Haptic Empathy: Conveying Emotional Meaning through Vibrotactile Feedback

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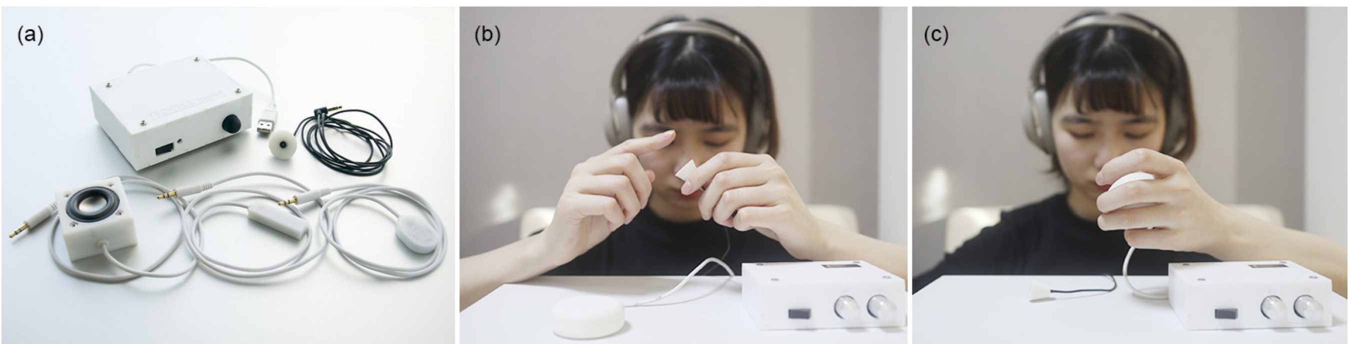

Figure 1: a) Experiment material - TECHTILE tookit. b) Experiment part one - recording vibration samples. c) Experiment part two - recognising emotions from recorded vibration samples.

ABSTRACT

Touch plays an essential role in communicating emotions and intensifying interpersonal communication[4]. A lot of research focuses on how to create or improve haptic interfaces looking into challenges and possibilities that the haptic technology can offer[30]. The objective of this research is to investigate whether people can share subjective feelings through simple vibrotactile feedback. In an initial experiment, we used the TECHTILE toolkit[19] to record 28 vibration sample sets for 4 different emotions (joy, anger, sadness, relaxation). We then replayed the vibrations to test how well they could be recognized. The results support the hypothesis that people can use vibration feedback as a medium for expressing specific subjective feelings. It also indicates some universalities in affective vibrotactile stimuli that even strangers with little to no knowledge about the senders could recognize the emotional meanings.

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CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **Haptic devices**; *User studies*.

KEYWORDS

affective computing, emotion encoding, emotion recognition, emotion expression, haptic interfaces, vibration

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1 INTRODUCTION

Nonverbal information plays a crucial role in human-human social interaction, often communicating emotional states between individuals. Touch, as one of the primary methods of human interaction, has been widely studied and applied in human-computer interaction. Although research on functions of adding tactile qualities to computer applications extended from the cognitive function, most of the current research has concentrated on the cognitive side. Our work focused on haptic technology in affective communication.

In general, haptic technology has contributed to affective communication in two main forms. First, some of the work focused on the relationships between emotion elicitation and tactile touch has shown that haptic stimulation can evoke emotional responses [25, 26]. Second, several research studies investigated how haptic stimuli can intensify emotional information received through other modalities [13]. As one of the most commonly used haptic feedback methods, vibration has been widely used in this field to enhance other stimuli (e.g.adding vibrotactile activation to a visual representation) [5, 8, 12, 15, 25, 31]. To be more specific, most of the research in haptic-based affective communication has focused on the use of tactile interfaces, which are manifested as tangible objects or robots, wearable items, or contactless devices (i.e., mid-air stimulation devices) [4].

Although vibration is mostly investigated as an auxiliary modality for communicating emotions, the study of using the single vibration modality to express feelings/emotions is not well explored [9, 21]. Some projects designed haptic expression icons to convey basic information like facial expressions [15]. Some researchers have also worked on the taxonomy of vibrotactile stimulation. However, those studies' vibrotactile stimuli were well designed in two measurable quantities (intensity and frequency).

Based on the premise of individual differences in haptic perception and preferences, we investigated whether unprocessed vibration samples can be used as a new communication method to convey emotional information. To this end, we present an initial study design and some qualitative results to investigate 1) whether people can use simple vibration feedback to express subjective feelings and 2) whether people can identify emotions conveyed by simple vibration feedback. To be more specific, we have built a 28-set emotional vibration database for four emotions: joy, anger, sadness, and relaxation. We have tested 196 emotional vibration trials in total and analyzed each sample's characteristics through their rhythmic graphs. The results indicated the universality in affective vibrotactile stimuli in which strangers with little to no knowledge about the sender could recognize the emotional meanings. Furthermore, we propose a new direction in accessing universal haptic empathy, which offers the possibility for haptic-based affect detection.

2 RELATED WORK

Many psychologists believe emotions embrace both universalism and differentialism[27]. On the one hand, emotion is a primary human functioning 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[14], speakers of a given language appear to feel that some of the emotion words are more basic than others. To be more specific, happiness, sadness, anger, fear, and love are known as five general and possible universal categories of emotion in 11 languages. In other words, these five emotions can lead to a consistent understanding of different language contexts.

In the field of the universality of emotion, facial expressions have a long and vital history in psychology. Many tests have been developed to assess emotion recognition ability, and reliability and validity have been well explored [6, 11, 16, 22, 23]. Among those research and tests, the ability to decode nonverbal cues from the face, body, and voice have been widely used. Despite the fact that touch provides a compelling method of eliciting and modulating emotion, applying haptic sensors for affect detection has been an understudied topic compared to facial and vocal displays. Matthew and his colleagues noted that previous research on this subject did not produce promising results[4]. However, these works opened a possibility of developing a multimodal system of affect detection that can be applied to several domains, such as people with autism spectrum disorders who do not share emotions through typical social cues.

Many studies discussed the effectiveness of using the haptic channel to communicate affective information through direct and mediated methods [4]. Bailenson et al. investigated the possibility of encoding emotional information through a haptic device [1]. Their work indicated that humans recognize emotions through haptic modality at 33% above chance (1/4). Many research designed haptic tools to explore the relationship between haptics and emotions. For instance, Haptic Face Display (HFD) were designed to study vibrotactile pattern and elicited emotional responses [17]. Similarly, some studies developed tactile icons to enrich user experience [30, 32]. The results of these tests indicated the possibility of employing a sense of touch as an alternative way of communication. However, the design of the vibrotactile patterns was based on the authors' own intuition, the ecological validity of the emotional qualities of the stimuli may be insufficient. POKE, a tactile-sharing device, was designed for people with intimate relations to communicate affections through tactile feedback and built their own tactile vocabularies [20]. Seifi and her coworker created a 120-item database and compiled research on tactile language into five taxonomies[28]. Although there is not yet agreement on an affective tactile design language [10], those studies show that touch can augment or even take the place of other emotional information cues.

Existing affective communication techniques have been widely used in many areas such as virtual reality, smart surveillance, natural interfaces, enhanced human-robot interaction, gaming and entertainment, online social interaction, etc.[29]. The majority of techniques use text, speech, gesture, and facial expression information to communicate affection. These techniques mainly augment two of the human senses in computer-mediated emotional communication: visual and auditory[18]. Although touch plays a pivotal role in human communication, research on communicating affection by touch is still limited. Therefore, we have attempted to explore more possibilities of applying the sense of touch to computer-mediated emotional communication.

3 METHOD

Our goal 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.

3.1 Participants

Seven graduate school students (3 males and 4 females) between ages of 24 to 30 years participated in our study. Three of them were

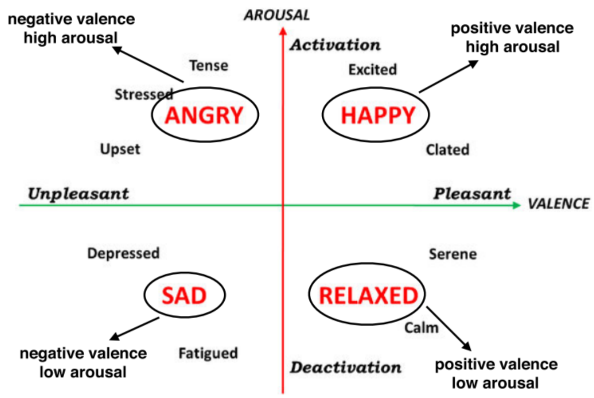

Figure 2: Russell's circumplex model of affect[24]

very familiar with the TECHTILE toolkit, one of them was mildly familiar with TECHTILE, and three 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.

3.2 Materials

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

3.2.2 TECHTILE Toolkit (see Fig. 1.a) is a device capable of recording and playback of vibrotactile patterns [19]. 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.

3.2.3 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. More details are described in 3.3.1.

Russell's dimensional circumplex model of affect is used to map emotions in the quantitative two-dimensional space of valence and arousal (see Figure 2). This work focus on four emotions: joy, anger, sadness, and relaxation (one for each quadrant). The emotions from the same quadrant may be difficult 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 the language barriers.

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

3.3 Design and Procedure

There are two major parts to this study: using vibration patterns to express certain emotions (see Fig.1.b) and recognizing emotions from recorded vibrations (see Fig.1.c). Each participant was firstly introduced to the "TECHTILE toolkit". In each trial they 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.

3.3.1 Expression: Emotions to Vibrations . After the practice trials, the participants were asked to try expressing four emotions (joy, anger, sadness, relaxation) within a 10 second recording. 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 they deem it necessary. 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 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 the emotions via the haptic device.

3.3.2 Recognition: Vibrations to Emotions. In the second session, we asked the same participants to distinguish the 4 selected emotions conveyed by each vibration sample. To avoid hearing the sound of the vibration, participants were asked to wear noise-canceling headphones and listen to white noise during the whole experiment. There were 7 vibrotactile samples for each emotion collected from the first session, for 28 viboratactile sets in total (including the samples participants created by themselves). All the vibrotactile samples were presented in random order using the "TECHTILE toolkit". 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. The researchers explained the purpose of this study at the end.

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.

4 RESULTS

The current 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).

Among 49 test trials for each emotion (joy, anger, sadness, relaxation) conveyed through vibration, there were 35 matched result for joy, 32 for anger, 25 for relaxation, and 23 for sadness (See Table 2). 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

Table 1: Recognition of 4-Types-Emotion Vibrations Samples of 7 Participants

	All Trials (28) [i]			Own (4) [ii]		Others (24) [iii]		Recognized by Others (24) [ix]	
	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;

[ix] *Recognized by others*: the emotional vibrations created by this participant and recognized by others.

Table 2: 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.

sometimes confused with joy, however, joy was almost never confused with anger (see confusion matrix on Fig.3). 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 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 1.

Analysis showed the vibration pattern recognition was significantly higher than by chance. After performing z-test, all of the results for four emotions are significant at $p < .05$ See Table 2. These results are based on counting all 28 feedback sets from each participant including the 4 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 showed in Table 2 when n= 42. Performing z-test without including the recognition of participants' own input, we still found the recognition of all four emotional vibrations were 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 2). The sadness and relaxation vibration trials were rated as more difficult to tell compared to anger and joy. This result match with 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.

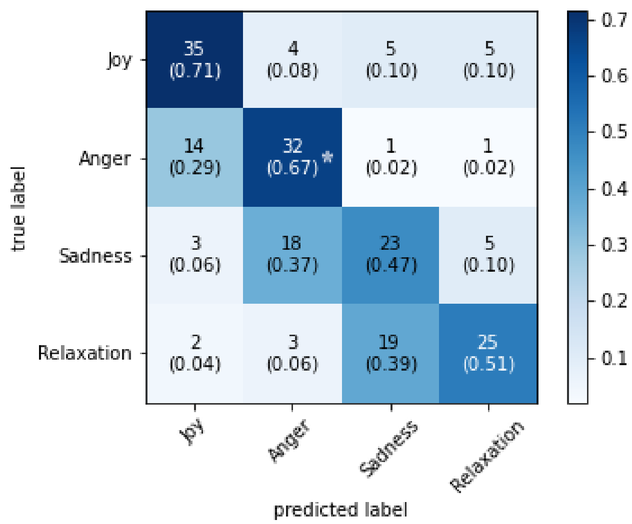

Figure 3: Confusion matrix for vibration patterns recognition.

5 DISCUSSION

The early results of this experiment supported the hypothesis that vibration can 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 current result is not high enough; yet, according to a work testing emotion recognition in face, voice, and body, the accuracy of these traditional emotion cues also averagely ranged from 56% to 70% [2]. 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 [2, 7]. The results also show 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. In other words, people who are better at recognizing emotions are also better at expressing emotion through vibrations. Regression shows that the rate of correct recognition by other participants correlates with the rate of the recognition rate of other participants' patterns (R = 0.87, R squared = 0.76, STDE = 0.047, significance = 0.0108). This leads us to hypothesize the existence of some form of haptic empathy, or some dimension of emotional intelligence leading to this result. Again, we have to recognize the low number of participants (n=7) and the ensuing consequences. There are also some cases that individuals who are poor at expressing one emotion through vibrations are relatively capable of expressing other emotions. There is 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 are at expressing 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.

We exported the recordings of the emotional vibrations to spectrograms and found that certain rhythmic characteristics were associated with specific emotions. Due to limited space, we only picked the highest recognition rate file for each emotion in Fig. 4 as an example, yet the 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.

In conclusion, the results suggest 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.

6 FUTURE WORK

Though the early results of this work have shown a potential connection between emotions and vibrotactile feedback, there may be

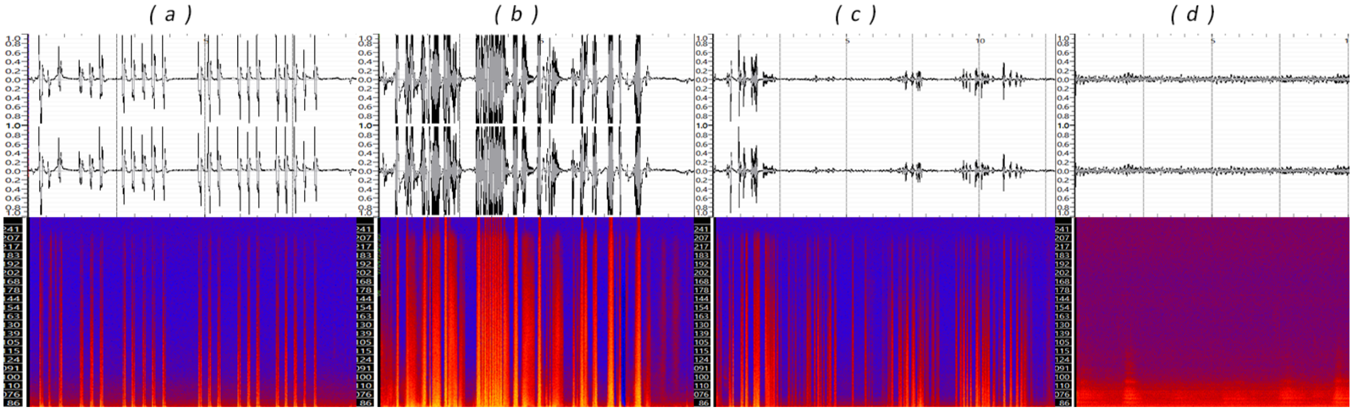

Figure 4: The Rhythmic Graphs of Four Emotional Vibrations from the database visualised with SonicVisualiser[3]. The top images are the waveform and the bottom images are the spectrogram. (a) 9-Joy (AR=100%), (b) 26- Anger (AR=100%), (c) 3-Sadness (AR=57.1%), (d) 24- Relaxation (AR=100%). *AR= Accuracy Rate of the sample file.*

some possible limitations that could be addressed in future research. For example, the recruited participants are all non-native English speakers from the same country, potentially making the results only applicable to this specific group of people. The possible impacts of gender, age, language contexts, and cultural backgrounds on this topic are also worth exploring. In addition, some data we did not record this time could also be beneficial to include in future studies. For instance, the response time of recognizing vibration samples can also help for better understanding the relationship between haptic empathy and emotion recognition ability. Furthermore, the link between haptic empathy and emotional intelligence is worthy of further investigation. With smartphones all-pervading today, vibrotactile haptic devices are accessible and affordable. Thus exploring haptic emotion research through vibrotactile patterns can lead to great potential of further applications.

Although the number of participants in this study is insufficient thus far, existing results have inspired us to acquire a larger sample of participants in our future work. In March 2021, we are going to collaborate with local schools and apply our experiment's results in workshops with autistic children. We believe that this kind of vibrotactile communication may help autistic children to share their emotions more easily, and the "vibrolanguages" could even be a fun way to enhance the understanding of emotions. It would be a nice opportunity to explore whether or not using vibration stimulation can help autistic children scaffold different representations for emotion and encourage them to be creative and express their emotions.

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