information requiring immediate action more likely having negative valence and vice versa. Consequently, motion-coupled vibration and continuous vibration appear on opposite sides of Russel's Circumplex Model, continuous being related to negative valence and high arousal, and motion coupled related to positive valence and low arousal. This highlights that adding embodied experiences to symbol design broadens the range of affect which might be designed into the experience of a tactile symbol. These results are also interesting within the context of shape-change in relation to emotion [38]. For example, studies indicated the shape itself as a parameter for valence and that arousal was communicated through shape changes or transitions [45].

Generally speaking, our study highlights, that combining embodied and hermeneutic experiences – here represented with continuous and motion-coupled vibration – works effortlessly in symbol design. The resulting designs are more varied than they would be without both types of stimuli. Providing designers with both types of stimuli, however, not only lead to more varied designs, it also prompted designers to think about symbols differently. Without being prompted to do so, designers integrated feed-forward mechanisms into their design and adapted their design based on the type of response they hoped to elicit from the user. Finally, it appears that combining embodied, and hermeneutic experiences might expand the range of affect designers are able to represent in their symbols.

8 LIMITATIONS & FUTURE WORK

It should be noted that all symbols were created on a dynamic interface. While we believe that this type of symbol has ecological validity, typically when designing tactile symbols, they are deployed in a more static context. Some of the observations we make here might also be due to the user movement, rather than symbol parameters. However, as by our very definition of embodied experience dynamic input from the user is required, it is difficult to separate the final symbols from human movement.

While we have observed anecdotal associations between parameters types and symbol properties, further studies are needed to reveal if there are more underlying conceptual associations involved in the design and use of haptic symbols and perhaps where these associations originate through culture, design craft, and other lived experience. Also, there are ways of combining motion-coupled and continuous vibration other than used in our rather dichotomous approach: An interesting recommendation which came out of the interviews of haptic experts was the ability of stacking motion-coupled vibrations on top of continuous vibrations, which the current system doesn't allow. This would also allow combining different vibration types to render more realistic effects, as well as to superimpose multiple vibrotactile illusions to create more robust experiences.

Finally, it is important to restate that the intent of our study is not to present a "how-to" of designing haptic symbols. Rather, we demonstrate the strategies and qualities associated with different vibration parameters by the haptic experts we worked with. This is true also for the preferences expressed during the creative explorations. It will be important to work with larger groups of designers in a cross-cultural study to gather more general design behaviors and material associations. The symbols designed by the haptic experts here would also benefit from additional evaluation by end-users. The observations we present here might act as inspiration for other design tools, or concrete designs, and provide an initial hypothesis for further quantitative studies to see if any of the observations we make generalize. However, the data we collected for this study does not allow us to make any claims of generalization. While we believe that both vibrations can be used to generate tactile symbols, demonstrating the standardization and translation to real world applications of the symbols, is up to future work.

9 CONCLUSION

We investigated the use of continuous and motion-coupled vibration in the design of tactile symbols to explore how embodied mediation might be used in hermeneutic design. We conducted a study with five haptic experts who were asked to design symbols using both types of vibration and were later interviewed to understand their approach and final designs. Thematic analysis of the interviews revealed that experts were able to associate both vibration types with lived experiences, and that the symbols they designed have affective qualities. Moreover, symbols can be active or passive based on the type of vibration and that experts integrate the context as a part of the symbol.

On a high level, our results show that embodied experiences can indeed be used for hermeneutic design. Resulting designs were more varied than they would be without both types of stimuli. In addition to more varied designs, this approach also shaped thinking about design: designers integrated feedforward mechanisms into their design and adapted active or passive symbols based on urgency. Overall, we showed that combining embodied, and hermeneutic experiences extends symbol design opportunities in useful ways.

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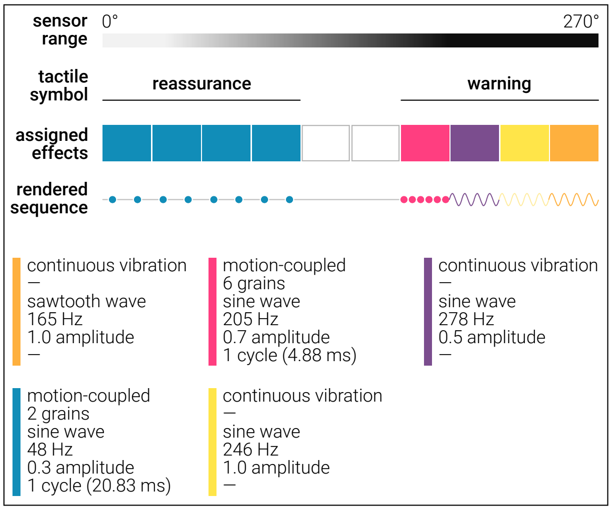
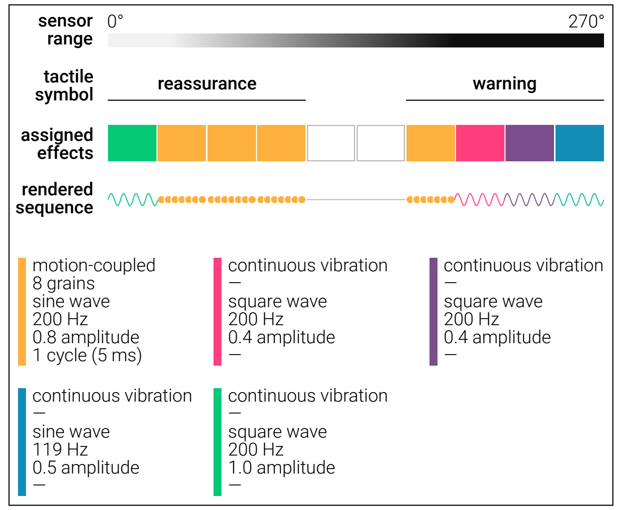
A APPENDIX: TACTILE SYMBOLS

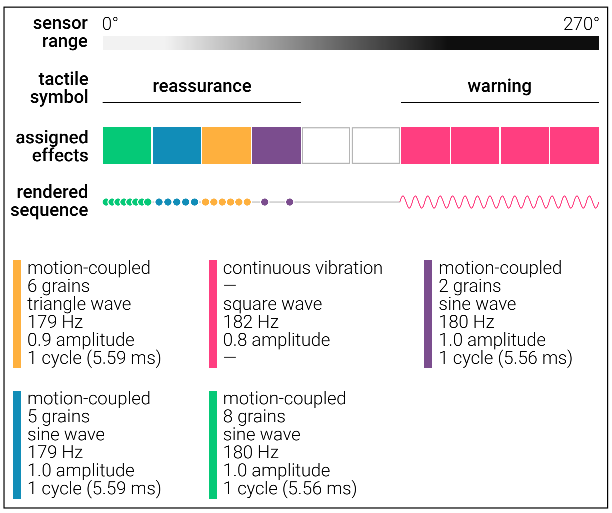
Here, we include all the tactile symbols designed by the participants, which were not shown in the paper.



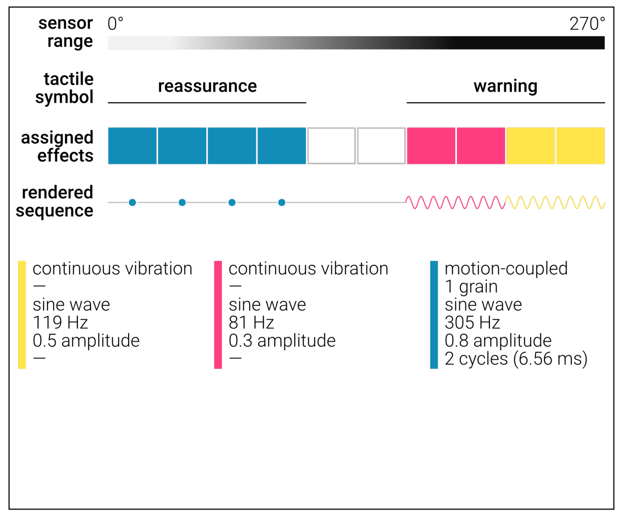
(a) Participant 1



(b) Participant 3

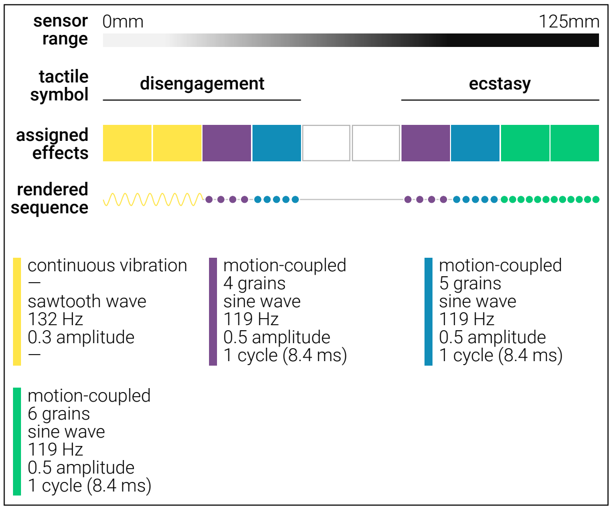


(c) Participant 4

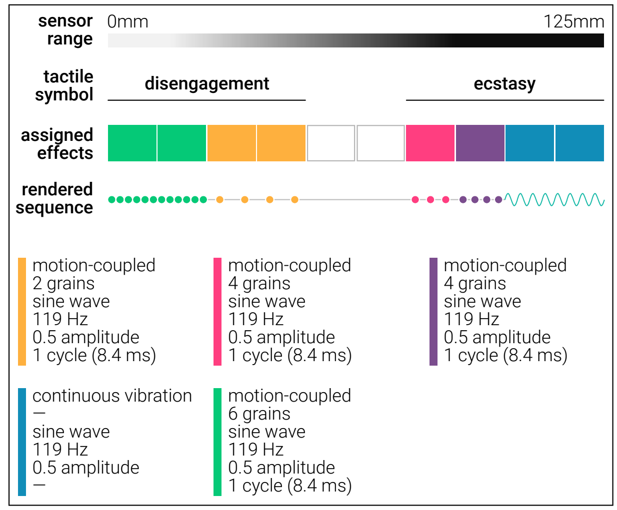


(d) Participant 5

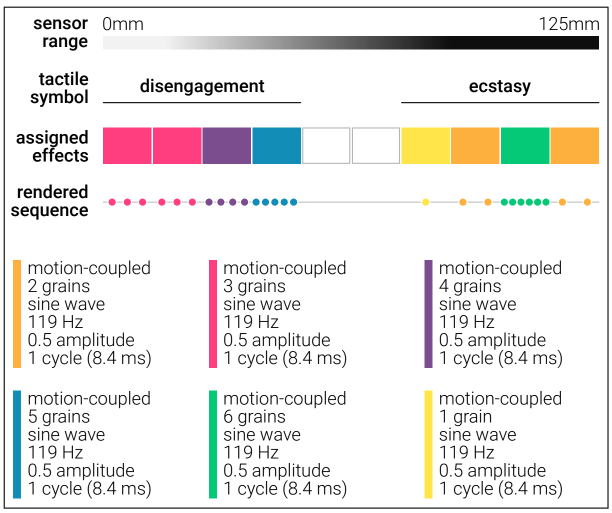
Figure 7: Tactile symbols designed by the participants to communicate *reassurance* and *warning*. These symbols were experienced on knobs.



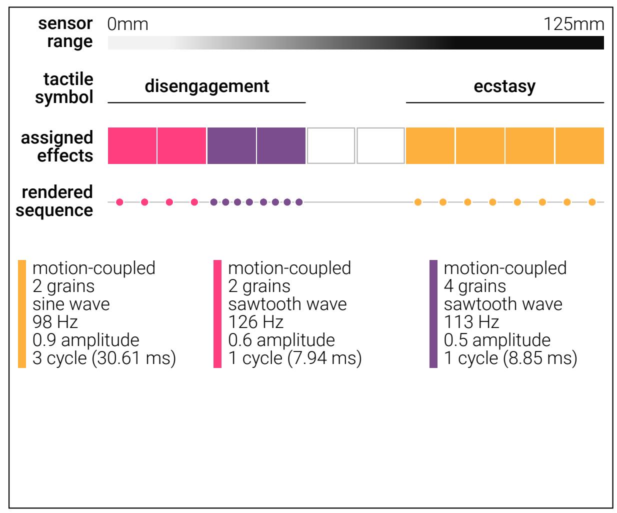
(a) Participant 2



(b) Participant 3

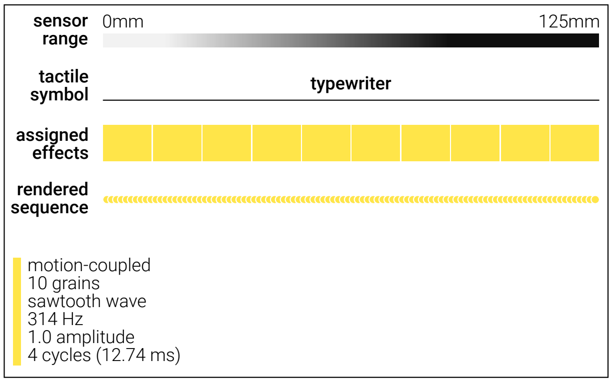


(c) Participant 4

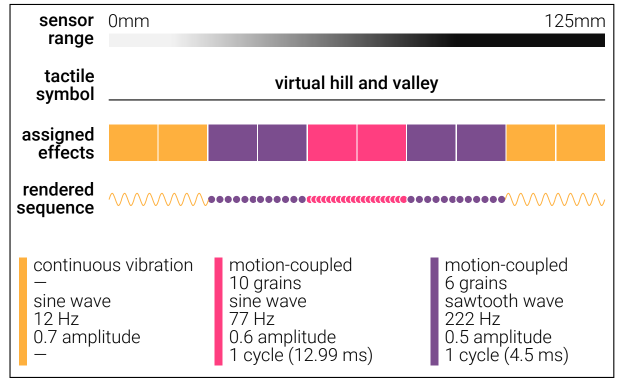


(d) Participant 5

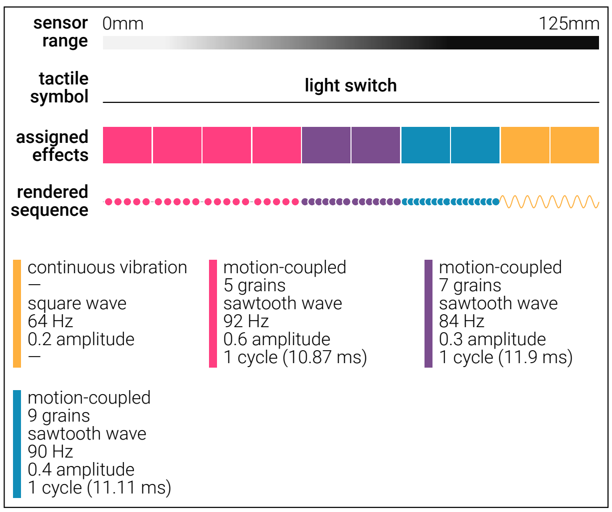
Figure 8: Tactile symbols designed by the participants to evoke *disengagement* and *ecstasy*. These symbols were experienced on sliders.



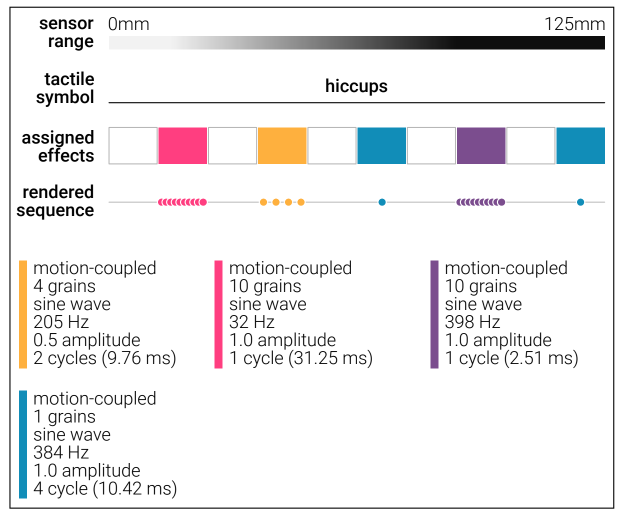
(a) P1’s design recreating a typewriter’s key press effect



(b) P5’s design of a virtual hill and valley



(c) P1’s design of a light switch



(d) P2’s design of hiccups

Figure 9: Additional free form designs by the participants using sliders.