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Master's Thesis
Academic Year 2021

Haptic Empathy: Embodying Emotions for Children with Autism

Keio University
Graduate School of Media Design

Yulan Ju

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Yulan Ju

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Abstract of Master's Thesis of Academic Year 2021

Haptic Empathy: Embodying Emotions for Children with Autism

Category: Design

Summary

Touch plays an essential role in communicating emotions and intensifying interpersonal communication. An increased number of our social interactions and communication is mediated through the computer in the digital age. As a result, the need for incorporating the sense of touch in computer-mediated emotional communication is further emphasized. Current haptic research focuses on the engineering aspects rather than human factors and particularities of human perception, especially related to affective touch.

This thesis attempts to bring a new perspective by shifting the focus from machines to humans and employing a human-centred design approach to developing novel practices, methods, and applications in haptic research. In this thesis, a new concept, "Haptic Empathy", is proposed, which is defined as the ability to interpret a haptic stimulus and entailing the corresponding affective response. Several studies are presented to support the viability of the proposed conceptual framework.

Additionally, a toolkit based on the concept of Haptic Empathy is being developed for the educators of young children relevant to emotional education. This application investigated the possibility of utilizing haptic technology to aid children with autism in expressing and comprehending emotions.

Keywords:

haptic emmpathy, affective, haptic, vibration, emotion, empathy, autism

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Chapter 1
Introduction

In our digital age, more and more of our social interactions and communication are mediated through remote phone calls, video conferencing, or text messages. It helps us to stay in touch with distant friends and family members easily and provides some degree of affective communication. However, the current communication systems still do not support communication of the sense of touch. Moreover, even in the research field and experimental devices, the recording, rendering, and communicating the physical touch is still a problem. Hence, the need for incorporating the sense of touch in computer-mediated emotional communication is further emphasized by the growing interest in the use of touch-enabled agents and robots [1]. Most existing techniques started with discriminative touch as an information channel, often in addition to visuals and audio modalities (e.g., touch and haptics for information rendering and comprehension). Recent studies have been devoted to employing the sense of touch for communication of affect and social cues (social touch) as well.

For the sake of simplicity, in the context of this work, the human ability to extract and encoding emotional meaning in the tactile aspects of human-to-human interactions or conveying and understanding emotional meanings through haptics is defined as Haptic Empathy.

1.1. Affective Haptics

Social interactions rely on complex signals in various modalities; we communicate through the synergy of even the subtlest and most intricate cues across all the perceivable modalities. Although verbal semantics play an essential role in our interactions, we must not overlook the importance of non-verbal signals. From the early 1960s, social psychologists have shown that non-verbal information plays a crucial role in human-to-human social interaction, and one of the main purposes of non-verbal information is to communicate emotional context between individuals. Among the different non-verbal communication modalities (e.g., facial expressions, gestures, tone of voice, prosody, etc.), touch has been considered one of the primary channels for conveying intimate emotions. The importance of touch as a modality in social communication is highlighted by the fact that the neural pathways processing discriminative touch (simple tactile perception of information with no affective meaning) differ from those responsible for affective touch (touch we use as part of communication, hugs, handshakes, pats, etc.).

Many studies have been done on using haptic technology to communicate affective information through different haptic displays. Furthermore, many applications in affective haptics have been proposed in various fields, such as social interaction, healthcare, games, entertainment, robotics, and human-computer interaction as a whole. Although these works and applications demonstrate that haptics can effectively communicate distinct emotions, they also show that the overall performance of the system is influenced by a variety of factors such as gender, relationship status, familiarity, social status, cultural background, etc. All these factors are crucial for the correct interpretation of the stimuli. Since we are not even at the stage where we can identify, classify, and quantify those factors, there is a lot of research necessary before implementing and deploying such haptic systems. It is evident that the ability of a human to interpret a haptic stimulus and infer the emotional context from it depends on far more than the physical properties of the haptic stimulus.

Currently, most haptic research is devoted to developing new interfaces capable of detecting haptic cues and providing high-fidelity haptic rendering. The role of humans and how they use touch in their daily lives is still an understudied topic. The emotional context is crucial for human-to-human interaction; the ability to extract this context or render it through haptic interfaces may play an essential role in human-to-computer interaction. Nevertheless, far too few studies to date have examined the role of the individuals and individual differences from this angle. Therefore, I believe that a more human-centered approach to human-computer and human-computer-human interactions should be further explored.

1.2. Problem Statement

The ultimate goal of the haptic field of research is generally considered to lie in the development of pervasive, unobtrusive, and natural haptic interfaces that are capable of detecting haptic cues and providing high fidelity haptic rendering, anywhere and anytime, in the same way, humans communicate touch with each other [1]. Most of the research has therefore focused on developing high-fidelity haptic interfaces. However, in the context of human-computer interaction, haptic interfaces provide bidirectional communication of the touch sensations [2]. In other words, the roles of the human and the machine are equally important. Despite this, the studies on human factors in this context are still relatively limited. Most studies concentrate on the machine and hardware side: improving the accuracy of the interpretation of haptic information or the fidelity of its rendering. However, on the human side, although the system is designed for and by humans, human-centered aspects of production and interpretation of the tactile stimuli are often overlooked.

This flaw is particularly evident in the field of affective haptics. As a personal subjective experience, emotions can be shared visually through emoticons, images, and colors, verbally, through language, and aurally through rhythms, melodies, and timbres. Although existing technologies have added a tactile dimension to the perception and representation of emotions, it still mainly remains in the visual dimension for initial emotion education. In most schools and after-school programs, the tools used for learning emotions are limited to picture books and music. The majority of works only use colors and facial expressions to help children learn and understand emotions. Only minimal works are exploring the possibility of using tactile interfaces in emotion education. In today's age of widespread tactile technology, this might restrict people's perception and expression of touch and the comprehension of emotions.

Another issue that arises in affective haptics is that most studies are conducted in a well-controlled lab environment and use haptic patterns that the researchers themselves have defined. However, it cannot be neglected that individual differences in understanding emotions and the interpretation of haptic feedback can generate communication problems. This is also why the tactile stimulus is mainly investigated as an auxiliary modality for communicating emotions. We believe that, instead of the pre-defined haptic stimuli, other scenarios of using haptic feedback to express emotions should be further explored.

To sum up the above, the present work focuses on haptic interfaces and the use of haptics for communication from a human-centered design perspective. Meaning that in the context of this work, the computational and hardware sides of the haptic interface are deemed to be less important than innate or learned haptic empathy, an intrinsic property of humans. Another focus point is the application of the findings related to the haptic empathy for emotion education, as it is not evident whether haptic empathy is purely innate and not learned. This echoes back to the common nature vs. nurture question relevant for most human abilities. One argument supporting the "nurture" side is how different the expressions of the affective touch can be across different cultures.

1.3. Goals and Contributions

Based on the premise of individual differences in haptic perception and preferences, we first investigated the possibility of conveying emotional information with minimal to no digital interference. While confirming that emotions can be shared using only simple vibrations, we further studied the individual differences in expressing and recognizing emotions through vibrotactile feedback. From these studies, we proposed the concept of haptic empathy, the ability to interpret a haptic stimulus and entailing the corresponding affective response. In simple terms, the individual ability to express and understand emotional meaning through vibrations. In addition to this, we have explored some possible applications based on the concept of haptic empathy. We chose the field of emotion education and tried to introduce tactile feedback techniques into teaching emotions to children. Realizing that conveying and understanding emotions is more challenging for some people, such as people with autism, we designed a toolkit that enables the teachers to use haptic technology in their work. We explored the potential of using haptic technology to assist children with autism in expressing and comprehending emotions.

1.4. Thesis Structure

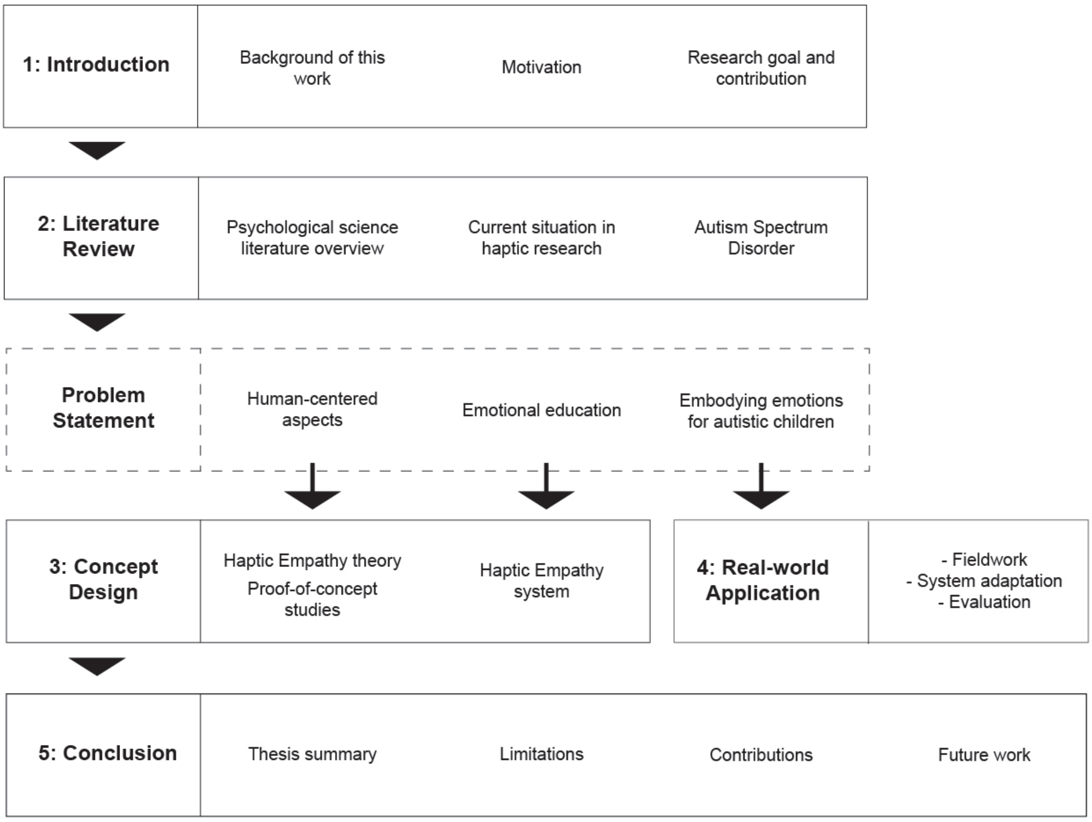


Figure 1.1 Thesis structure and flow

The general flow of this writing is illustrated in Fig.1.1. This thesis consists of 5 chapters. Below is a short overview of each of the chapters.

- Chapter 1: This chapter introduces the background of this work, describes the motivation and purpose of this research.
- Chapter 2: Consists of three major parts. The first part introduces theories related to emotion quantification and classification. It focuses on two theories used in this thesis: Plutchik-Model and Russell ' s Circumplex Model of Affect. The second part describes the current status and the development of affective haptics. It provides theoretical support for our study. The

third section provides background information on autistic children and discusses several case studies illustrating the therapeutic application of haptic methods for people with autism.

- Chapter 3: This chapter first introduces the initial idea of enhancing emotional communication through the haptic device, from where the concept of Haptic Empathy system. Concept description is followed by a series of studies that support the hypothesis of the existence of Haptic Empathy and investigate its characteristics. Finally, the application scenario is proposed.

- Chapter 4: This chapter presents an application scenario of the proposed theory. It contains descriptions of the fieldwork, user studies, concept design, and prototyping iterations and discusses the workshop results for concept validation.

- Chapter 5: Summary of the present work, discusses the conclusions, future prospects, and limiting factors of this research.

Chapter 2
Literature Review

2.1. Measurement and Classification of Emotions

The haptic research community has studied the emotional and affective aspects of users' perception of various haptic stimuli using various methods, such as physiological reactions (e.g., heart rate or electrodermal activity), facial expressions, gesture expressions, or brain activity. Many studies employ subjective measures like rating personal emotional experiences with various scales, such as the PAD 3D affective space [3], the Positive and Negative Affect Schedule (PANAS) [4] and the State-Trait Emotion Measure (STEM) [5]. In most of the studies in this field, two prominent theories of emotion break emotions down into a dimensional emotion model and a categorical one [6]. Both theories have their merits when endeavoring to quantify emotions, and their relationship to other variables in the perception of a design [7], and I will call on both frameworks in this thesis.

2.1.1 Plutchik-Model

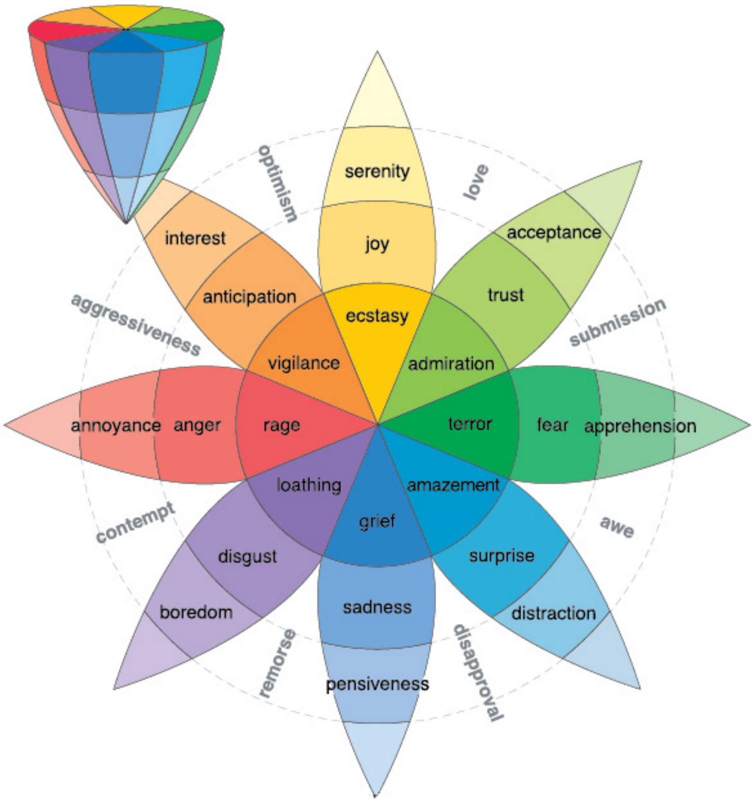
Psychologist Robert Plutchik [8] developed one of the most prevalent emotion models, known as the Plutchik Wheel. It is a three-dimensional circumplex model that describes the relations among emotion concepts analogous to the colors on a color wheel (see Figure 2.1). The Plutchik wheel can be interpreted from four aspects: primary emotions, opposites, combinations, and intensity. The eight sectors are designed to indicate eight primary emotions: anger, anticipation, joy, trust, fear, surprise, sadness, and disgust. Each primary emotion has a polar opposite. In other words, eight primary emotions are arranged as four pairs of opposites based on the physiological reaction each emotion creates in animals: joy is the opposite of sadness; fear is the opposite of anger; anticipation is the opposite of surprise; disgust is the opposite of trust. Plutchik also defined the mixtures or combinations of these primary emotions as the primary dyads shown in the wheel's blank spaces. For example, anger and disgust combine to be contempt. Fear and surprise combine to be awe. The vertical dimension of the cone reflects intensity; emotions become more intense as they progress from the outside to the center of the wheel, as shown by the color: The stronger the feeling, the darker the color. For instance, serenity is joy at its least level of intensity, and it becomes ecstasy when joy reaches its pinnacle of intensity.

2.1.2 Russell ' s Circumplex Model of Affect

In contrast to the describe affect as a set of dimensions with each dimension varying independently of the others (categorical emotion model), dimensional emotion models characterize emotions using a set of continuous scales. Valence (indicating the positivity or negativity of the emotion) and arousal (indicating the excited or calm emotional state) are two common dimensions proposed in this theory. For example, Russell ' s dimensional circumplex model of affect [9] was proposed as a means for psychologists to represent the structure of affective experience, as well as a representation of the cognitive structure that laypeople use to conceptualize affect. It enables a more precise definition of complex or subtle emotions and words, in which 28 affect variables were mapped in the quantitative two-dimensional space of valence and arousal (Figure 2.2 (a)). In addition, because of the appearance of monopolar factors, five of the variable components were further investigated in a second-order factor (Figure 2.2 (b)). The first two components were bipolar. The first component was labeled happy-sad, and the second component was labeled tense-relaxed. The third and fourth components, labeled sleepy and angry, were monopolar. The fifth component was labeled as alarmed.

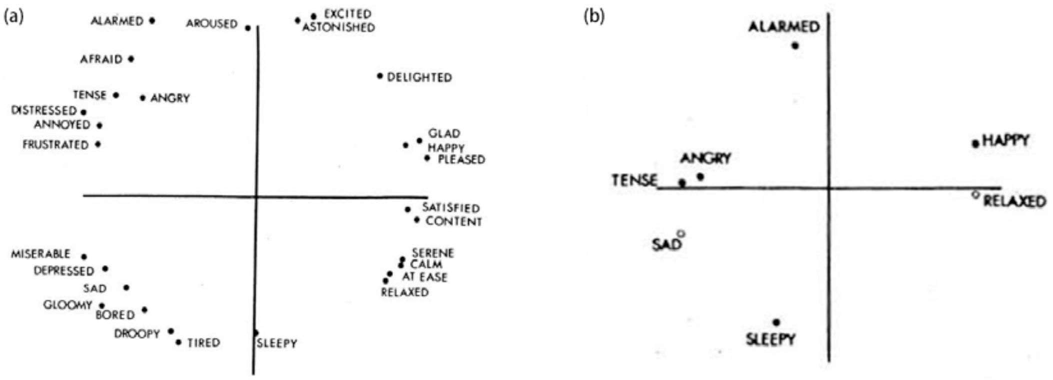
2.1.3 Cross-cultural Similarities in Emotion

Since the subjects of this thesis belong to various cultural backgrounds, cross-cultural similarities and differences in emotion and its representation also need to be considered. Many psychologists believe emotions embrace both universalism and differentialism [10]. On the one hand, emotion is a primary human functioning



(Source: The Nature of Emotions: Human emotions have deep evolutionary roots, a fact that may explain their complexity and provide tools for clinical practice [8])

Figure 2.1 Plutchik ' s emotion wheel showing the primary emotions (inside the circle) and list of dyads (edge of circle)



(Source: A circumplex model of affect [9])

Figure 2.2 (a) Russell ' s circumplex model of affect, 0°axis representing valence, 90°axis representing arousal; (b) Second-order principal components of five components of self-reported data

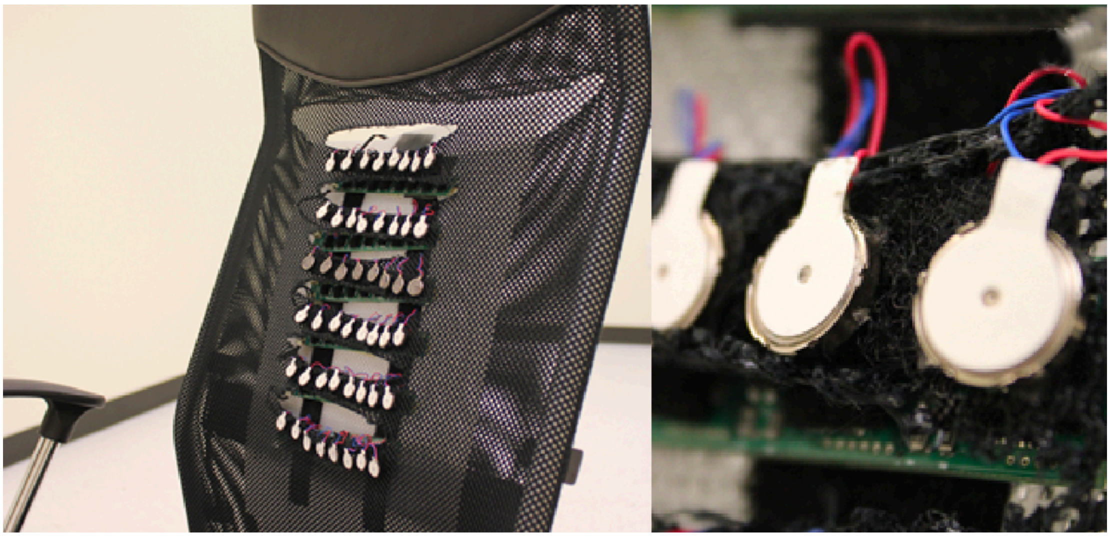
mechanism that is relatively invariant across races and cultures, just like perception, cognition, or learning. On the other hand, as identified by different language labels, emotions are differentiated from physiological symptoms, expressive behavior, motivation, and subjective feelings. Based on cross-cultural research by Kövecses, Z [11], speakers of a given language appear to feel that some of the emotional words are more basic than others. To be more specific, happiness, sadness, anger, fear, and love are five general and possibly universal emotions in 11 languages. In other words, these five emotions can lead to a consistent shared understanding of emotions across linguistic and cultural contexts.

2.2. Affective Haptics

Affective communication with mediated touch involves the use of an interface to convey the haptic sensation from one user to another or from a machine to a user. To implement these systems, force feedback (kinesthetic) and tactile mediated touch are two main mediated touch technologies developed and applied. We will go over these categories in more detail in the following sections, as well as the evidence that supports the use of these technologies for affect communication [12].

2.2.1 Affect Communication with Mediated Tactile Touch

As one of the most commonly used haptic feedback methods, tactile haptic devices stimulate the skin to simulate objects' texture, usually achieved by the generation of vibrations. This tactile communication modality has been studied in much research, especially for people with visual impairments or hearing disabilities. Most current work in this area has focused primarily on displaying facial expressions [12]. For example, one early project called vSmileys [13] investigated the possibility of substituting emoticons by vibrotactile patterns. They encoded nine smileys by changing the frequency and duration parameters of vibrotactile patterns and asked five participants to do the "vSmiley testing" matching games. The results showed that participants could identify vibration patterns and choose the right smiley after training, which indicated a possible alternative way of communication.



(Source: Affective Haptics for Enhancing Access [14])

Figure 2.3 Haptic Face Display

Also, in the field of design for individuals with visual impairment, McDaniel et al. [14] proposed a haptic device, the Haptic Face Display (HFD), for communicating facial-expressions emotions. Compared to the single vibration motor used in vSmileys, this device consists of a two-dimensional array of vibration motors capable of displaying rich spatiotemporal vibrotactile patterns presented through passive or active interaction styles (see Figure 2.3). It is embedded on the back of a chair and provides vibrotactile patterns corresponding to the partner's emotional response. This work explored the relationship between vibrotactile pattern design and elicited an emotional response. The results indicate that pattern shape and duration influence emotional response. Furthermore, it was also demonstrated that specific spatiotemporal vibration patterns could evoke emotion without any training or paired stimulus.

In addition to those applications for special populations, many studies are developing new interfaces for our everyday communication. These devices are often designed to be portable or wearable. One example developed by Park et al. [15] called POKE. It is a tactile-sharing device designed for people with intimate relations to communicate affections through tactile feedback. Users can deliver touches through an inflatable surface on the front of the device during the phone call, and the index finger pressure inputs can be received on the back of another device (see Figure 2.4). After one month of observation of three couples using POKE, it was shown to be helpful in expressing and comprehending emotions, settling conversations easily by replacing words, feeling connected to the partner, and concentrating on phone calls. In addition to this, they also found that all three couples developed and shared their own tactile vocabularies through POKE, which provided a new direction of affective communication. However, this device is only suitable for communication between couples, and users express resistance if the relationship with the recipient was not intimate.

With the common use of affective haptics in various fields, we can see that the design of the vibrotactile patterns in most research was based on the authors' own intuition. To support haptic designers in finding their desired vibrations, Seifi et al. [16] created VibViz, a 120-item database, and compiled research on tactile language into five taxonomies. Although the ecological validity of the emotional qualities of the stimuli may be insufficient, those studies explored various design variables of vibrotactile stimuli, such as amplitude, frequency, duration, waveform, envelope, rhythm, and body site, to establish effective design guidelines.

Unlike most studies on tactile patterns focused on vibrotactile stimuli, Yoo et al. [17] concerned with emotional responses of tactile patterns. Instead of describing participants' emotions as basic emotions, they estimated 24 participants'

(Source: The roles of touch during phone conversations: Long-distance couples' use of POKE in their homes [15])

Figure 2.4 Phone conversation using POKE

valence and arousal scores with three sets of vibrotactile patterns. The vibrotactile patterns were systematically varied in physical parameters-amplitude, frequency, duration, and envelope. The results showed that four parameters are linked to the valence and arousal of vibrotactile patterns. The finding provided a design guideline for the vibrotactile patterns with desired emotional features.

2.2.2 Affect Communication with Mediated Force Feedback Touch

Although most of the research in haptic-based affect communication focuses on the use of tactile interfaces, some studies still provided evidence that force feedback medium can be used to convey emotional meanings within a limited way. In one early study, Smith and MacLean [18] considered a design space for mediated interpersonal haptic interaction composed of three sub-spaces: the type of human interaction, the haptic device, and the virtual mediating model. Through their integrated objective and subjective observations, the results imply that affect can be communicated over a purely haptic link.

Similarly, Bailenson et al. [19] investigated the possibility of encoding emotional information through primary force-feedback haptic devices. Their work indicated that humans recognize emotions through haptic modality at 33% above chance (1/4). To be more specific, they conducted three experiments to explore the expression of seven basic emotions (anger, disgust, joy, fear, interest, sadness, and surprise) through Virtual Interpersonal Touch. In the first experiment, they asked a group of subjects to convey the seven emotions using a 2 DOF force-feedback joystick. In the second experiment, another group of subjects was asked to recognize emotions generated in the last experiment. In the third experiment, pairs of subjects were asked to communicate the seven emotions via a physical handshake. Their work compared the accuracy rate of communicating emotions through mediated touch and non-mediated handshake. This study provided a theoretical framework for understanding emotions expressed through touch. Although the results suggested that people have an advantage in transmitting their feelings through direct touch, it also showed the great potential of affect communication through mediated touch.

Unlike Bailenson ' s study, which studied human-computer interactions using only haptic feedback, Bonnet et al. [20] built a visual-haptic platform (see Figure 2.5) to improve the recognition of facial expressions of emotions using haptic feedback through a kinesthetic approach. Their study selected primary (anger, fear, joy, sadness, disgusts, and surprise) and complex emotions (disregard, interest, guilt, fascination, embarrassment, envy, pride, love, gratitude, and sympathy). The experimental results showed varying levels of recognition improvement. For example, some emotions, such as anger and disgust, are better recognized by combining haptic feedback and visual feedback. Although some emotions had a low level of recognition of the haptic expression, what cannot be denied is that haptic feedback improved the level of recognition.

2.3. Children with Autism

2.3.1 Autism and Empathy

Autism is a set of neurodevelopmental conditions characterized by social interaction and communication difficulties, as well as deep, narrow interest, and islets of ability [21, 22]. Their development of social communication is very low compared to neurologically typical children who learn social cues naturally while growing up [23]. People with autism have a learning disability in this area, often ac-

(Source: Improvement of the recognition of facial expressions with haptic feedback [20])

Figure 2.5 Visual-haptic platform

companied by deficits in language, motor, and perceptual development. There is currently no cure for autism. Thus many research has been devoted to improving their quality of life and independence, focusing on associations between autism and empathy. Although it is difficult to make a standard, agreed-upon definition of empathy in research, we can understand empathy more clearly by breaking it down into component stages [24].

First of all, to feel empathy, an individual must first notice that someone else is feeling something, which requires the ability to understate social cues such as eye contact and facial expression [24]. Most people with autism, especially young children, lack the ability to detect someone else ' s emotional cues. Two factors are thought to have contributed to this result: autistic children are less likely to orient to people [25], and they have a single-minded attention system [26].

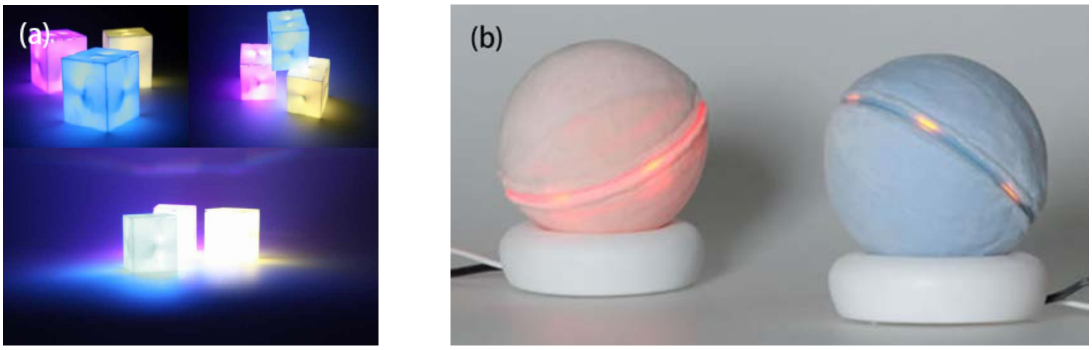
The second step is to correctly interpret emotional behavior, which is difficult for people with autism [27], especially if that person has difficulty understanding their own emotions or if that person is expected to read the emotional signs of someone from another group (non-autistic people).

The third step is to feel how that person feels – have an affinity for, resonate with, or mirror those feelings. This is the step we most often refer to when we talk about empathy. In this step, we tend to express corresponding responses to some emotional signals. Responses to emotional signals are generally dictated by social norms and expectations that are necessarily defined by the non-autistic majority [24]. However, people with autism often do not follow the same response scripts. This is also one of the reasons why most interventions are designed to help them learn the response scripts.

2.3.2 Technology-based Intervention

A developing number of studies have explored diverse applications of technology-based interventions for autistic children [28]. In general, most of the interventions are behavioral and designed to improve social skills development by socially mediating interaction and aiding peer-to-peer relations and collaboration. The humanoid robots have been successfully implemented in the robotic intervention program [29]. Some high-performance robots such as NAO [30], and KASPAR [31] were equipped with many sensors and designed to function as a therapeutic toy. Those robots have been found to meet educational or therapeutic objectives successfully.

However, due to the high cost and consistent challenges of developing a robot that fulfills the complexities of human feelings and emotions, some robotics research explicitly targets the training of imitation skills, engaging autistic children in direct eye contact, or taking turns. Therefore, some robotic toys with simple appearance and single or relatively simple interaction are widely used in games with autistic children. For example, i-blocks [32] (see Figure 2.6 (a)), a tangible multi-agent platform of interactive blocks, were designed to help autistic children develop the ability of imitation and turn-taking. In the experiment, children were asked to complete the following three tasks: watch the video of the target behavior, describe the content of the video, and imitate the scenario with the i-blocks. The results showed that the majority of the children were able to complete the task. More importantly, they performed turn-taking cooperative behaviors after training. Similarly, another paired robotic device called COLOLO [33] (see Figure 2.6 (b))was designed to assist children to achieve turn-taking through play. This study used visual cues as guidance information to guide children to manipulate the toys and change the colors. Both studies provide evidence that robotic toys appeal to children with autism because of their predictable and controlled behavior.



(Source: (a) Engaging Autistic Children in Imitation and Turn-Taking Games with Multiagent System of Interactive Lighting Blocks [32], (b) Effect of Sensory Feedback on Turn-Taking Using Paired Devices for Children with ASD [33])

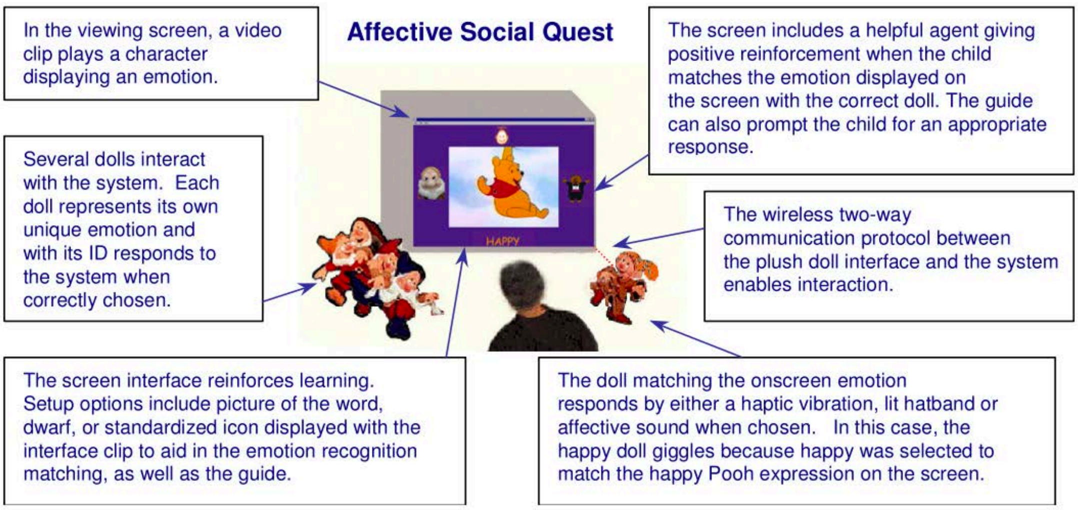
Figure 2.6 Robotic toys: (a) i-blocks, (b) COLOLO

In addition to visual cues being widely used in this field, tactile stimulation has been widely used in various research programs for children with autism [28]. One early study [34] attempted to use a tactile prompting device (the Gentle Reminder) as a prompt for children with autism to make verbal initiations. To be more specific, the authors used a multiphase multielement design to assess the effects of the device in three conditions: no prompt, verbal prompt, and tactile prompt. Tactile prompting resulted in substantial increases in verbal initiations compared to the no prompt and verbal prompt conditions. This result indicates that the tactile prompting device can be an effective, unobtrusive verbal initiation cue for children with autism during their play sessions or learning activities.

Similarly, Shabani et al. [35] also provided supportive evidence that the tactile promoting device can increase verbal initiations for autistic children. They used an ABAB design to determine if the vibrating pager effectively changed the behavior of 3 children with autism during free-play activities. The results indicated increased verbal initiations for all three children and increased responses to peers' initiations for 2 participants when tactile prompting was used.

2.3.3 Enhance Emotional Competences for Autism

Many studies have been working on conveying emotional meanings by vibrotactile feedback, especially for and between people with a sensorial deficiency (deaf, blind) [36, 37]. Nevertheless, only a few technological endeavors were applied to convey emotions to individuals with autism. Although one early project called Affective Social Quotient [38] developed synthesized interactive social situations to promote the recognition of affective information for autistic children, the haptic vibration used in the system is only for attracting children ' s attention. The system (see Figure 2.7) consists of a computer, custom software, and toy-like objects through which the child communicates to the computer. It provided persistent assistance that teaches basic emotional expressions and tracks children's progress. Children develop their recognition ability through the simple matching game. While the system will never replace a skilled human practitioner, it offered a direction in the field of emotional education for children with autism.

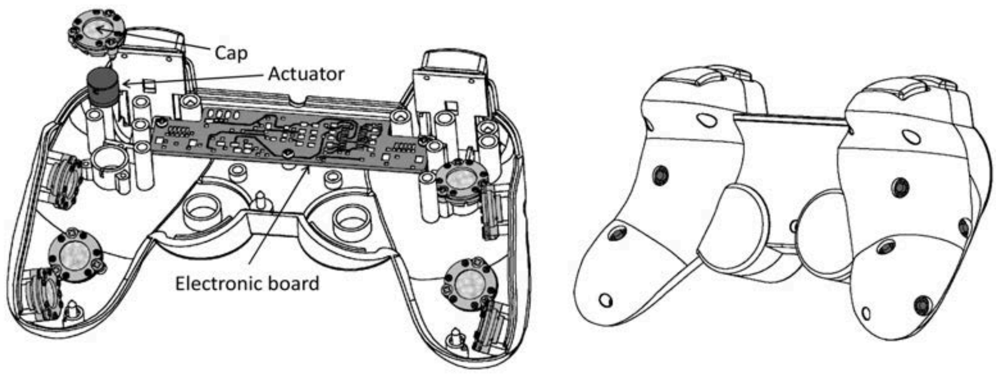


(Source: Affective Social Quest [38])

Figure 2.7 Affective Social Quotient

Unlike Affective Social Quotient, another research team, Changeon et al. [39] from Sensorial and Ambient Interfaces Laboratory, France focused on using vibrotactile feedback to communicate emotional messages to children with autism.

They designed an innovative vibrotactile gamepad used as complementary therapeutic aids. The device (see Figure 2.8) is composed of eight electromagnetic actuators embedded in the gamepad shell to provide distributed tactile feedback. They first created 144 vibration patterns corresponding to six basic emotions (anger, disgust, fear, happiness, sadness, and surprise) through the gamepad. After testing and matching, the most intuitive emotional patterns were selected and integrated into a designed video game to enhance the emotional competences of children with autism. Then they conducted a user test with nine children who had problems identifying basic emotions. According to the observation, half of the participants relied on vibrotactile stimulations to identify and memorize the emotions presented in the game. In addition to this, they also found that the vibrotactile stimulations can help children focus on the task and reducing stereotypical behaviors.



(Source: Tactile emotions: A vibrotactile tactile gamepad for transmitting emotional messages to children with autism [39])

Figure 2.8 Gamepad interior view: 8 actuators and the electronic board are embedded in new special slots

Although the above studies proved that vibration could be used as an auxiliary means to enhance the emotional competences of children with autism, the relevant research and applications remain limited. Many programs are still using emotions learning cards or showing children photographs of people exhibiting emotional expressions to help children learn about emotions or instruct children using emotional words.

2.4. Summary

Our literature study shows that the focus of current haptic research seems to be more biased towards the machine and hardware side: improving the accuracy of the interpretation of haptic information or the fidelity of its rendering. However, on the human side, although the system is designed for and by humans, human-centered aspects of production and interpretation of the tactile stimuli are often overlooked. We believe that a change of perspective and shift the focus from machines to humans will bring new inspiration in the field of affective haptics.

In addition, we have listed lots of affective computing applications that use the haptic modality for the communication of emotions. However, most applications or studies use pre-defined haptic patterns and rely on information transfer, salience, and learnability of haptic feedback. This is also why the tactile stimulus is mainly investigated as an auxiliary modality for communicating emotions. We believe that other scenarios of using haptic feedback to express emotions should be further explored.

Furthermore, we found that existing technologies have added a tactile dimension to the perception and expression of emotions, but we are still limited to the visual dimension when it comes to emotion education. So, we decided to bridge the gap by introducing haptic technology into emotional education. Consider that children with autism are challenging to understand and express emotions, we decided to focus our research on them. Although related studies proved that haptic feedback could be used as an auxiliary means to enhance the emotional competences of children with autism, the relevant research and applications remain limited. Many programs are still using emotions learning cards or showing children photographs of people exhibiting emotional expressions to help children learn about emotions or instruct children using emotional words. We hope that introducing haptic technology will help them perceive and express emotions on a new level.

Chapter 3
Concept Design: Haptic Empathy

3.1. Inspiration of Haptic Empathy

3.1.1 Emotional Communication

Communication plays a significant role in human society. Its purpose can be divided into two main categories: one is for the transmission of objective information between people in order to share and spread information; and the other is for people to express their subjective emotions to others, based on the fact that people have a complex emotional system and have the desire to express themselves and receive emotions from others.

Research shows that people communicate with others after almost any emotional event, whether it is positive or negative, and that emotion sharing offers intrapersonal and interpersonal benefits [40]. Because individuals feel inner satisfaction and relief after sharing their emotions, social relationships are also strengthened through interaction. Therefore, emotional awareness, or the ability to share feelings, play a vital role in communication.

However, given the differences between people in expressing and comprehending subjective emotions, the ability of individuals to express and interpret their own and others' subjective emotional messages varies, increasing the possibility of people making mistakes in the dimensions of expression and reception, ultimately leading to misunderstandings in communication.

Therefore, we proposed the "emotional barometer" (see Figure 3.1), a medium for user emotion mapping during the conversation. It aims to improve the level of understanding during the communication by introducing different physical dimensions.

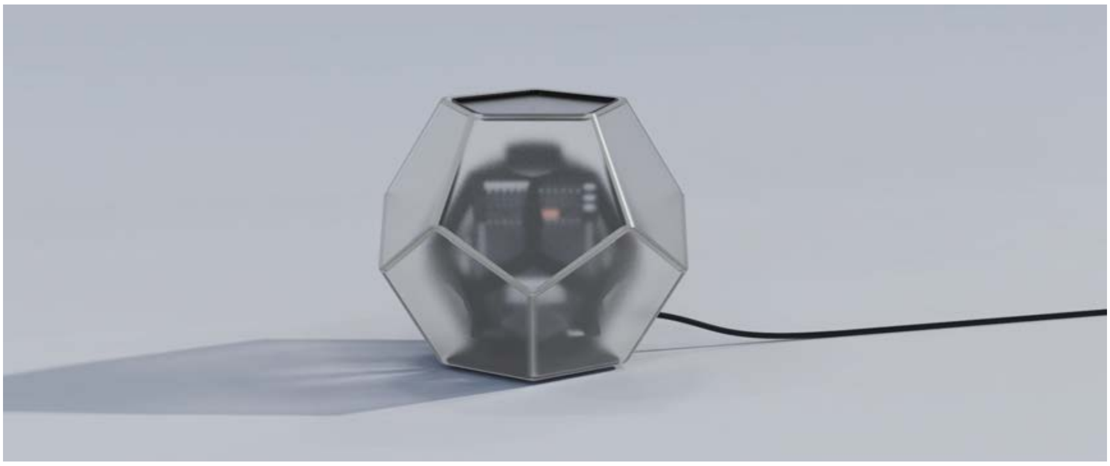


Figure 3.1 Rendering of Emotional Barometer

3.1.2 Emotional Barometer

" Emotional barometer " is a device that identifies people ' s emotional states by analyzing their voices. The voice analysis function is based on an existing emotion and conversation AI called Empath. It can analyze the quality and emotion of verbal conversations from audio files. It uses machine learning to evaluate emotions based on voice speed, intonation, and tone rather than the semantic content of words.

Interactions with the " emotional barometer " are explained in Figure 3.2. To begin with, the user needs to clap to the microphone placed on the top of the "emotional barometer" once. This behavior was set as a sign to start the "emotional barometer". When the object starts flashing rapidly, the user can start talking. The object will record 5 seconds of audio and perform real-time analysis. The result will show the user's current emotional state in the form of both light and vibration. It can detect five emotions, which are calm, anger, joy, sorrow, and energy. Each detected emotion corresponds to a color of light and a vibration pattern shown in Figure 3.2. We changed the frequency and intensity of the vibration to represent different emotions. For example, the vibration pattern corresponding to anger will be very strong and fast; sadness is slow and gentle; for energy, the vibration intensity and frequency tend to increase.

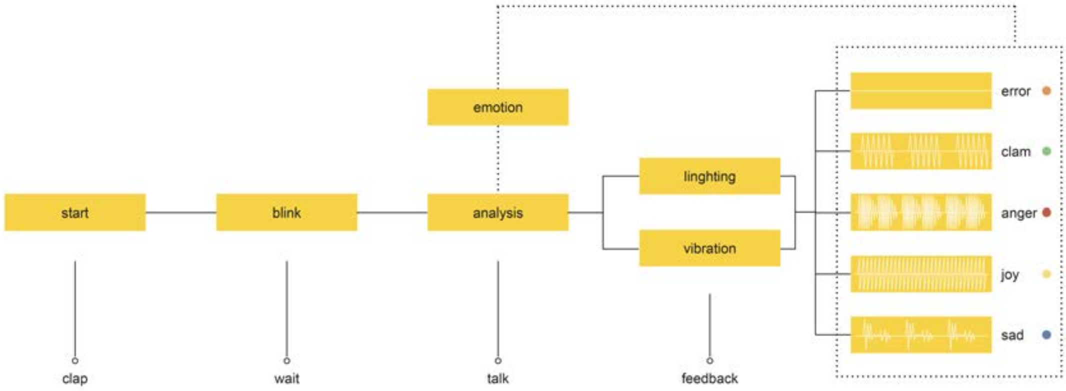


Figure 3.2 Interaction with the " Emotional Barometer "

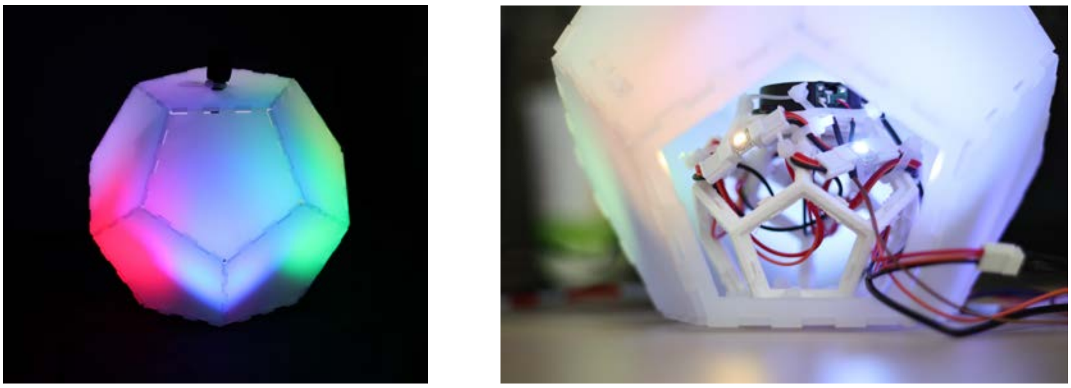


Figure 3.3 Prototype of Emotional Barometer

We conducted a user test using a fully functional prototype (see Figure 3.3) to observe behavior change while introducing an " emotional barometer " in user casual conversations. During the test, more than 30 people interacted with it within one hour and showed great interest. According to the observations, when one individual ' s emotions were decoded and expressed through lights and vibrations, others pay more attention to the emotional messages conveyed during the conversation. Also, people agreed to the correspondence of the colors and the vibration patterns to their emotional state. One problem noted was that the overwhelming presence of the device led to the topic of conversation being focused on the device itself.

3.2. What is Haptic Empathy

Inspired by the preliminary results from the user test, we believe that people can have a general perception of emotions through the sense of touch and can empathize through only haptic feedback. We define this ability to interpret a haptic stimulus and the entailing corresponding affective response as haptic empathy. Just like empathy, which is the ability to comprehend the emotions of others and to elicit those feelings in ourselves, we believe that haptic empathy can also be divided into two stages: Interpreting emotions from haptic sensations and elicit feelings through haptic feedback.

3.2.1 Interpreting Emotions through Haptic Feedback

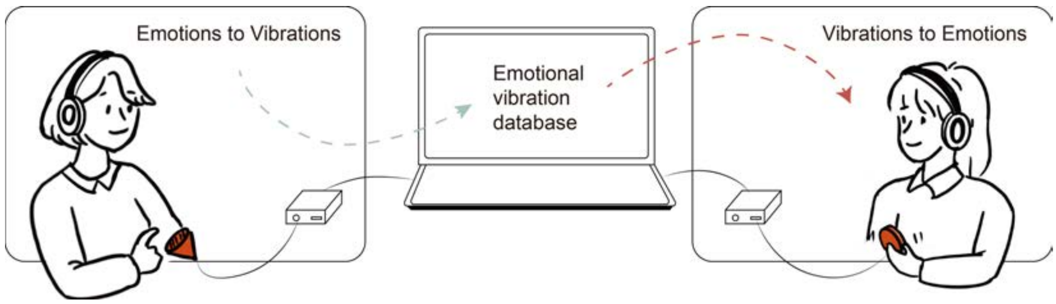


Figure 3.4 Concept of Haptic Empathy

Although many studies have shown that haptic feedback can convey certain emotional information, the conclusions vary depending on each study's encoding and decoding devices. Therefore, it is necessary to investigate how much emotion can be conveyed from one person to another with a much simpler setup. In other words, to test how much emotional meaning can be transferred using raw haptics alone. To this end, we designed an experiment using an existing haptic device called Techtile Toolkit [41]. The experiment can be divided into two major parts (see Figure 3.4): using vibration patterns to express certain emotions and recognizing emotions from recorded vibrations. Through the study, we aimed to understand the ability to interpret emotions through haptic feedback by investigating 1) whether people can express emotions through simple vibration feedback. 2) what emotions simple vibration feedback can convey as the emotional expressions of the sender.

3.2.2 Elicit Feelings through Haptic Feedback

We tried two approaches in our study to identify whether people distinguish the emotions based on the properties of vibration patterns or the haptic feedback elicits specific feelings. First, we attempted to detect human emotions using biological brain signals. In this case, we used Electroencephalography (EEG) to measure people ' s brain activity. Secondly, we asked participants how they identified the emotional information conveyed by vibration and asked them to describe how they feel during the experiment.

3.3. Pilot Test

We conduct a pilot study to 1) initially verify the existence of haptic empathy, 2) test the reliability of the haptic device used in subsequent experiments, 3) determine the applicability of the selected emotion theory, and 4) select a suitable approach for inferring emotional states.

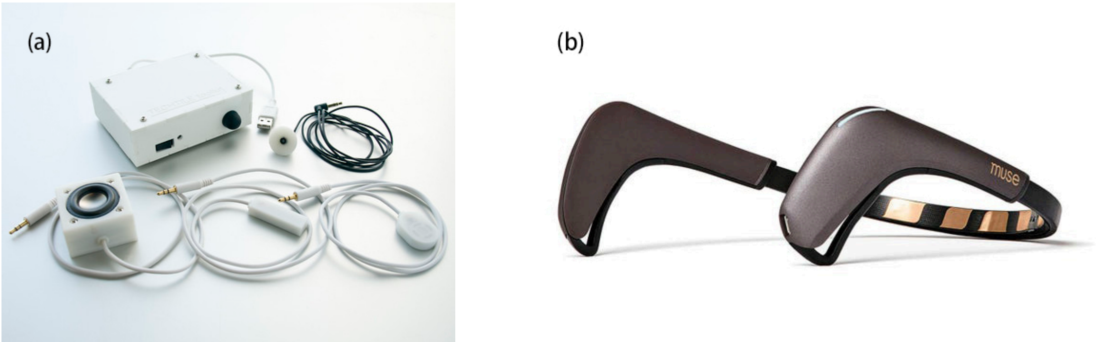
3.3.1 Method

Participants

Six graduate school students (2 males, 4 females) ranging from 24 to 30 years old (M = 24.83, SD = 2.71) participated in this experiment. Two of them were very familiar with the TECHTILE toolkit, and four of them never tried TECHTILE before. To remove emotional perception variations caused by cultural differences, all participants were Chinese. All the participants were students at Keio University ' s Graduate School of Media Design. No compensation was offered.

Materials and Apparatus

TECHTILE Toolkit [41] is an existing haptic device capable of recording and playback of vibrotactile patterns (see Figure 3.5 (a)). This device consists of a haptic recorder, a tactile display, and a signal transceiver. We used it to collect tactile sensations created by the participants and play the recordings back to them. Participants are able to share their experiences through this "create-record-play" process.



(Source: (a) TECHTILE toolkit, A prototyping tool for design and education of haptic media [41], (b) muse 2 website)

Figure 3.5 Experiment material: (a) TECHTILE tookit, (b) Muse2

Demographic Questionnaire A background information questionnaire was designed to collect participants' biological information (gender, age, and race) and general background of familiarity with haptic devices.

Vibrotactile Emotions Data Base All of the vibration trials used in this study are recorded from the participants when they were asked to express their emotions.

Muse 2 [1] (see Figure 3.5 (b)) is a multi-sensor wearable device mainly used to collect physiological data and provide white noise in this experiment. It can monitor brain activity, heart rate, breathing, and body movements. Once connected with Muse Meditation App, it can provide real-time feedback based on the physiological data to help users build a consistent meditation practice. When the device detects that the user is calm and settled, the user will hear peaceful weather. On the contrary, if the user's focus drifts, they will hear stormy weather.

1 Muse 2: `https://choosemuse.com/muse-2/`

Noise canceling headphones In order to avoid the experimental error caused by hearing the vibration sound, participants were asked to wear noise-canceling headphones during the experiment. Moreover, the white noise was generated by Muse Meditation App.

Emotion Referring to the Plutchik's emotion wheel introduced in section 2.1.1, we selected four basic emotions in this study: joy, anger, sadness, and fear. In addition, these four emotions can lead to a consistent shared understanding of emotions across linguistic and cultural contexts. This reduces the possibility of emotional comprehension errors due to the fact that our participants were all non-native English speakers.

Difficulty Rating Survey A self-report difficulty rating survey was designed to record how the participants felt about expressing or recognizing the four selected emotions by vibration. It used a 5-point Likert scale from 1 (extremely easy) to 5 (extremely difficult).

Testing Environment Several measures were taken to ensure a comfortable testing environment. Testing was performed in familiar environments with ample table space and mostly comfortable seating. The administrator was present during the testing to answer questions and record data, and sit with the participants.

3.3.2 Design and Procedure

Expression: Emotions to Vibration

The first session aimed at collecting vibration samples (see Figure 3.6). Each participant was first introduced to the "TECHTILE toolkit." Then participants were asked to try to express four emotions (joy, anger, sadness, and fear) without fixed order within a 10-second recording. To reduce the impact of the emotion fluctuations generated by the previous emotion expression on the latter sample, the interval between each sample recording was 30 seconds. At the end of this session, we asked the participants to select the difficulty level of expressing each specific emotion and further describe this experiment.

Figure 3.6 Session one - recording vibration samples

Recognition: Vibrations to Emotions

In the second session, we asked the same participants to distinguish the four selected emotions conveyed by each vibration sample. Three were six vibrotactile samples for each emotion collected from the first session, for 24 vibrotactile sets in total (including the samples participants created by themselves). All the vibrotactile samples were presented in random order using the "TECHTILE toolkit".

Participants were first asked to touch the surface of the tactile vibrator only with their fingers (see Figure 3.7). After feeling each sample, participants were asked to distinguish the emotions and describe the elicitation intensity. The interval between presenting each sample is 15 seconds. After 10 minutes break, participants were tested with the same samples by holding the tactile vibrator. At the end of this session, participants were asked to further describe the whole experiment.

For each trial, if the emotion the participant chose matched with the intended input emotion when the vibration sample was recorded, we considered the task to have an accurate result and marked it as 1; if the participant failed to identify the vibration sample representing the emotion type as the same as the intended input, we considered the task to be a false result and mark it as 0.

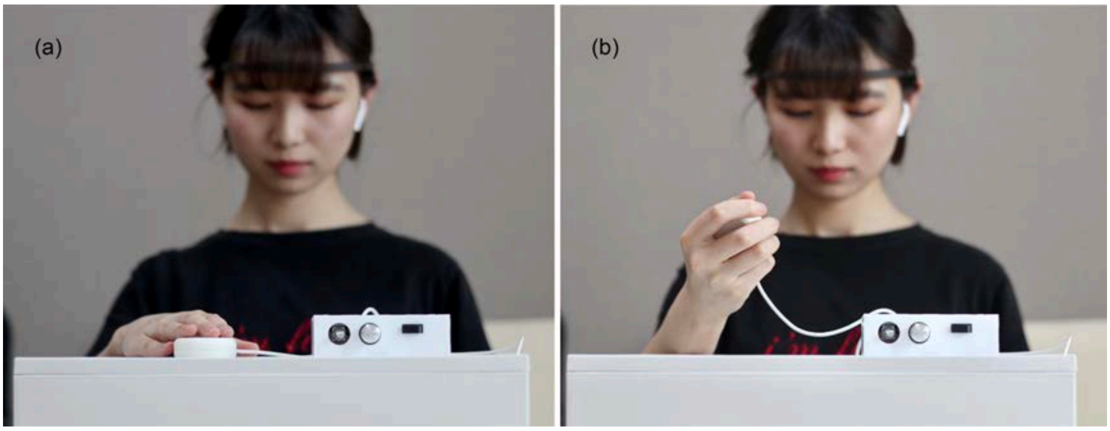


Figure 3.7 Session two - recognising emotions from recorded vibration samples

3.3.3 Results

The results for the first session are shown in Table 3.1. Five out of six people started from emotion “joy”. All the participants thought it is easy to express emotion “joy” through haptic modality and selected level 1 (simple). Most participants thought the most difficult emotion to covey among four basic emotions is “fear”.

Table 3.1 Experiment order and difficulty

	First		**Second**		**Third**		**Fourth**	
	Emotion	**Difficulty**	**Emotion**	**Difficulty**	**Emotion**	**Difficulty**	**Emotion**	**Difficulty**
P1	Joy	1	Sad	2	Anger	1	Fear	5
P2	Joy	1	Sad	1	Fear	1	Anger	2
P3	Joy	1	Sad	1	Fear	1	Anger	2
P4	Joy	1	Anger	1	Fear	3	Sad	4
P5	Sad	1	Joy	1	Anger	1	Fear	2
P6	Joy	1	Sad	3	Anger	2	Fear	5

In the second session of recognizing emotions by touching the surface of the tactile vibrator, because the noise-canceling headphones used by participants during the experiment did not achieve complete noise reduction, partially samples were not included in the sample for this data analysis. We discarded 24 samples and analyzed the remaining 72 samples. Among 18 test trials for each emotion (joy, sad, anger, fear) conveyed through vibration, there were 13 matched results for joy, 7 for anger, 5 for fear, and 3 for sadness (See Table 3.2). Based on that, the accuracy rate of joy was the highest 72.22%, followed by anger 38.89%, fear 27.78%, and sadness 16.67%. In the session of recognizing emotions by holding the tactile vibrator, participants were able to distinguish more emotions through vibration. There were 17 matched results for joy, 8 for anger, 6 for fear, and 5 for sadness. The accuracy rate of joy was still the highest 94.44%, followed by anger 44.44%, fear 33.33%, and sadness 27.78%.

It is worth noting that there are several anomalies in the data. E.g., Although most participants considered fear to be the most difficult emotion to express in terms of vibration, it had a higher accuracy rate than sadness when it came to recognition. Comparing the accuracy rate and difficulty level among four emotions, the more difficult emotions were perceived by participants, the lower the corresponding correct rate was. However, comparing the results of using two different gestures to feel the vibration, accuracy rate and difficulty are not positively correlated. Based on the data, participants generally thought it was harder to identify emotions through vibration by holding the tactile vibrator, but the results showed increased correctness. Also, no participant can identify the samples created by themselves, and no obvious data indicates that the experimenters have a higher accuracy rate when testing their samples.

Table 3.2 Accuracy and difficulty

	Surface			**Hold**		
Emotion	**Difficulty**	**Correct**	**Accuracy**	**Difficulty**	**Correct**	**Accuracy**
joy	1.93	13	72.22%	1.50	17	94.44%
sad	3.06	3	16.67%	3.61	5	27.78%
anger	2.71	7	38.89%	3.28	8	44.44%
fear	2.88	5	27.78%	2.89	6	33.33%
total	2.65	28	38.89%	2.82	36	50.00%

At the end of the pilot study, we asked the participants what skills they used in identifying emotions and how they felt about this experiment. Four of them mentioned that the vibration pattern of joy reminded them of musical beats. They tended to imagine an actual scene to bring in the vibration pattern. For example, one participant brought up that the vibration pattern of fear reminded her of an earthquake. In general, participants automatically endow the vibration with their particular mood. The results of these interviews implied that vibration patterns could trigger people's emotions.

3.3.4 Discussion

The accuracy rate of recognizing "joy" through simple vibration feedback is over 70%, and humans identify the emotional meanings conveyed by a haptic device at a rate 50%. This result indicated that humans could recognize emotions via haptic modality, and certain vibrations were more likely to elicit specific emotions compared to others.

Although from the data, participants thought it was harder to identify emotions by holding the tactile vibrator; based on the information collected from the interview, they felt it is easier to recognize emotions while holding the tactile vibrator. Besides, the accuracy rate is higher than only touching the surface of the vibrator. However, some other factors may cause some deviations during the experiment: participants may be exhausted due to long-term experiments, or learning effects may arise due to the familiarity with the system over multiple experiments.

Based on the pilot study, several parts need to be improved in the actual study. First, according to the feedback from participants, the wearable devices (muse 2) could easily lead to distraction. The study was interrupted by poor contact with the muse two several times during the experiment. Therefore, we will dispense with the use of muse 2 in our study. Second, we found that emotional fear was hard to be identified (accuracy rate 27.78%). We decided to change to a different theory of emotion and observe how people's behavior would change. In addition to the above two important changes, there are also some detailed adjustments, details explained in section 3.4.2.

3.4. Study One

The main procedure of the experiment is relatively similar to the previous one, although some details have been adjusted and improved by the conclusions drawn from the pilot study. The study was divided into two parts: using vibration patterns to express certain emotions and recognizing emotions from recorded vibrations.

3.4.1 Method

The goal of this experiment is to understand how an emotion can be transmitted between people using haptics. Firstly, we need to investigate whether vibrations can be used as a medium for emotions. Secondly, to investigate what emotions can be conveyed.

Participants

Seven graduate school students (3 males, 4 females) ranging from 24 to 30 years old (M = 26.00, SD = 1.91) participated in this study. Three of them were very familiar with the TECHTILE toolkit, one of them was mildly familiar with TECHTILE, and three of them never tried TECHTILE before. All participants were Chinese, and they were all students at Keio University ' s Graduate School of Media Design. No compensation was offered.

Materials and Apparatus

The following materials were the same as the instruments used in the pilot study: Demographic Questionnaire, Vibrotactile Emotions Data Base, Difficulty Rating Survey, TECHTILE Toolkit, and noise-canceling headphones. Muse 2 was not used in this study due to its disruption to participants.

Russell ' s dimensional circumplex model of affect was used to map emotions in the quantitative two-dimensional space of valence and arousal (see Figure 3.8). This experiment focused on four emotions: joy, anger, sadness, and relaxation (one for each quadrant). The emotions from the same quadrant might be challenging to distinguish, but the difference increases for emotions from different quadrants.

For instance, depressed and gloomy are close to sad but distinct from angry. We chose the four most basic emotions to avoid complications related to language barriers.

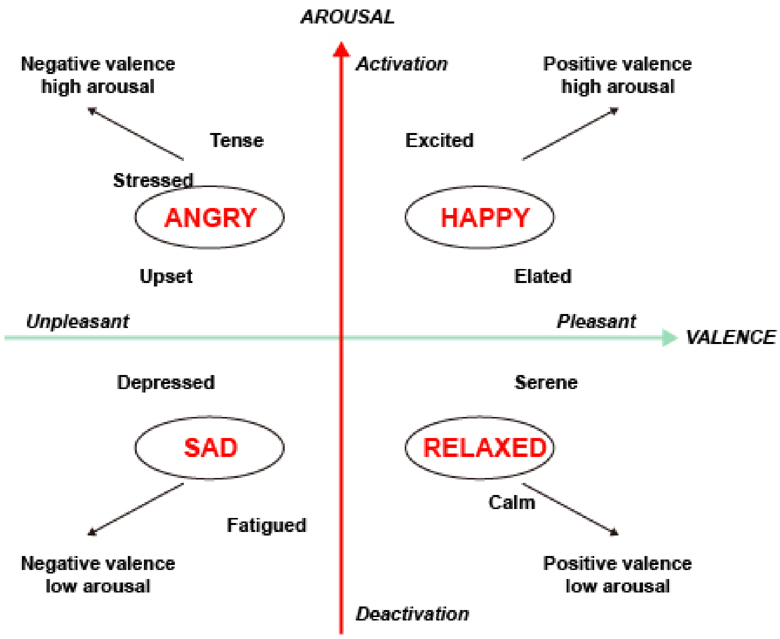


Figure 3.8 Russells-circumplex-model-of-affect

3.4.2 Design and Procedure

We first introduced the "TECHTILE toolkit" to the participants and conducted a practice trial before the official experiment. The participants were asked to create a 10-second vibration pattern by any means (e.g., tapping, rubbing, pressing, etc.). The same 10-second recording was then played back to them. The practice trials lasted for 3 minutes.

Expression: Emotions to Vibration

After the practice trials, the participants were asked to express four emotions (joy, anger, sadness, relaxation) within a 10-second recording (see Figure 3.9 (a)).

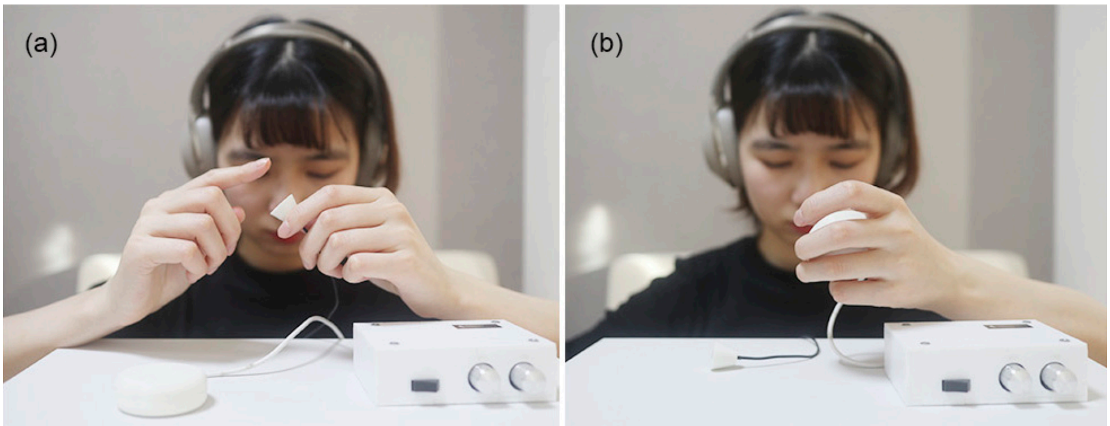


Figure 3.9 a) Experiment part one - recording vibration samples. b) Experiment part two - recognising emotions from recorded vibration samples.

For each trial, the researcher would verbally tell the participant the designated emotion and then allowed the participants to record no more than 10 seconds. After each recording, participants were allowed to check the recording and redo it if necessary. The interval between each sample recording was 60 seconds. At the end of this session, we asked participants how they felt about the task and whether they used any strategies to express their emotions via the haptic device.

Recognition: Vibrations to Emotions

In the second session, we asked the same participants to distinguish the four selected emotions conveyed by each vibration sample (see Figure 3.9 (b)). There were seven vibrotactile samples for each emotion collected from the first session, for 28 vibrotactile sets in total (including the samples participants created by themselves). We ranked the vibrotactile samples from 1 to 28 and used the random number service to play them back to the participants in random order. After each trial, participants were asked to rate from 1 to 5 how difficult it was to determine each emotion conveyed by vibration. The interval between presenting each sample was 15 seconds. After all the trials, participants were asked to provide a further description of the whole experiment. We asked the same question about how they felt about the task and whether they used any strategies to distinguish the emotions. At the end of this study, the researchers explained the purpose of this study to participants.

3.4.3 Results

This study linked four different emotions expressed and recognized through vibrations. One tail z-test was performed to test whether the accuracy rate was significantly higher than random results (1/4).

Table 3.3 Recognition of 4-Types-Emotion Vibrations Samples of 7 Participants

	All Trials (28) [i]			Own (4) [ii]		Others (24) [iii]		Recognized by Others (24) [iv]	
	Difficulty	**Correct**	**Accuracy**	**Correct**	**Accuracy**	**Correct**	**Accuracy**	**Correct**	**Accuracy**
P1	3.43	14	50.0%	1	25.0%	13	54.2%	14	58.3%
P2	2.79	15	53.6%	3	75.0%	12	50.0%	13	54.2%
P3	2.89	20	71.4%	4	100.0%	16	66.7%	16	66.7%
P4	2.18	18	64.3%	2	50.0%	16	66.7%	15	62.5%
P5	2.57	13	46.4%	2	50.0%	11	45.8%	11	45.8%
P6	2.46	20	71.4%	4	100.0%	16	66.7%	17	70.8%
P7	2.46	15	53.6%	2	50.0%	13	54.2%	11	45.8%
Average	2.68	16.22	57.91%	2.57	64.30%	13.86	57.74%	13.86	57.74%

[i] *All Trials*: All 28 emotional vibration files created by these 7 participants;
[ii] *Own*: The emotional vibrations created by this participant;
[iii] *Others*: The emotional vibrations created by others only– left out self input files;
[iv] *Recognized by others*: the emotional vibrations created by this participant and recognized by others.

Table 3.4 Mean Accuracy and Difficulty levels of the Recognition of 4-Types-Emotion Vibrotactile Emotion Samples

Emotion	All Vibration (n= 49)				Others' Vibration (n= 42)		
	Difficulty	**Correct**	**AR of All(M)**	**p-value**	**Correct**	**AR of Reg. Oths(M)**	**p-value**
Joy	2.31	35	71.4	$< .00001$***	31	73.8	$< .00001$***
Anger	2.67	32	65.3	$< .00001$***	31	73.8	$< .00001$***
Sad	2.93	23	46.9	0.0002***	17	40.5	0.0102*
Relax	2.91	25	51.0	$< .00001$***	22	52.4	$< .00001$***
Total	2.68	28.75	58.67	$< .00001$***	24.25	57.74	$< .00001$***

*p <.05, ***p <.001, *Population SD*=0.062
AR=Accuracy Rate, *M*= Mean, recognition accuracy values are in percent. *All Vibration*:all 49 tested trials. *Others' Vibration*:42 tested trials that excluded the self input ones.

Among 49 test trials for each emotion (joy, anger, sadness, relaxation) conveyed through vibration, there were 35 matched results for joy, 32 for anger, 25 for relaxation, and 23 for sadness (See Table 3.4). Based on that, the accuracy rate of joy was the highest 71.43%, followed by anger 65.30%, relaxation 51.02%, and sadness 46.94%. It is interesting to note several anomalies in the data. E.g., anger was sometimes confused with joy; however, joy was rarely confused with anger (see confusion matrix on Figure 3.10). The same holds true for anger-sadness and sadness-relaxation pairs. There was one participant who failed to choose any emotion for one of the anger vibration trials. That result was removed from the confusion matrix since it was not mistaken for any other emotions, yet remained as an incorrect result for the calculation. We can only speculate about the underlying reasons at this point. Further investigation of this phenomenon is required. For 28 tested trials, the accuracy rate for each participant ranged from 46.43% to 71.43% (Mean= 0.579; SD=0.095). See Table 3.3.

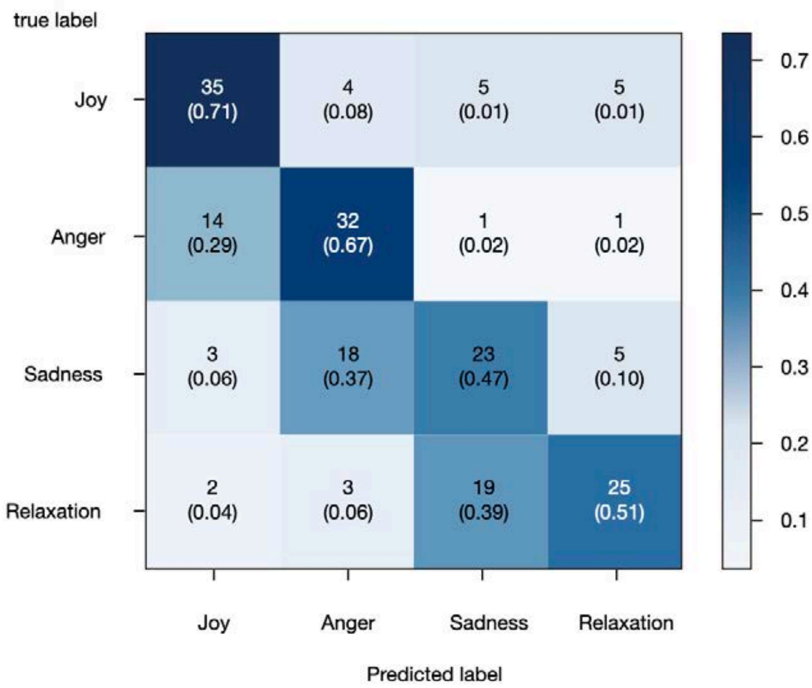


Figure 3.10 Confusion matrix for vibration patterns recognition.

Analysis showed that the vibration pattern recognition was significantly higher than chance. After performing z-test, all of the results for four emotions are significant at $p < .05$ (See Table 3.4). These results are based on counting all 28 feedback sets from each participant, including the four emotional vibrations trials created by themselves. Nevertheless, in the case of omitting self input emotional vibration trials, the accuracy rate did not differ much, as shown in Table 3.4 when n= 42. Performing z-test without including the recognition of participants' input, we still found the recognition of all four emotional vibrations was significantly higher than random results. All of the results are significant at $p < .05$.

Overall, because the p-value of all performed z-tests for four emotion recognition samples were still less than .05, we reject the null hypothesis. Therefore, we have sufficient evidence to say the emotions of anger, joy, sadness, and relaxation can be expressed and recognized by vibrations.

The average difficulty levels perceived by the participants for each emotion conveyed by vibration ranged from 2.31 to 2.93 (see as Table 3.4). The sadness and relaxation vibration trials were rated as more difficult to tell compared to anger and joy. This result matched the order of their accuracy rate for these four emotions. The perceived difficulty of recognition somewhat correlates with the correct recognition rate (R = 0.44, R square = 0.2, STDE = 0.601, significance = 0.0169). This would imply that the vibration patterns which were deemed confusing by the participants had a lower correct recognition rate. This may seem obvious, but such a finding supports the validity of the gathered data.

3.4.4 Discussion

The results of this experiment supported the hypothesis that vibration could be utilized as a medium for expression and recognition of four selected emotions - joy, anger, sadness, and relaxation. Some may think the general accuracy (46.9% - 71.4%) from the current result was not high enough; yet, according to a work testing emotion recognition in the face, voice, and body, the accuracy of these traditional emotion cues also averagely ranged from 56% to 70% [42]. If the current accuracy rate remains with a large sample, it would be interesting to explore how the haptic emotion cue can be comparable with those traditional emotion cues.

We also found joy and anger, compared with sadness and relaxation, were easier to both express and recognize through vibration. This tendency is also consistent with other studies on traditional emotion expression cues [42, 43]. There are also some cases that individuals who are bad at expressing one emotion through vibrations are relatively capable of expressing other emotions. There was one emotional vibration sample created by one participant, which received 0% accuracy in the study. The vibration file 25-joy was not recognized by any participants, including the creator P7. However, created by the same participant, the vibration file 26-anger was recognized by all 7 participants. The vibration file 11-sad was not recognized by anyone besides the creator P3, but all the other three emotional vibrations had relatively high recognition feedback (between 6 to 7). It would be interesting to see how well these individuals express those particular emotions in general and compare their performances with vibrotactile emotion feedback. A further research study with a bigger sample size may be needed to conclude more findings.

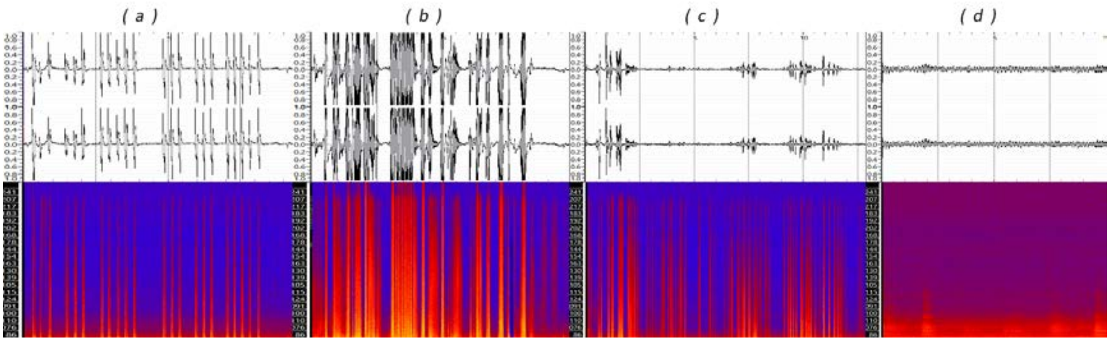


Figure 3.11 The waveforms and spectrograms of Four Emotional Vibrations from the database. (a) 9-Joy (AR=100%), (b) 26-Anger (AR=100%), (c) 3-Sadness (AR=57.1%), (d) 24-Relaxation (AR=100%). *AR*= Accuracy Rate of the sample file.

After performing a basic spectral and acoustic analysis of the recorded samples (See visualizations from SonicVisualiser in Figure 3.11 [2]) and found that certain rhythmic characteristics were associated with specific emotions.

2 Sonic Visualiser `https://www.sonicvisualiser.org/`

We picked the highest recognition rate file for each emotion in Figure 3.11 as an example. The top images are the waveforms, and the bottom images are the spectrograms. Similar patterns are shared across the highly recognized vibration files:

1. Joy - rhythmic patterns are mostly consistent and prominent. The rhythms tend to be more quantized than others.
2. Anger - rhythmic patterns are very prominent and constant. These patterns are more driving and abstract than joy.
3. Sadness - rhythmic content is sparse and tends to come in short patterns/gestures, with large sections of inactivity.
4. Relaxation - rhythmic content/density is quite sparse. The amount of rhythmic content is nearly non-existent.

Analyzing waveforms and spectrograms, we deduced that joy and anger share similarities in terms of rhythmic structure. These patterns tended to consist of dense clusters of rhythms interspersed with moments of inactivity. In joy, the rhythms were typically more consistent, whereas in anger the rhythms were noticeably more abstract and disjointed. Much like the relation of joy and anger, sadness and relaxation share similarities in rhythmic content. With these two emotions, the rhythmic content was quite sparse, with much of the waveforms containing large amounts of inactivity. In sadness were small clusters of rhythmic content. In relaxation, there were nearly no discernible rhythmic peaks. Apart from these two similar groups, we also found a connection between joy and relaxation in terms of rhythmic consistency. For example, the waveforms shown for joy and relaxation show that the activity is occurring in a mostly repetitive or consistent manner. On the other hand, anger and sadness were quite the opposite. These waveforms show rather inconsistent and varied rhythmic content. Though the other highly recognized sample files shared the patterns, since the sample size was small, more research will be necessary.

The relation of haptic interpretations of emotions was most identifiable between joy and anger, as well as sadness and relaxation, in regards to rhythmic density. In addition, the rhythmic variation of these waveforms showed connections between joy and relaxation, as well as anger and sadness. Further study will be needed to determine what these connections fully imply and how these connections can be utilized for further studies.

3.5. Study Two

This study was conducted to further investigate the characteristics of haptic empathy, such as individual differences in haptic empathy, the probable links between haptic empathy and other emotion-related abilities (refers to emotional capability and empathy quotient in this study).

3.5.1 Emotional Competence (EC)

The idea of Emotional Competence (EC), often known as Emotional Intelligence (EI), refers to how people deal with intrapersonal and interpersonal emotional information [44]. In more specific terms, it refers to the way each individual identifies, understands, expresses, regulates, and uses their emotions, and those of others [45, 46]. Emotion-related individual differences have been conceptualized into three levels: knowledge, abilities, and traits [46, 47]. The knowledge level relates to people's understanding of emotions. The ability level refers to what people are capable of and their capacity to apply knowledge in an actual situation. In terms of the trait level, it describes what people typically do in emotional situations. The self-reported measure of empathy [22] used in this study, the Short Profile of Emotional Competence (S-PEC) [48], focuses on the trait level.

3.5.2 Empathy Quotient (EQ)

Empathy is an essential ability that enables people to sense how someone else is feeling or what they might be thinking. It allows people to comprehend other people ' s intentions, predict their behavior, and experience emotions triggered by other emotions. It is hard to define and measure this concept. Research in this field has been divided into two camps: affect theory and cognitive theory [22]. The affective approach defines empathy as feeling an appropriate emotion triggered by another ' s emotion. And cognitive theories empathize that empathy involves understanding the other ' s feelings. Leach, M C [22] believes that empathy consists of both the affective and cognitive components and proposed a self-assessment instrument, the Empathy Quotient (EQ), for use with adults of normal intelligence.

3.5.3 Method

Participants

Same participants from study 1 (3 males, 4 females) ranging from 24 to 30 years old (M = 26.00, SD = 1.91) participated in this study. All participants were Chinese, and they were all students at Keio University ' s Graduate School of Media Design. All participants had sufficient English reading levels to complete the study. No compensation was offered.

Materials and Apparatus

Participants were sent a questionnaire by google form and were instructed to complete it on their own, as quickly as possible, and to avoid thinking about responses too long. The questionnaire consists of two parts: a self-reported measure of emotional capability and a self-reported measure of empathy. Both of the questionnaires were validated. Details are explained below:

The S-PEC is a short version of The Profile of Emotional Competence (PEC) [49], which measures ten dimensions (identification of own emotions, identification of others ' emotions; understanding of own emotions, understanding of others ' emotions; expression of own emotions, listening to others ' emotions; regulation of own emotions, regulation of others ' emotions; use of own emotions, use of others ' emotions) loading on two higher-order factors: intrapersonal EI and interpersonal EI, forming together a single EI score. Because the S-PEC has just two items per subscale (for a total of 20), subscale ratings may be inaccurate. However, the validation process of the questionnaire [48] showed that it is sufficient to use a shorter version for the factor scores.

Empathy Quotient (EQ) is a self-assessment instrument that consists of 60 questions (40 questions that test empathy and 20 filler items). The 40 items describe empathic behavior in both affective and cognitive terms. A person can score 2, 1, or 0 on each empathy item, giving the EQ a maximum score of 80 and a minimum score of 0. The validation process of the questionnaire was conducted by two studies with 287 subjects (study 1, n=90; study 2, n=197), indicating that the EQ measured empathy. Since our participants were all Chinese, we used the English version of the questionnaire along with the official Chinese translation [3].

3.5.4 Results

Table 3.5 Empathy Quotient Score and Emotional Competence Score (PEC subscales and factors) for individuals

		P1	P2	P3	P4	P5	P6	P7	Mean	SD
Empathy Quotient		17	54	46	50	47	28	52	42.0	14.0
Intrapersonal CE	Identification	9	10	10	10	8	8	8	9.0	1.0
	Expression	7	7	8	10	8	5	8	7.6	1.5
	Comprehension	6	7	8	9	10	8	9	8.1	1.3
	Regulation	7	6	6	9	8	9	10	7.9	1.6
	Utilization	9	8	8	10	6	4	6	7.3	2.1
Interpersonal CE	Identification	6	10	8	8	9	8	9	8.3	1.3
	Expression	6	10	9	9	8	8	10	8.6	1.4
	Comprehension	5	10	9	7	9	7	7	7.7	1.7
	Regulation	5	7	9	7	8	6	7	7.0	1.3
	Utilization	7	5	7	9	6	6	6	6.6	1.3
Factors scores	Intrapersonal CE	38	38	40	48	40	34	41	39.9	4.3
	Interpersonal CE	29	42	42	40	40	35	39	38.1	4.7
Global score	CE Global score	67	80	82	88	80	69	80	78.0	7.4

To tally the results, we used the scale's scoring guidelines. The table 3.5 gives detailed scores of Emotional Competence and Empathy Quotient for each individual. To investigate correlations among haptic empathy, EC, and EQ, we first drew scatterplots of all variables (see Figure 3.12). From the scatterplots, we can see that some linear relationship appears among pairs of variables, such as

3 Translated by Qing Zhao, School of Applied Psychology, Griffith University, Brisbane, Australia `https://www.autismresearchcentre.com/tests/empathy-quotient-eq-for-adults/`

express and recognize, EC and EQ, inter and EQ, etc. It indicates that the vibrotactile emotion samples collected from people who are better at recognizing emotions from vibrations also had a higher recognition rate by other participants, and there is some linear relationship between EC and EQ.

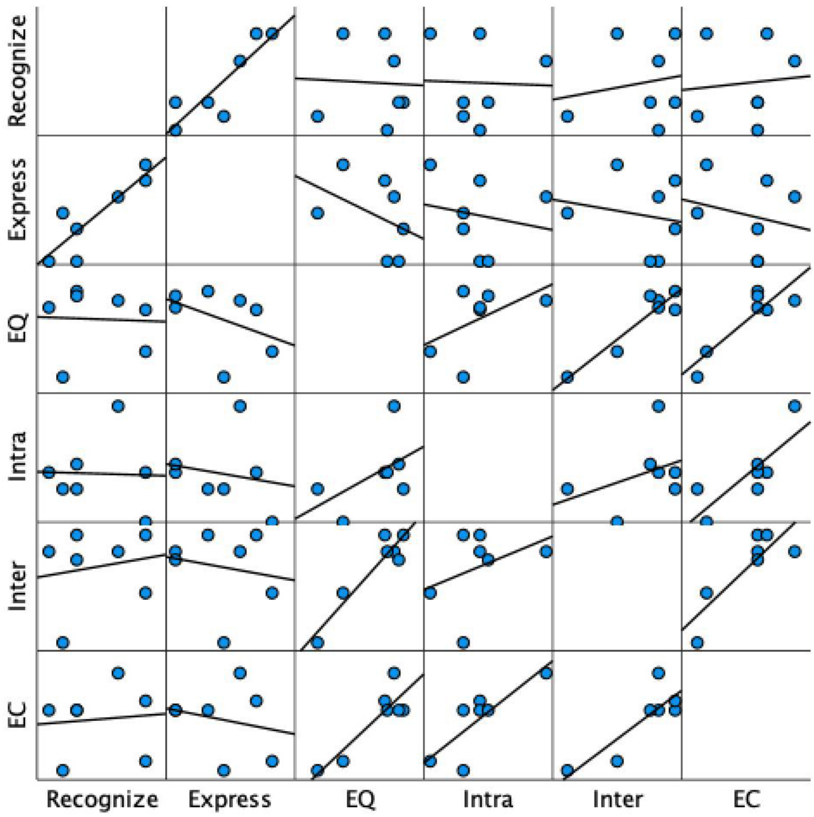


Figure 3.12 Scatterplots

To further determine whether there is statistical evidence for a linear relationship among the same pairs, we used the bivariate Pearson Correlation in this study, and the results were listed in table 3.6. Based on the results, we can state that recognize and express have a statistically significant linear relationship (r = .877, p < .001). Regression also shows that the accuracy rate of being recognized by other participants (Express) correlates with the accuracy rate of recognizing vibration patterns (Recognize) (R = .877, R squared = 0.769, significance = 0.0096). In other words, people who are better at recognizing emotions are also better at expressing emotion through vibrations. However, we have to recognize the low number of participants (n=7) and the ensuing consequences.

From the table, we can also see some other correlations appear between EQ and interpersonal factor ($r = .938$, $p < .001$), EQ and EC ($r = .887$, $p < .001$), intrapersonal factor and EC ($r = .813$, $p < .005$), and interpersonal factor and EC ($r = .847$, $p < .005$). However, we could not conclude from the available data that haptic empathy is related to EQ or EC.

Table 3.6 Correlations

	Mean	**SD**	**Recognize**	**Express**	**EQ**	**Intra**	**Inter**	**EC**
Recognize	58.7	10.3	1					
Express	57.7	9.8	.877**	1				
EQ	42.0	14.0	-0.045	-0.421	1			
Intra	39.9	4.3	-0.034	-0.186	0.516	1		
Inter	38.1	4.7	0.181	-0.179	.938**	0.378	1	
EC	78.0	7.4	0.095	-0.219	.887**	.813*	.847*	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Recogniz: Accuracy rate of recognize all the emotional vibrations *Express*: Accuracy rate of the emotional vibrations created by this participant and recognized by others. *EQ*: Empathy Quotient *Intra*: intra-personal competence *Inter*: inter-personal competence *EC*: Emotional Competence

3.5.5 Discussion

We do not have sufficient evidence that people who have a deeper understanding of emotions (higher score of EC), or who empathize more easily, also have a better ability to empathize through haptics. The possible reasons for this result are the following. First, and most importantly, the small sample size resulted in our inability to collect enough evidence to test our hypothesis. Secondly, the emotional capability scale (S-PEC) used in this study focused on people's trait levels rather than their understanding of emotions. The three levels of EI are loosely connected: knowledge does not always translate into abilities, which, in turn, do not always translate into usual behavior [50]. That is, haptic empathy might be used to help a broader variety of people, such as people with autism better understand and feel their emotions.

3.6. Haptic Empathy System

While exploring the scenarios of using haptic feedback to express emotions, we concentrated on emotion education and tried to introduce tactile feedback techniques to teach children emotions. We believe that learning emotions through only the visual modality is not enough, and based on our previous experimental findings, haptic technology has great potential to help people express and identify emotions. Therefore, based on the concept of haptic empathy, we proposed Haptic Empathy System.

3.6.1 System Description

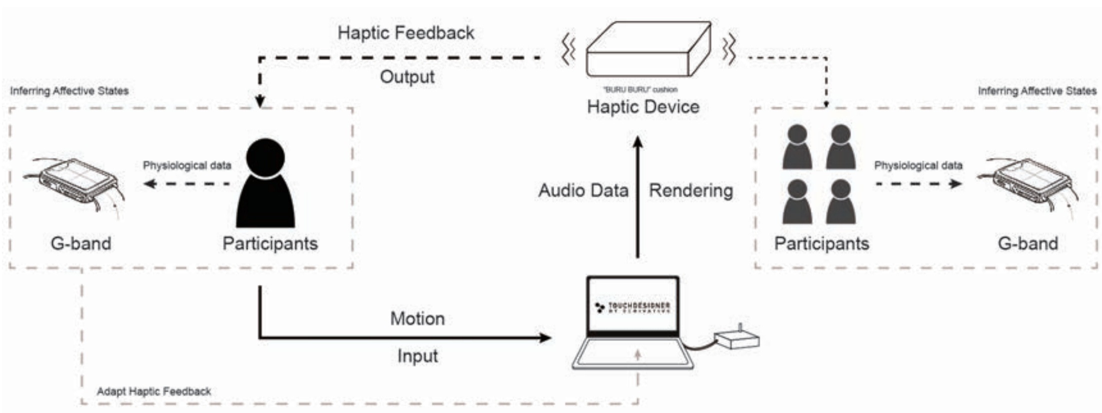


Figure 3.13 System description

Instead of a one-way learning approach (learning emotions through picture books), we attempted to introduce an interactive system by promoting children to create their own emotional vibration patterns. We aimed to help them express and understand emotions in a simpler and more creative way by embodying emotions. The system (see Figure 3.13) can be divided into three parts: express emotions, share emotions, and feel emotions. Given that children cannot create precise vibration patterns through Techtile Toolkit, we promote them using their body language to express emotions. After we capture their body movements, we converted motion data into audio waveforms, then display it in the form of vibration using the Buruburu cushion [51]. In addition, we included physiological signals in this system to help infer different affective states of autistic children. And we also attempted to adapt the haptic feedback based on children's ongoing affective states.

3.6.2 Design of Physiological Data Acquisition Unit

In order to achieve both physiological data (heartbeats, EDA, and the LF/HF ratio related to the heart rate variability) and motion data collection, we used a custom-designed smart wristband [52]. The device was designed to be worn on the wrist, measuring EDA from two electrodes on the fingers and heart rate using an optical blood volume pulse sensor. However, the current version was hard to wear (see Figure 3.14 (a)), especially for autistic children. Therefore, we redesigned its appearance while leaving the hardware unchanged (see Figure 3.14 (b)). The design process was shown in Figure 3.15.

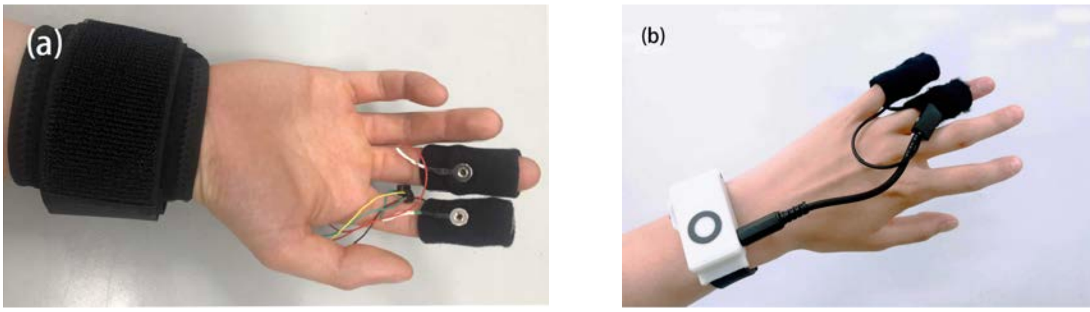


Figure 3.14 (a) Previous version of wristband with electrodermal, heart activity, acceleration and gyro sensors, (b)Redesigned version

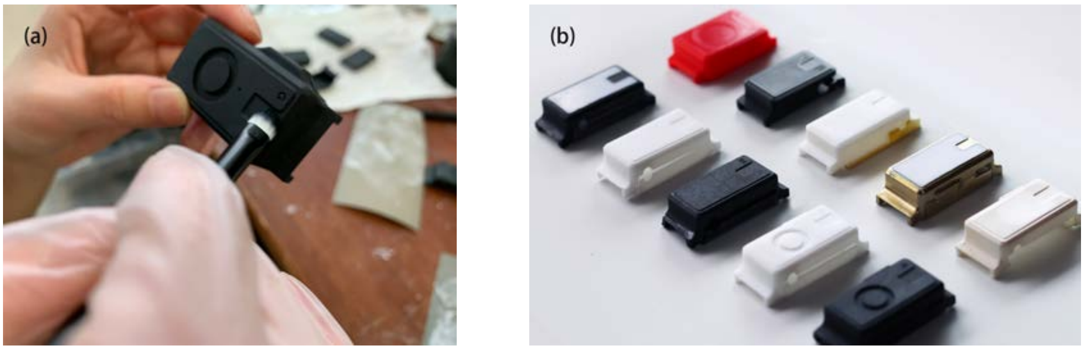


Figure 3.15 (a) Prototyping, (b) Several prototype iterations

3.7. Summary

In conclusion, the results of the studies show reasonable support for the concept of haptic empathy. It can be suggested that 1) people can share subjective emotions through simple vibrotactile feedback; 2) people who are better at recognizing emotions from vibrations are better at expressing emotions through a haptic device; 3) people have certain common understandings about haptic interpretations of emotions.

For further concept development, it was deemed necessary to verify it on larger numbers and different populations. So as discussed further, the preparations and design of an emotion education toolkit for young children have started.

Chapter 4
Emotions Embodiment for Children with Autism

To develop our concept and generalize our finding to individuals with autism, we collaborated with the Tokyo Metropolitan Rinkai District Special Support School[1] and Miraikan (The National Museum of Emerging Science and Innovation)[2] since August 2020. All participants are students with the Intellectual Disability Certificate (Ai-no-Techo) from Tokyo Metropolitan Rinkai District Special Support School. Tokyo Metropolitan Government issues the "Ai-no-Techo" to those with an intellectual disability due to some reason during their developmental period (under 18 years of age), which causes considerable inconvenience in their daily lives and requires welfare considerations. Children diagnosed with autism spectrum disorder only will not be issued with the "Ai-no-Techo".

During their elementary school year, the school divides students into Group A and Group B for instruction according to their level of impairment. Students in Group A receive courses corresponding to severe multiple disabilities and intellectual disabilities. Students in Group B receive courses corresponding to autism spectrum disorder. For middle school students, students are combined and receive all three courses. Here we refer to them as Group C.

1 https://www.kyoiku.metro.tokyo.lg.jp/en/list/special_needs/intellectually_disabled.html

2 https://www.miraikan.jst.go.jp/en/aboutus/

4.1. Pre-design Session

4.1.1 Ideation Session

In the early stage of this project, we conducted four ideation sessions (see Figure 4.1) in the Cyber Living Lab with project managers from Miraikan and the school teachers. We discussed the possibilities of applying haptic technology to autistic children and listed three main directions: enriching tactile experience, promoting communication among children, and promoting physical activity. Realizing that it may be difficult for children with autism to learn emotions using only the visual modality, such as facial expressions, we hypothesized that haptic technology has great potential to help them express and identify emotions. In addition, some research [53] suggests that proper tactile feedback can motivate and improve performance and works as a learning tool for individuals with autism. Therefore, this work aims to promote their communication by enriching their tactile experience and developing devices that help them understand and express their emotions.

Figure 4.1 Ideation session: (a) brainstorming, (b) demonstrating Techtile Toolkit

4.1.2 Fieldwork

We conducted three workshops at Tokyo Metropolitan Rinkai District Special Support School. Workshop details and information about participants are shown in table 4.1) and the classroom environment is shown in figure 4.2. Consent was obtained from children, parents, and the school. Before the official workshop, schoolteachers conducted two practice trials for each group, following the same procedure and using the same content and equipment (cushion without vibration). This fieldwork aimed to understand children's behavior better and help children adapt to haptic technology in advance. We also conducted two semi-structured interviews with schoolteachers and coordinators before and after each workshop.

Table 4.1 Basic information of the fieldwork

Group	Date	Location	Participants
A	2020/11/4	classroom	First-year students in primary school (N = 21)
B	2020/11/10	gymnasium	First-year students in middle school (N = 10)
C	2020/11/17	gymnasium	Second-year students in middle school (N = 14)

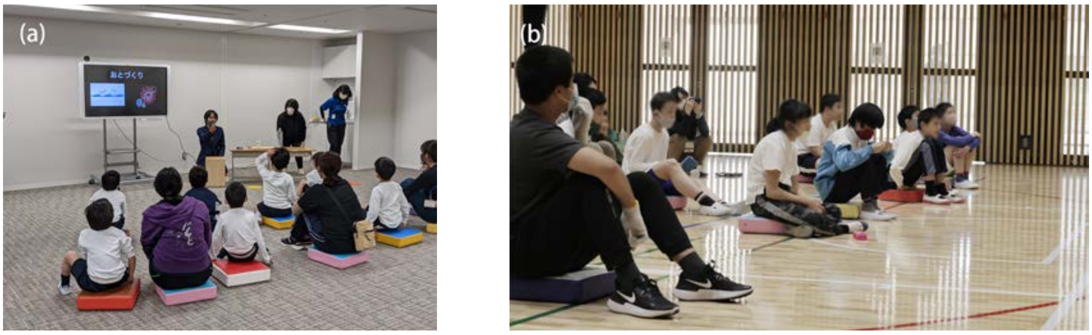


Figure 4.2 Experimental scene: (a) in the class, (b) in the gymnasium

Materials and Apparatus

We provided two existing haptic devices, "Kinder BURU BURU cushion" [51] and "Techtile Toolkit", during the workshops. "Kinder BURU BURU cushion" is a vibrotactile cushion that aims to grab children's attention during storytelling time. The picture books used during the workshops were licensed by the authors and publishers. Three digital video cameras were used to record workshops. The footage collected from this workshop was used for academic research purposes only; it was not and will not be shared with any third parties.

Procedure

The design of the workshop was based on the existing teaching model. Each workshop lasted for 30 minutes. The flow of the three workshops remains unchanged from the usual, as shown below.

1. Introduction (5 mins): The coordinators guided each student to sit on the "Kinder BURU BURU cushion" and introduced the workshop organizers to the participants.

2. Warm-up (5 mins): The schoolteacher showed the video of " haptic gymnastics " on the screen and guided participants to warm up by imitation.

3. Storytelling (10 mins): The schoolteacher used a screen to show the picture book and played the corresponding vibration feedback through " Kinder BURU BURU cushion " while reading the picture book.

4. Free activity (10 mins): After the schoolteacher demonstrated how to use Techtile Toolkit and instruments to create vibrations, 3-4 participants volunteered to imitate what the schoolteacher did and try to create vibrations. Then all participants were divided into three groups according to their impairment level to experience different tactile promoting devices.

Observation

During the workshops, four researchers were present. Three of them were responsible for coordinating the workshop process and had direct interaction with the participants. One of them was present to observe and had no interaction with the participants. The excessive concerns of researchers had been observed among a few participants, but the majority of participants were able to focus on the tasks. Moreover, no participants showed abnormal behaviors such as panic or resistance from participants due to engaging with new facilities during the workshop. During the storytelling session, participants showed a great interest in the cushion. The behaviors observed included attempting to flip the cushion and feel the vibration with their hands or face. Nevertheless, the vibration noise from the cushion and sound played by the cushion was too loud for participants. Two to four participants in each workshop were covering their ears with their hands at some point. During the last session, some participants were observed to tap along with the vibrotactile beats made by the TECHTILE toolkit and tend to share how their cushion vibrates. Overall, participants showed great interest in using the TECHTILE toolkit to explore different vibrations and expressed interest in using the cushion to share vibrations.

Feedback from Schoolteachers

An unstructured interview with schoolteachers was used to gather additional information about the participants. The feedback from schoolteachers is shown below:

- One of the main characteristics is that subtle changes in the environment could easily lead to pressure and anxiety in children. Therefore, it is necessary to practice beforehand with a similar procedure and equipment.
- Some individuals seemed to be somewhat scared during the workshop, but there was no panic or anxiety noted. The majority of children exhibited a positive attitude towards the "BURU BURU cushion" and "TECHTILE toolkit".
- Children's concentration was improved with haptic feedback, and they can stay seated for a longer time. Furthermore, children developed their interest in creating vibration through the "TECHTILE toolkit".

4.2. Design Process

Through fieldwork, participants had a relatively high acceptance of the tactile devices and did not panic. Based on the positive feedback from workshops, we believe that adding vibration aspects for emotion education may benefit children with autism in understanding emotions.

Instead of designing a technology that can "fix" people, we aimed to build a co-learning system for children with autism to augment their natural abilities to recognize and express affect. We aim to use vibration stimulation to 1) help the child scaffold different representations of emotion, 2) promote them to create and express their emotions in many ways. We hypothesize that this kind of vibrotactile communication allows children with autism to share their emotions more easily, and the "vibrolanguages" can even be a fun way to improve the understanding of emotions.

4.2.1 Design Requirements

Based on the discussions with teachers and fieldwork observations, Requirements for the prototype design can be concluded as follows.

- The device needs to be portable for young children to use.
- The shape of the device could reference items that children are familiar with, such as a ribbon wand.
- Use simple inputs and outputs to avoid the high costs of learning.
- Since visual sensations are dominant in the majority of children, and it is preferable to use different colors in the design to assist children in distinguishing between emotions.
- Avoid wearable devices.
- The external design should take into account safety issues and prevent inappropriate or potentially dangerous use such as throwing devices.

4.2.2 System Adaptation

Integrating our concept of haptic empathy and the design requirements collected from fieldwork, we proposed a system to embody emotions for autistic children (see Figure 4.3). This system can be divided into three parts: express emotions, share emotions, and identify emotions. Given that children cannot create precise vibration patterns through Techtile Toolkit, we promote them using their body language to express emotions. After we capture their body movements, we converted motion data into audio waveforms, then display it in the form of vibration using the Buruburu cushion [51].

Since we already introduced a new device in this study, using multiple new devices at the same time may cause a distraction for children with autism. In particular, introducing wearable devices is a big challenge in autism research. It required several attempts to get children with autism comfortable and accepting the new objects in their environment. Considering the time limitation and the schoolteacher's advice based on the students' actual situation, we did not use wearable devices in our workshop.

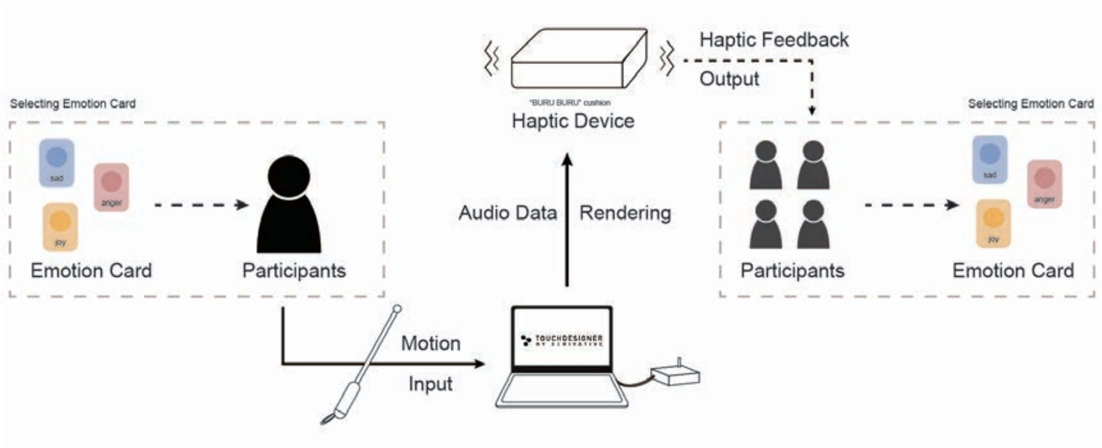


Figure 4.3 System adaptation

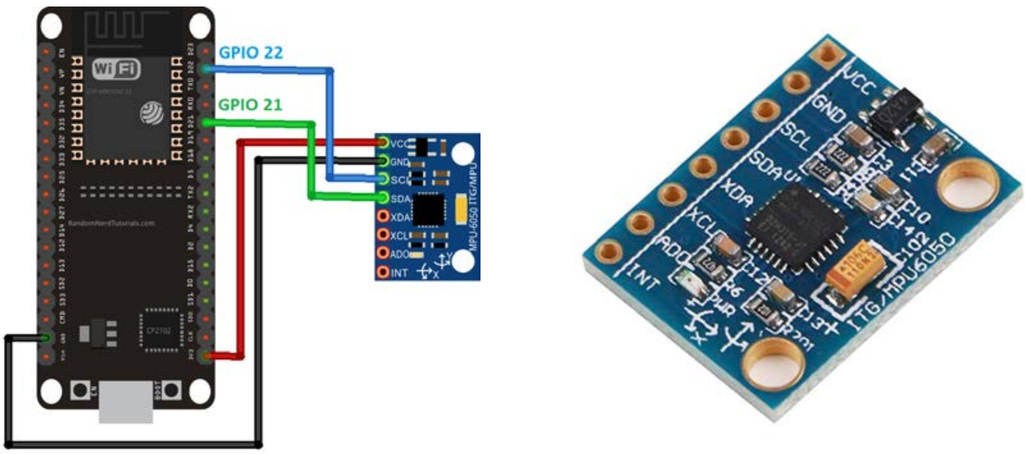
4.2.3 Prototyping

Hardware Design

We used an inertial measurement unit (IMU) MPU6050 controlled by the ESP32 module to capture the motion. MPU6050 includes both, 3-axis accelerometer and a gyroscope. IMU provides data on acceleration and changes in angular velocity, thus providing sufficient information about the movement and child's activity. As shown in Figure 4.4 [3], The device included two IMUs, one in the handle and the other in the tip of the wand. IMUs were polled at 50HZ frequency and were sharing one I2C bus. After the proof-of-concept implementation and

3 Schematic Diagram – ESP32 with MPU-6050 https://randomnerdtutorials.com/esp32-mpu-6050-accelerometer-gyroscope-arduino/

ensuring that the system can capture and stream motion data, we re-designed the hardware to allow battery power, battery charging, and miniaturization of the electronics. PCB designs were done in Diptrace and firmware was written using Arduino framework[4] shown in Figure 4.5.



(Source: random nerd tutorials)

Figure 4.4 Interfacing ESP32 with MPU6050

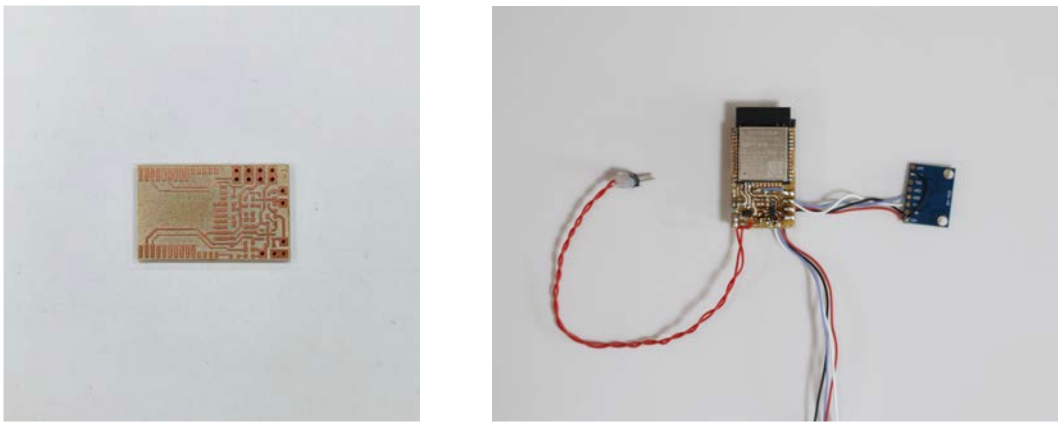


Figure 4.5 Redesigned PCB

4 Diptrace `https://diptrace.com/`

Haptic Design

We used TouchDesigner to convert motion data into audio data as shown in Figure 4.6. In order to stream the IMU data from the device to TouchDesigner, we used the WiFi capabilities of the ESP module. On the TouchDesigner side, data was received through Data Operators (or DATs). It is used to hold text data that is later on parsed into numeric values. Then we used Math CHOP and Limit CHOP to filter the data stream and normalize the data. We used a mathematical model to recognize one specific gesture at the same processing stage – raising the hand vertically upwards and rendered it separately. Given that the final output is audio data, we used the processed motion data to render a neutral sound in real-time. The speed of the movement was mapped to both the frequency and volume of the sound. In the end, the audio stream was fed out through an Audio File Out CHOP to the audio interface. All the data was recorded with standard TouchDesigner functionality. Audio Spectrum CHOP was used to monitor the frequency spectrum of the output channels.

Product Design

From the design perspective, we have followed two basic principles of designing for autism: simplicity and robustness [53]. According to an autistic-led theory [26], autism is defined by a single-minded attentional system, which means that they prefer to take in one information source at a time. Therefore, in order to avoid interfering with their ongoing tasks, we minimized the details in the design and chose white as the color of the main part of the product (see Figure 4.7). For the ribbon part, we used red, yellow, blue, and green, four colors corresponding to the mood, as a reminder for children. Also, in the shape of the design, we referred to their everyday items and hidden the technology from view.

In addition, we also considered the inappropriate usage in the wild – repeated switching off the device, repeated touching, banging, licking, or hitting the device. Therefore, we used metal and 3D printed material (resin) for the outer casing to ensure its robustness; white leather and wool for the outer layer to avoid any sharp and dangerous parts being exposed. A cover that can only be screwed open was designed at the bottom, and the switch and battery are fixed hidden in it to prevent inappropriate usage.

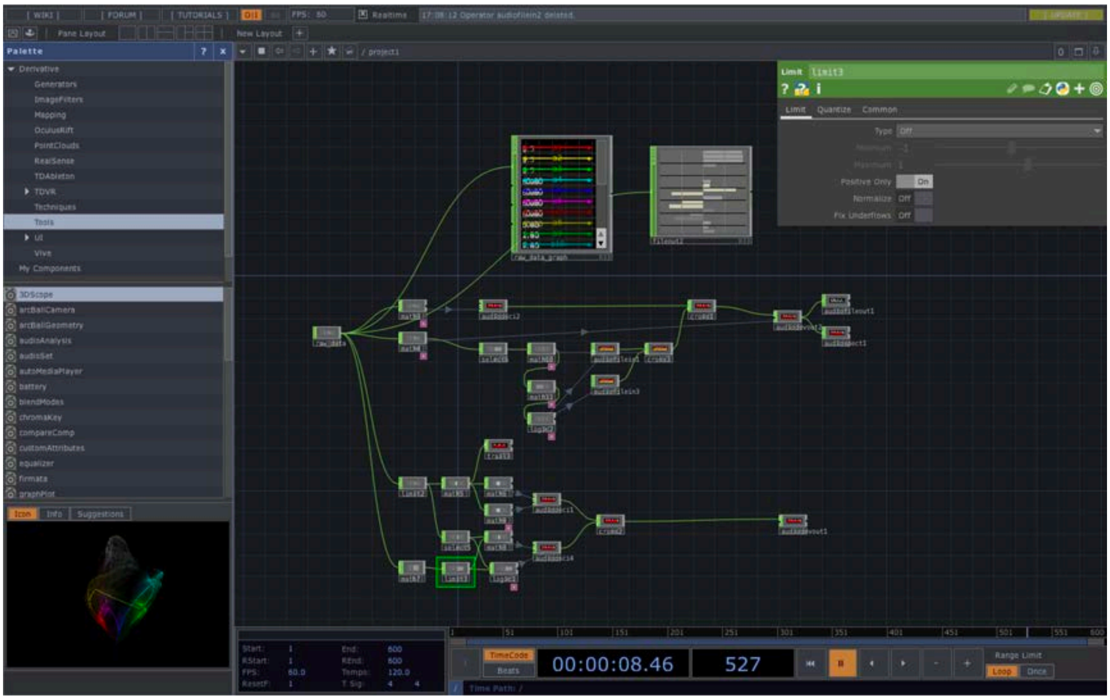


Figure 4.6 TouchDesigner Patch for audio data rendering

4.3. Workshop Design

Many studies related to children with autism [53] have confirmed that autistic children often show low tolerance towards novel technology, devices, or contexts, but repetitive exposure helps to improve their tolerance. As we introduced new devices and contexts in the workshop, the school conducted two desensitization sessions for each group to get children comfortable and accepting. In desensitization training, the school used the same contexts as in the final workshop, as well as a normal ribbon wand similar to the device used in the workshop. After the final workshop, the school conducted one more session, the same as the desensitization session. In summary, we referred ABA design method to measure children's behavior before the intervention, during the intervention, and once the intervention is removed.

Figure 4.7 Final prototype

4.3.1 Workshop Content

(Source: The Color Monster: A Story About Emotions (Used by permission))

Figure 4.8 The Color Monster: A Story About Emotions

Research [54] suggested that emotion recognition becomes easier for children with autism when they use cartoons instead of photographs of real faces. Thus, we used a children's picture book, The Color Monster: A Story About Emotions, as the content of the workshop (see Figure 4.8). The story is about a little girl who helped a colorful but confused monster sort out its emotions. In the book, all the different colored feelings are separated and put into glass jars to convey that feelings can be managed and are containable. We followed the background of this story and guided children to identify emotions in the same way, as follows (see Figure 4.9):

1. One child stands in front of the whiteboard and tells the class about the feeling he or she wants to express.
2. The child needs to pick up the corresponding emotion card from the whiteboard and put it into a glass jar.
3. Standing in front of the whiteboard and using the wand to convey the chosen emotion.
4. Children sitting on the cushion need to identify which emotion was expressed and select the right emotion card.

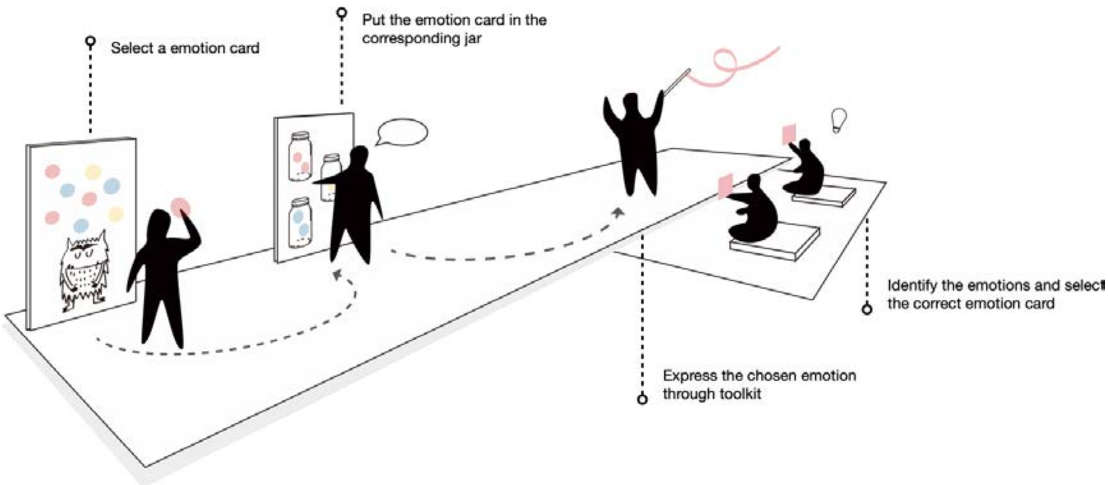


Figure 4.9 Workshop content

4.3.2 Procedure

Table 4.2 Basic information of workshop

Group	Date	Location	Subjects
A	2021/3/3	classroom	first-year students in primary school (N = 10)
B	2021/3/3	classroom	first-year students in primary school (N = 10)
C	2021/3/2	hallway	first-year students in middle school (N = 8)

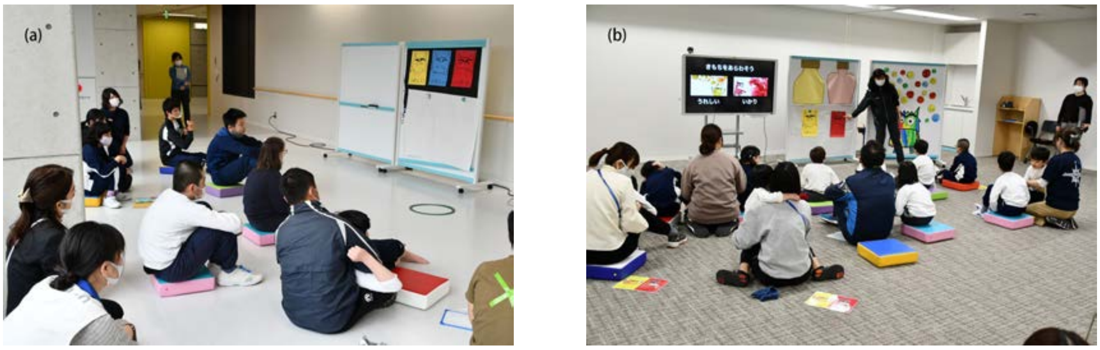


Figure 4.10 (a) Workshop scene in the hallway, (b) Workshop scene in the class

The workshop was conducted once for each group, three times in total. The basic information of the workshop is shown in Table 4.2and the class environment is shown in Figure 4.10. The first workshop was held on March 2nd, 2021, at Tokyo Metropolitan Rinkai District Special Support School from 13:05-13:35. Two more workshops were conducted on March 3rd, 2021, at the same place from 9:50-10:55 (30 minutes for one workshop). Based on the results of the fieldwork, we kept the main structure of the workshop and only changed the content of each session to avoid confusion for the children. The procedure of the workshop is shown below:

1. Introduction session (5 mins): the mentors gathered all participants in the audiovisual room and guided them to sit on the Kinder Buru Buru Cushion. To begin with, the schoolteacher briefly introduced the workshop topic and flow to participants and then introduced workshop organizers and researchers.

2. Warm-up session (5 mins): the schoolteacher guided participants to do the haptic gymnastics twice as a warm-up activity.

3. Storytelling session (10 mins): the schoolteacher read the picture book of the Color Monster to participants and helped them identify emotions through colors.

4. Demonstration (5 mins): the schoolteacher led the first five minutes and gave instructions regarding emotional expression. Details were explained in session 4.3.1

5. Directed activity (10 mins): 3 participants were selected to present in front of the class. They were taught to imitate what the schoolteacher did in the last session and created vibration patterns.

6. Free activity: participants were divided into two groups. The mentors supported participants in using the wand correctly and gave orders such as "it is your turn" and "try to wave on it".

4.4. Results

4.4.1 Observation

Device Acceptance Level

During the workshop, two participants from the primary school group refused to sit on the cushion. One participant from the middle school group showed strong resistance and refused to participate in the workshop.

Group A

In the desensitization session, it was found that the children had difficulty distinguishing between the four emotions, so only two emotions (joy, anger) were used during the workshop. Six children (P1 $\sim$ P6) were asked to identify and express both emotions. When expressing joy, children's movements are divided into two main types. P1, P2, P3, and P5 waved the device in circles, with a large swing

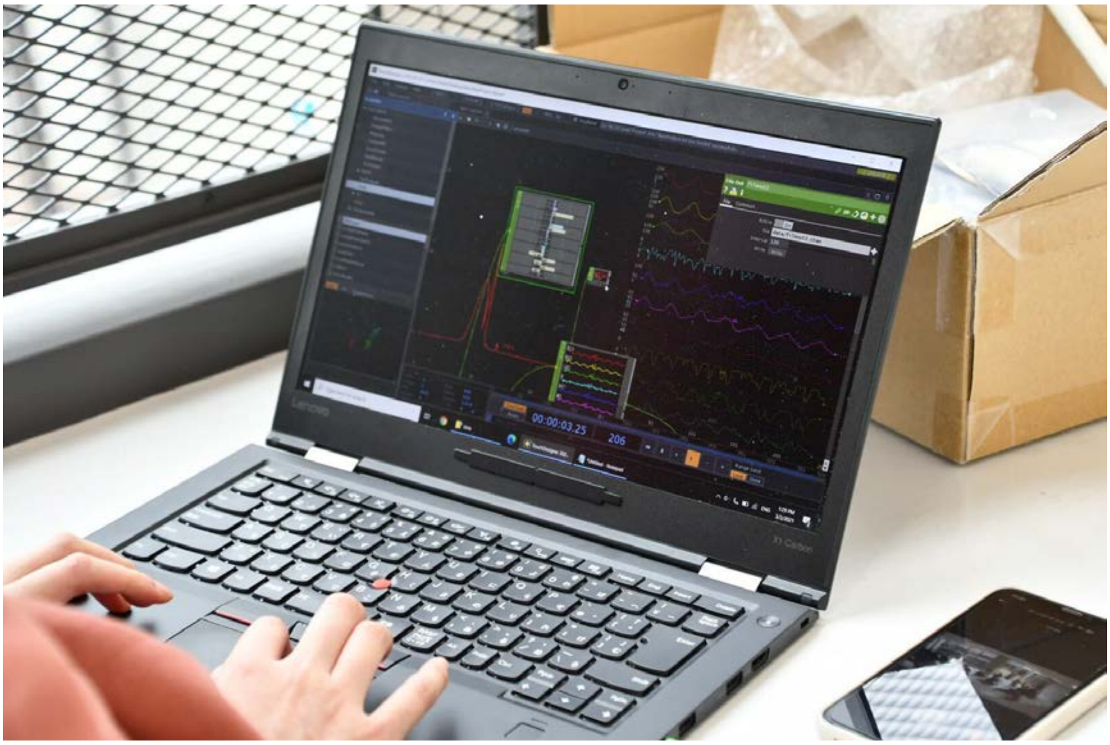


Figure 4.11 Data collection by TouchDesigner

and relatively gentle speed. P6 also expressed joy by waving the device in circles but with a slight swing. P4 expressed the emotion of joy in a form that is more different from others. In the beginning, P4 waved the device in an up and down pattern with a tiny amplitude and a big amplitude from left to right.

Behaviors that express anger are more diverse than the high degree of consistency in the expression of joy. Compared to waving in circles while expressing joy, children's movements were more linear. P1 waved the device more heavily and intensely. P2 and P6 both stomped the floor while waving the device up and down. P4 and P5 expressed themselves more intensely as she swung and bounced simultaneously to the rhythm. P3 had a completely different way to express anger, which involved making furious noises with his mouth rather than vigorously waving the device.

As for the children sitting on the cushion, their reactions were diverse compared to Group one and Group three. When the cushion started vibrating the first time, four children immediately felt confused and started checking the cushion. After a few minutes, one child started to smile and respond to the teacher's questions. At the same time, one child found the vibrating cushion insufferable and refused to keep sitting on the vibrated cushion. When P1 started to express anger, one child covered up her ears to avoid the sounds made by the cushion because of the more intense sounds and vibrations. The same thing happened again when P2 was expressing anger. Moreover, as the workshop proceeded, the number of children who covered their ears increased. Three children showed this behavior. After the mentors stopped them doing it, this behavior did not recur in the subsequent workshop. Throughout the workshop, one child repeatedly showed a refusal to sit on the cushion.

Group B

In this group, only three emotions (joy, anger, and sadness) were used during this workshop. A total of five children (P1 $\sim$ P6) tried to express their feelings through the device, and each was asked to choose two different emotions to express. All children are able to use different actions when expressing two different emotions. Four children (P2, P3, P4, and P5) selected the emotion of joy, and they all waved the device in circles to express joy. In addition to this, P5 was jumping happily while waving the equipment happily. While expressing anger, all children (P1, P2, P5, and P6) exhibit the same behaviors. They waved the device up and down heavily and stomped the floor. While expressing sadness, each child (P1, P3, P4, and P6) swung the device slowly. It is worth noting that when the children expressed their feelings, they did not just use the device, but their other body movements became more abundant., such as bowing their heads and stamping their feet. At the same time, they also made an effort to convey such emotions through facial expressions. All behaviors implied that they were pretending they were in this affective state.

Group C

Same as Group B, only three emotions (joy, anger, and sadness) were used during this workshop. We observed and recorded the behavior of eight children (P1 $\sim$

P8) using the device to express their emotions. P1, P5, and P7 chose joy, and their actions appeared similar: P1 waved the device briskly; P5 swung the device substantially in the pattern of drawing a cross in the air; P7 not only swung the device andante but also was shaking his head. Only P2 and P8 expressed the emotion of anger, and they both swung up and down the device vigorously. P3, P4, P6, and P8 waved the device much slower when expressing sadness with a smaller amplitude. P8 was asked to show two different emotions (angry and sadness), and we found a clear difference in her behavior.

During the workshop, all children sitting on the cushions were able to identify what emotions were depicted. Although most children were able to give feedback, three children were easily distracted by their surroundings. One child swung his body to the rhythm of vibration while P1 was using the device.

Summary

Overall, we can draw three conclusions from observations. Firstly, children can distinguish basic emotions and express them in different forms. There is a clear difference in the vibration patterns generated by each child when expressing two different emotions. Moreover, the features of these vibration patterns (rhythm and frequency) all overlap somewhat with the emotional vibration patterns we found in previous studies. Secondly, when the emotional haptic toolkit was used, it elicited more body movements and richer facial expressions than when the emotion cards were used only. In addition, we also observed that the children made eye contact with the mentors several times after they felt the vibration. Finally, we observed that the children would respond differently to different vibrations they felt. In particular, when they felt the vibration of anger, a few children showed fear and scared. And they prefer to follow the beat and wiggle their bodies when they sense the vibration of joy. Although children nearly always accurately identified the emotion conveyed through vibration by picking the emotion card, the possibility of being visually guided is very high. However, their different responses to different vibrations implied that they could perceive the different messages conveyed by the vibrations.

4.4.2 Feedback from the Teacher

We conducted an unstructured interview with schoolteachers after each workshop. And after all the workshops were completed, we consulted teachers who specialized in special needs education to gain more insights. The feedback from schoolteachers is shown below:

Primary School Teacher

- Through the first few workshops (fieldwork), children were already familiar with the Buru Buru cushion and showed interest in it.
- It was difficult for children to express and recognize emotions through vibration. The understanding of emotional haptics required a contextual story.
- The children showed interest in using the wand to express emotions. But some children may fully comprehend what they are required to do in order to express emotions.
- Because of the sound emitted by the cushion itself, most of the children's attention was drawn to the sound itself. This led to a situation where the children did not listen to the teachers.
- The children noticed the process of feeling the vibrations through their own actions (waving the wand) to others. In other words, the children understood the transmission of emotions on a certain level by expressing figurative emotions through vibrations.

Middle School Teacher

- Similar to the children in the primary group, there were problems with excessive attention to vibration or sound.
- The children became more involved in the class compared to the class with no intervention (no vibration).
- Without vibration, children tended to imitate other people's behavior; with vibration, children tended to interact based on their own understanding.

However, the variability of the children's behavior decreased with vibration was added.

Teacher who Specialized in Special Needs Education

- Lack of indicators to measure children's understanding of emotions.
- Need to observe the children's daily behavior by the schoolteachers and compare how the behavior changed before and after the workshop.
- It is a good attempt to encourage children to express their emotions freely without defining the right or wrong way to express emotions.
- Compared to students in regular schools, the difference of haptic experience among children in special needs schools is big. Based on the feedback from children, introducing haptic technology into daily instruction was a good starting.

4.5. Summary

To generalize our findings to individuals with autism, our study lasted six months. Based on the fieldwork, we have some knowledge of the challenges children are facing. To design and evaluate our technology, we have followed design guidelines for using innovative technology to aid children with autism. We utilized multiple sessions to explore the role of haptic technology in the emotional education of children with autism.

Initial results indicate a high level of acceptance and interest in haptic technology among children, which is a good sign. Although we lacked indicators to show that children better understood emotions after the intervention, there is no doubt that the emotional haptic toolkit increased their desire to express themselves and promoted more physical activity. Our findings further suggest that children have their own perception and understanding of emotions and attempt to express them through body language. In addition, from the responses given by children to the vibration, we believe that our technology was making a difference in helping autistic children improve their social, educational, and learning skills.

Though the early results of this work have shown the potential of utilizing our theoretical basis as an educational tool for autistic children, there may be some possible limitations that could be addressed in future work. First of all, to improve our device, the sound generated by the cushion easily distracted children and led to some discomfort. This will be the main problem to overcome in our future work. In addition, we made a compromise in not using the physiological data we proposed in section 3.6.2, which leave us with limited data to collect. We believe that if we can collect the data about children ' s real-time affective states and adapt the haptic feedback to it, it may have greater potential to keep the children engaged, help them learn, or attain mastery in specific tasks.

Chapter 5
Conclusion

As discussed in the first chapter, this thesis presents an attempt to employ a human-centered design approach to the development of novel practices, methods, and applications in haptic research. This work is an attempt to bring a new perspective and shift the focus from machines to humans since the focus of current haptic research seems to be more biased towards the engineering aspects rather than human factors and particularities of human perception, especially related to affective touch. Within the present work, the change of the angle that we approach research problems in the field of haptics has resulted in some interesting findings and proposals of the Haptic Empathy theory. According to the results of the studies described in Chapter 3, it seems that people possess an intrinsic ability to express and perceive emotional connotations through simple vibrotactile patterns.

Although this theory indeed brings more questions than answers, it may be an interesting angle for future works in haptic research. We still do not know why certain people are better at recognizing and encoding emotions into vibrations. We do not know whether this ability is innate and what are cultural and other aspects may influence it. But the spectral analysis of the produced haptic waveforms supports that there are many similarities between patterns created by different subjects for the same emotion. Implying that there is some common understanding of how certain emotions should "feel". However, there is no definite answer on where this commonality stems from. On the other hand, if confirming one hypothesis leads to more questions than answers, it only highlights that the hypothesis was interesting and implies progress for the whole field of study. Also, it demonstrates the usefulness of a different perspective on the subject matter.

After several studies demonstrating support for Haptic Empathy, there was a clear need for a proof of concept application, which resulted in utilizing the proposed concept for emotional education. Workshops, alongside the results and findings, are discussed in Chapter 4. Workshops were held in a school for children with special needs. The main goal is to attempt to utilize the proposed approach and the theoretical basis as an educational tool. Although in order to hold such a workshop, certain compromises had to be made, they are understandable considering the particularities of the workshop participants. So some measures had to be taken to accommodate the needs of autistic children.

We aimed to help autistic children understand and express their emotions by embodying them through haptic technology. Our early findings suggest that haptic technology is well-received by children with autism, which is a promising indication. There is no doubt that after using the emotional haptic toolkit, children wanted to express themselves and became more physically active. It indicates that interactive technologies have the potential to keep the children engaged, help them to learn, or attain mastery in specific tasks. Although there are some limitations in our current study, we believe that our concept was making a difference in helping autistic children improve their social, educational, and learning skills.

As discussed above, conceptualizing the ability to communicate and perceive the emotional meanings through vibrotactile stimulation as Haptic Empathy indeed raises many questions about the nature of the phenomenon. Such as the old and omnipresent in the field of psychology, nature vs nurture question. Is the Haptic Empathy innate, or is it learned? How does it relate to other psychological aspects of human emotions? These unknown variables significantly limit the design of applications for this concept. However, on the other hand, they open new horizons for further research. Some of the limitations that were encountered were outlined in the description of the workshop.

Aside from conceptual limitations, it is important to highlight that this work uses only vibrotactile actuation, which is only a fraction of what our somatosensory system can perceive. Nevertheless, it is rather fascinating that using just a fraction of our perceptive resources. We could demonstrate inspiring and promising results. What could be the results if more haptic modalities are employed remains to be seen.

Another limitation of this work is the need to perform validation on non-autistic children. It is hard to argue for the applicability of the designed tools for neurotypical children without a trial. Such a trial was planned, however, due to time restrictions and COVID-19 related difficulties, it has to be omitted in this work.

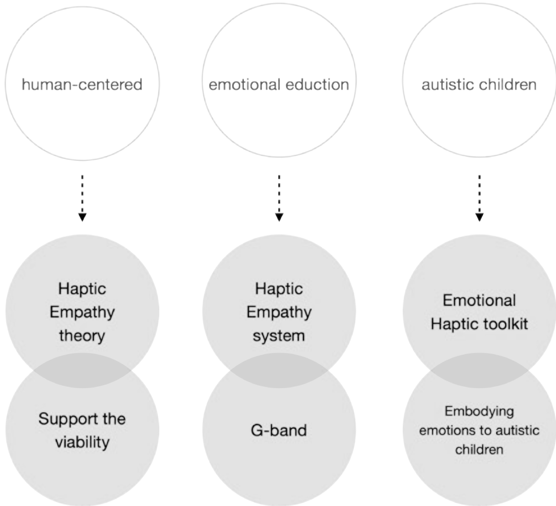


Figure 5.1 Contributions of this work

The contribution of this work can be discussed in three main aspects (see Figure 5.1). The main contribution is bringing a new, more human-centred design approach to tackling the questions in the field of haptic research, especially the branch concerned with emotion communication through haptics. The proposed name for this concept is Haptic Empathy. This work demonstrates several studies showing support for the viability of the proposed conceptual framework. For example, the ability of a subject to create vibrotactile patterns containing emotional meaning and extracting the emotional contents of such patterns made by other study participants.

Another important contribution is the tools designed for the educators of young children relevant to emotional education. The Haptic Empathy system explored the potential of introducing haptic technology in emotion education. Such an application of haptic technology can indeed bring fruitful results. However, further investigation on this matter is needed.

Moreover, we utilized the proposed approach and the theoretical basis as an educational tool for children with special needs. The results indicate that our technology was making a difference in helping autistic children improve their social, educational, and learning skills.

As mentioned several times above, the concept of Haptic Empathy indeed opens very interesting questions related to its nature that each deserves a separate publication. Further investigation and more clarity related to the concept are needed. One future prospect is matching the Haptic Empathy to some more grounded and defined variables, such as personality traits well defined in the field of psychology or physiological data well described in the fields of medicine and neuroscience. Another direction is continuing to develop the educational tools to be used for young children related to their emotional education. As was mentioned, more workshops and more data are needed for a more definitive validation of such an application.

References

[1] Mohamad A Eid and Hussein Al Osman. Affective haptics: Current research and future directions. *IEEE Access*, 4:26–40, 2015.

[2] Mohamad Eid, Mauricio Orozco, and Abdulmotaleb El Saddik. A guided tour in haptic audio visual environments and applications. *International Journal of Advanced Media and Communication*, 1(3):265–297, 2007.

[3] Cati Vaucelle, Leonardo Bonanni, and Hiroshi Ishii. Design of haptic interfaces for therapy. *Conference on Human Factors in Computing Systems - Proceedings*, pages 467–470, 2009. doi:10.1145/1518701.1518776.

[4] David Watson, Lee Anna Clark, and Auke Tellegen. Development and validation of brief measures of positive and negative affect: the panas scales. *Journal of personality and social psychology*, 54(6):1063, 1988.

[5] Edward L Levine, Xian Xu, Liu-Qin Yang, Dan Ispas, Horia D Pitariu, Ran Bian, Dan Ding, Roxana Capotescu, HongSheng Che, and Simona Musat. Cross-national explorations of the impact of affect at work using the state-trait emotion measure: a coordinated series of studies in the united states, china, and romania. *Human Performance*, 24(5):405–442, 2011.

[6] Rafael A Calvo and Sunghwan Mac Kim. Emotions in text: dimensional and categorical models. *Computational Intelligence*, 29(3):527–543, 2013.

[7] Pieter MA Desmet and Paul Hekkert. Framework of product experience. *International journal of design*, 1(1):57–66, 2007.

[8] Robert Plutchik. The nature of emotions: Human emotions have deep evolutionary roots, a fact that may explain their complexity and provide tools for clinical practice. *American scientist*, 89(4):344–350, 2001.

[9] James A Russell. A circumplex model of affect. *Journal of personality and social psychology*, 39(6):1161, 1980.

[10] Klaus R Scherer and Harald G Wallbott. Evidence for universality and cultural variation of differential emotion response patterning. *Journal of personality and social psychology*, 66(2):310, 1994.

[11] Zoltán Kövecses. *Metaphor and emotion: Language, culture, and body in human feeling*. Cambridge University Press, 2003.

[12] M. A. Eid and H. Al Osman. Affective haptics: Current research and future directions. *IEEE Access*, 4:26–40, 2016. `doi:10.1109/ACCESS.2015.2497316`.

[13] Tampereen Yliopisto, Grigori Evreinov, Leena Vesterinen, Antti Nyman, Jalo Kääminen, Jarno Jokinen, and Deepa Vasara. vsmileys: Imaging emotions through vibration patterns. 01 2005.

[14] Troy McDaniel, Shantanu Bala, Jacob Rosenthal, Ramin Tadayon, Arash Tadayon, and Sethuraman Panchanathan. Affective haptics for enhancing access to social interactions for individuals who are blind. pages 419–429, 06 2014. `doi:10.1007/978-3-319-07437-5_40`.

[15] Young-Woo Park, Kyoung-Min Baek, and Tek-Jin Nam. The roles of touch during phone conversations: long-distance couples' use of poke in their homes. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 1679–1688, 2013.

[16] H. Seifi, K. Zhang, and K. E. MacLean. Vibviz: Organizing, visualizing and navigating vibration libraries. In *2015 IEEE World Haptics Conference (WHC)*, pages 254–259, 2015. `doi:10.1109/WHC.2015.7177722`.

[17] Yongjae Yoo, Taekbeom Yoo, Jihyun Kong, and Seungmoon Choi. Emotional responses of tactile icons: Effects of amplitude, frequency, duration, and envelope. In *2015 IEEE World Haptics Conference (WHC)*, pages 235–240. IEEE, 2015.

[18] Jocelyn Smith and Karon MacLean. Communicating emotion through a haptic link: Design space and methodology. *International Journal of Human-Computer Studies*, 65(4):376–387, 2007.

[19] Jeremy N Bailenson, Nick Yee, Scott Brave, Dan Merget, and David Koslow. Virtual interpersonal touch: expressing and recognizing emotions through haptic devices. *Human–Computer Interaction*, 22(3):325–353, 2007.

[20] David Bonnet, Mehdi Ammi, and Jean-Claude Martin. Improvement of the recognition of facial expressions with haptic feedback. In *2011 IEEE International Workshop on Haptic Audio Visual Environments and Games*, pages 81–87. IEEE, 2011.

[21] R Sutton and A Barto. The diagnostic and statistical manual of mental disorders, iv. *Washington, DC: American Psychiatric Association*, 1994.

[22] Simon Baron-Cohen and Sally Wheelwright. The empathy quotient: an investigation of adults with asperger syndrome or high functioning autism, and normal sex differences. *Journal of autism and developmental disorders*, 34(2):163–175, 2004.

[23] Katharine Blocher and Rosalind W Picard. Affective social quest. In *Socially intelligent agents*, pages 133–140. Springer, 2002.

[24] Sue Fletcher-Watson and Geoffrey Bird. Autism and empathy: What are the real links?, 2020.

[25] Peter Mundy. A review of joint attention and social-cognitive brain systems in typical development and autism spectrum disorder. *European Journal of Neuroscience*, 47(6):497–514, 2018.

[26] Dinah Murray, Mike Lesser, and Wendy Lawson. Attention, monotropism and the diagnostic criteria for autism. *Autism*, 9(2):139–156, 2005.

[27] Madeline B Harms, Alex Martin, and Gregory L Wallace. Facial emotion recognition in autism spectrum disorders: a review of behavioral and neuroimaging studies. *Neuropsychology review*, 20(3):290–322, 2010.

[28] Tina R Goldsmith and Linda A LeBlanc. Use of technology in interventions for children with autism. *Journal of Early and Intensive Behavior Intervention*, 1(2):166, 2004.

[29] Luthffi Idzhar Ismail, Thibault Verhoeven, Joni Dambre, and Francis Wyffels. Leveraging robotics research for children with autism: a review. *International Journal of Social Robotics*, 11(3):389–410, 2019.

[30] Adriana Tapus, Andreea Peca, Amir Aly, Cristina Pop, Lavinia Jisa, Sebastian Pintea, Alina S Rusu, and Daniel O David. Children with autism social engagement in interaction with nao, an imitative robot: A series of single case experiments. *Interaction studies*, 13(3):315–347, 2012.

[31] Kerstin Dautenhahn, Chrystopher L Nehaniv, Michael L Walters, Ben Robins, Hatice Kose-Bagci, N Assif, Mike Blow, et al. Kaspar–a minimally expressive humanoid robot for human–robot interaction research. *Applied Bionics and Biomechanics*, 6(3, 4):369–397, 2009.

[32] Jeroen CJ Brok and Emilia I Barakova. Engaging autistic children in imitation and turn-taking games with multiagent system of interactive lighting blocks. In *International conference on entertainment computing*, pages 115–126. Springer, 2010.

[33] Eleuda Nunez, Soichiro Matsuda, Masakazu Hirokawa, Junichi Yamamoto, and Kenji Suzuki. Effect of sensory feedback on turn-taking using paired devices for children with asd. *Multimodal Technologies and Interaction*, 2(4):61, 2018.

[34] Bridget A Taylor and Len Levin. Teaching a student with autism to make verbal initiations: Effects of a tactile prompt. *Journal of Applied Behavior Analysis*, 31(4):651–654, 1998.

[35] Daniel B Shabani, Roger C Katz, David A Wilder, Kenneth Beauchamp, Crystal R Taylor, and Kirsten J Fischer. Increasing social initiations in children with autism: Effects of a tactile prompt. *Journal of applied Behavior analysis*, 35(1):79–83, 2002.

[36] Deepa Mathew. vSmileys : Imaging Emotions through Vibration Patterns. (March), 2005.

[37] Sreekar Krishna, Shantanu Bala, Troy McDaniel, Stephen McGuire, and Sethuraman Panchanathan. VibroGlove: An assistive technology aid for conveying facial expressions. *Conference on Human Factors in Computing Systems - Proceedings*, pages 3637–3642, 2010. doi:10.1145/1753846.1754031.

[38] Katharine Blocher and Rosalind W. Picard. Affective Social Quest. pages 133–140, 2002. doi:10.1007/0-306-47373-9_16.

[39] Gwénaël Changeon, Delphine Graeff, Margarita Anastassova, and José Lozada. Tactile emotions: A vibrotactile tactile gamepad for transmitting emotional messages to children with autism. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 7282 LNCS(PART 1):79–90, 2012. doi:10.1007/978-3-642-31401-8_8.

[40] Jamil Zaki and W Craig Williams. Interpersonal emotion regulation. *Emotion*, 13(5):803, 2013.

[41] Kouta Minamizawa, Yasuaki Kakehi, Masashi Nakatani, Soichiro Mihara, and Susumu Tachi. Techtile toolkit: a prototyping tool for designing haptic media. 08 2012. doi:10.1145/2343456.2343478.

[42] Tanja Bänziger, Didier Grandjean, and Klaus R Scherer. Emotion recognition from expressions in face, voice, and body: the multimodal emotion recognition test (mert). *Emotion*, 9(5):691, 2009.

[43] Holger Hoffmann, Henrik Kessler, Tobias Eppel, Stefanie Rukavina, and Harald C Traue. Expression intensity, gender and facial emotion recognition: Women recognize only subtle facial emotions better than men. *Acta psychologica*, 135(3):278–283, 2010.

[44] Kostantinos V Petrides and Adrian Furnham. Trait emotional intelligence: Behavioural validation in two studies of emotion recognition and reactivity to mood induction. *European journal of personality*, 17(1):39–57, 2003.

[45] John D Mayer, Peter Salovey, et al. What is emotional intelligence. *Emotional development and emotional intelligence: Educational implications*, 3:31, 1997.

[46] Moïra Mikolajczak. Going beyond the ability-trait debate: the three-level model of emotional intelligence. *E-Journal of Applied Psychology*, 5(2), 2009.

[47] M Mikolajczak, KV Petrides, N Coumans, and O Luminet. An experimental investigation of the moderating effects of trait emotional intelligence on laboratory-induced stress. *International Journal of Clinical and Health Psychology*, 9(3):455–477, 2009.

[48] Moïra Mikolajczak, Sophie Brasseur, and Carole Fantini-Hauwel. Measuring intrapersonal and interpersonal eq: The short profile of emotional competence (s-pec). *Personality and individual differences*, 65:42–46, 2014.

[49] Sophie Brasseur, Jacques Grégoire, Romain Bourdu, and Moïra Mikolajczak. The profile of emotional competence (pec): Development and validation of a self-reported measure that fits dimensions of emotional competence theory. *PloS one*, 8(5):e62635, 2013.

[50] Mark A Lumley, Britta J Gustavson, R Ty Partridge, and Gisela Labouvie-Vief. Assessing alexithymia and related emotional ability constructs using multiple methods: Interrelationships among measures. *Emotion*, 5(3):329, 2005.

[51] Mina Shibasaki, Youichi Kamiyama, Elaine Czech, Koichi Obata, Yusuke Wakamoto, Keisuke Kishi, Takayuki Hasegawa, Shinkuro Tsuchiya, Soichiro Matsuda, and Kouta Minamizawa. *Interest arousal by haptic feedback during a storytelling for kindergarten children*, volume 12272 LNCS. Springer International Publishing, 2020. URL: `http://dx.doi.org/10.1007/978-3-030-58147-3{_}57`, `doi:10.1007/978-3-030-58147-3_57`.

[52] Moe Sugawa, Taichi Furukawa, George Chernyshov, Danny Hynds, Jiawen Han, Marcelo Padovani, Dingding Zheng, Karola Marky, Kai Kunze, and

Kouta Minamizawa. Boiling mind: Amplifying the audience-performer connection through sonification and visualization of heart and electrodermal activities. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*, pages 1–10, 2021.

[53] Moushumi Sharmin, Md Monsur Hossain, Abir Saha, Maitraye Das, Margot Maxwell, and Shameem Ahmed. From research to practice: Informing the design of autism support smart technology. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–16, 2018.

[54] Delphine B Rosset, Cecilie Rondan, David Da Fonseca, Andreia Santos, Brigitte Assouline, and Christine Deruelle. Typical emotion processing for cartoon but not for real faces in children with autistic spectrum disorders. *Journal of autism and developmental disorders*, 38(5):919–925, 2008.

Appendices

A. Exploded-view of G-band

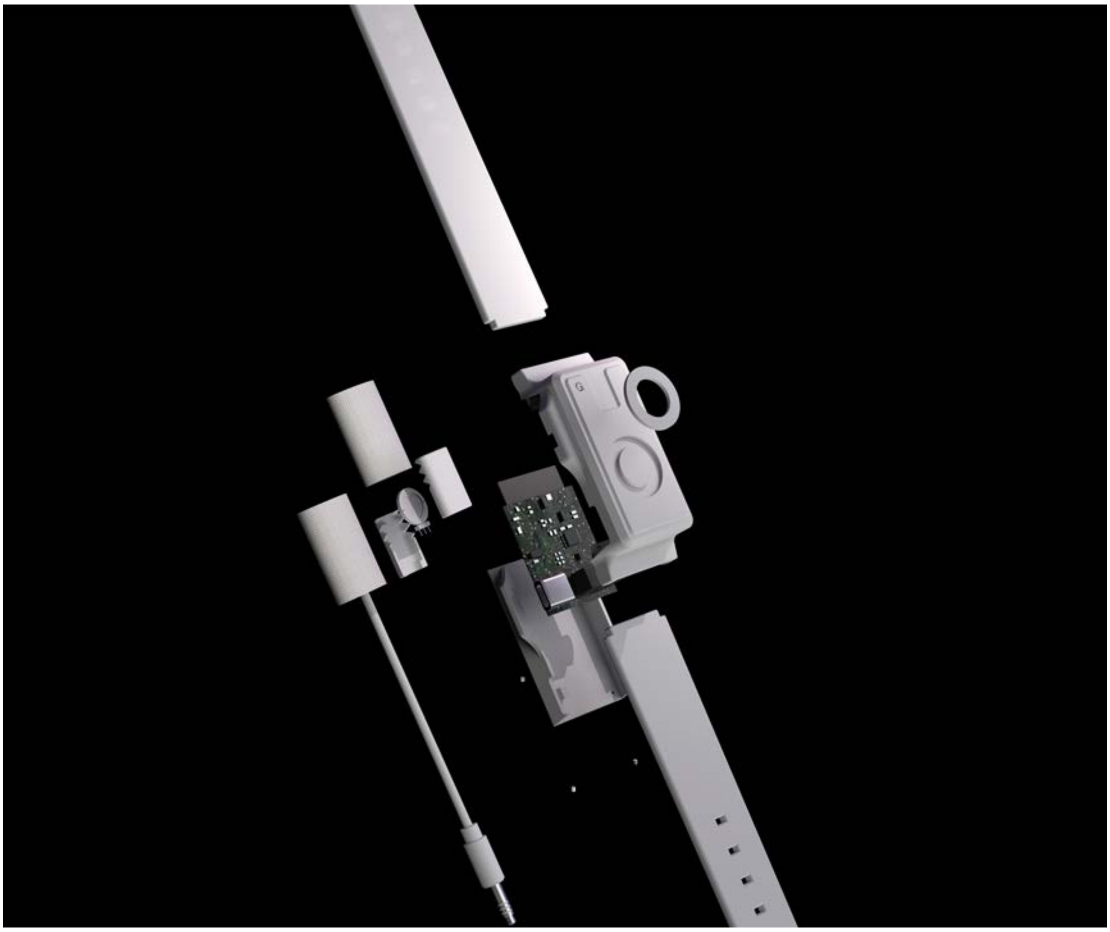


Figure A.1 Exploded-view of G-band

B. Author's permission of the Colour Monster

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Flamboyant

LETTER OF ENGAGEMENT

Barcelona, February 20th, 2021

On the one hand, Embodied Media Laboratory (hereinafter the LAB), from Keio University, Japan, herein represented by Yulan JU, as a master's student, and in charge of the research project "Emotional Haptics" (hereinafter the PROJECT), in collaboration with Miraikan (The National Museum of Emerging Science and Innovation), and Tokyo Metropolitan Rinkai District Special Support School. The PROJECT includes conducting workshops for children with autism to help children with autism understand emotions and share emotional experiences through tactile technology.

On the other hand, Editorial Flamboyant, S.L. having its registered office in Bailén, 180, bajos, local 2, 08037, Barcelona, Spain, VAT Number ESB65072910 herein represented by Eva Jiménez Tubau, with National Identity Document 46969007V, as Legal Representative, (hereinafter the EDITOR), acting on behalf of the title *The Colour Monster* (hereinafter the WORK) from the author Anna Llenas, published in Japanese language by the publisher Nagaoka.

Hereby the EDITOR grants the LAB the right to use the WORK for the PROJECT, provided there is no commercial use, in the following formats:

1. Displaying the YouTube video (https://www.youtube.com/watch?v=h19uYmSRKH8) during workshops and recording the workshops with the WORK on display.
2. Using the photos and videos we take during the workshops for scientific conference presentations and research publications.
3. Displaying the photos and videos taken during the workshops in Miraikan (The National Museum of Emerging Science and Innovation) and other museums for exhibitions and public presentations.

In all cases, the WORK will be referred to (author, title and publisher) in a visible way.

Signed on February 20th, 2021.

DocuSigned by: Eva Jiménez Tubau CE57CF73C0404DE... DS

Eva Jiménez Tubau
Editorial Flamboyant, S. L.

Yulan JU
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Figure B.1 Author's permission of Colour Monster