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ORIGINAL ARTICLE

Affective Vibrotactile Stimuli: Relation between Vibrotactile Parameters and Affective Responses

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Abstract: Affective communication in the interaction with touch panel displays could be improved by vibrotactile feedback. Hence, we address the relation between vibrotactile stimuli and affective responses. Specifically, we aim to determine the response to comprehensive vibrotactile stimulus parameters, i.e., waveform, amplitude, envelope frequency, and rhythm, by rating 48 types of amplitude-modulated vibrotactile stimuli according to five affective responses: arousal, comfort, preference, familiarity, and dominance. By determining the effects of each parameter, we found that amplitude and envelope frequency were the most effective parameters triggering affective responses. Amplitude influenced arousal and dominance positively, and comfort, preference, and familiarity negatively. Envelope frequency influenced arousal and dominance negatively. In contrast, waveform and rhythm showed lower effectiveness, which contradicted expected outcomes. Likewise, we verified that affective responses mainly include two dimensions, namely, arousal (and dominance) and comfort (or valence). Overall, the results from this study serve as initial guidelines for designing electronic devices with affective vibrotactile stimuli.

Keywords: *Vibrotactile stimuli, Affective response, Tactile texture display, Amplitude modulation*

1. INTRODUCTION

Vibrotactile stimuli can be a source to convey affective responses through electronic devices such as personal computers, smartphones, and wearable devices. In fact, this application has been demonstrated in a variety of studies. For instance, vibrotactile stimuli have been shown to elicit affective responses including pleasantness, arousal, and urgency [1, 2], and influence the responses to emotionally charged images such as facial expressions [3, 4]. Hence, affective communication through electronic devices can be improved by adding vibrotactile feedback to existing applications such as audiovisual content.

The successful implementation of affective vibrotactile stimuli depends on establishing the relationship between the stimuli and human affective responses. In a broader sense, affective responses to different haptic stimuli have been widely studied [5, 6]. However, there is scarce research on affective responses elicited by vibrotactile stimuli, and the related studies did not consider a comprehensive set of parameters [4, 7-10]. For example, Yoo et al. [7] investigated the affective responses to amplitude-modulated vibrotactile stimuli by controlling carrier frequency, envelope, and duration, but disregarding rhythm, which shows affective impacts according to some studies [8, 9]. In contrast, for this study we investigated comprehensive parameters that can be controlled in typical vibrotactile actuators from commercial electronic devices to determine those that elicit the clearest affective responses. It has practical value to specify vibrotactile parameters that significantly influence affective responses under multivariate changes, as this extends previous studies that only investigated the effects of few types of parameters on affective responses.

Specifically, in this study, we determine affective responses considering five types of vibrotactile parameters and their combination, which enable us to thoroughly assess the effects of vibrotactile stimuli and determine the most influential parameters by comparing their effects. Overall, we use 48 types of vibrotactile stimuli obtained from variations of the five parameters. Eleven participants rate the vibrotactile stimuli according to five affective responses, which are arousal, comfort, dominance [4, 5, 7-10], preference, and familiarity. We then analyze the response rating to determine the most effective vibrotactile parameters eliciting human affective responses. Through the results from this study, we expect to provide guidelines for the design of devices that include affective vibrotactile stimuli.

Another important aspect is to determine the structure of affective responses influenced by vibrotactile stimuli. Understanding the relation between the space of affective responses and vibrotactile stimuli will be instrumental for designing effective stimuli. We focus on responses including arousal, comfort, and dominance, derived from the Russell's circumplex model [11]. These responses are often used to express affective responses depending

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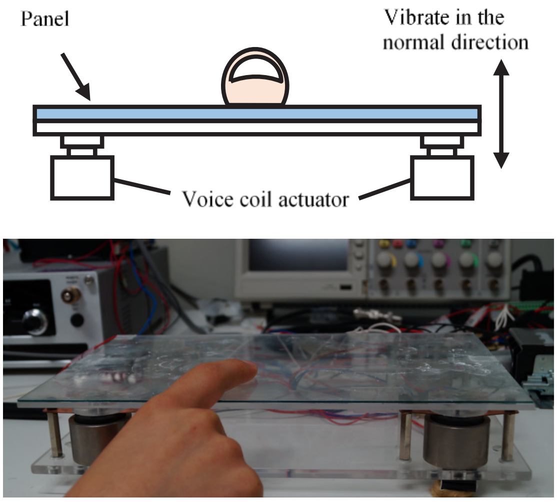

Figure 1: Vibrotactile stimuli generator for experiments

Diagram of the generator front view (top) and photograph of the generator (bottom).

on haptic perception in previous studies [4, 5, 7-10]. Moreover, we consider preference and familiarity in this study, as these responses can be beneficial for commercial applications. We apply the principal component analysis on these five types of affective responses to acquire their dimensional structure.

2. VIBROTACTILE STIMULI GENERATOR

We used the same vibrotactile stimuli generator that was employed in a previous work [12]. The generator is composed of X-1741 voice coil actuators (Neomax Engineering Co. Ltd., Japan) to mechanically stimulate the fingertips by producing displacements in the normal direction to the panel, as illustrated in Figure 1. The voice coil actuators are more responsive than eccentric motors, which are adopted in some mobile devices and present single-tone vibration. We activated the voice coil actuators through an ADS 50/5 servo-amplifier (Maxon Motor AG, Switzerland) and executed a feedforward computer-based control at 1 kHz. To emulate a touch panel, which is one of the most promising applications for vibrotactile feedback, we mounted a flat panel over four voice coil actuators as shown in Figure 1.

3. EVALUATED PARAMETERS

Some studies reported parameters of vibrotactile stimuli that influence human perception including waveform, frequency, amplitude, and duration [13, 14], as well as rhythm [14-16], from which length and unevenness showed the highest effectiveness [16].

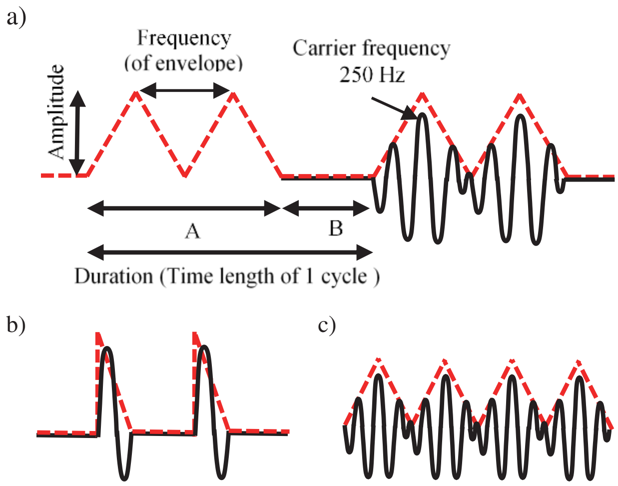

Figure 2: Amplitude-modulated vibrotactile stimuli

a) Parameters constituting vibrotactile stimuli, where the duty ratio is given by $A/(A+B)$.
b) Vibrotactile stimulus with reverse sawtooth waveform and envelope frequency of 250 Hz, which is equal to the carrier frequency.
c) Vibrotactile stimulus with triangular waveform and duty ratio of 100%.

We employed amplitude-modulated sinusoidal waves for vibrotactile stimuli, as illustrated in Figure 2, because it is difficult for voice coil actuators to generate complex waves, such as a triangular signal, using other approaches. In addition, these types of waves enabled us to evaluate low-frequency stimuli evoking large perceptual magnitudes. We fixed the carrier frequency of amplitude modulation at 250 Hz, because most of the actuators employed for delivering vibrotactile stimuli are highly effective when resonating in the range of 100−300 Hz [17], which elicits an intense vibrotactile sensation.

Besides waveform, frequency, and amplitude, we considered rhythm as a parameter of vibrotactile stimuli in this study, given its reported effectiveness on affective responses [8, 9]. However, there is no consensus on the definition of rhythm for vibrotactile stimuli, and different approaches have been proposed. For instance, either melodies [18, 19] or number of cycles and tone duration [8] can be used to define rhythm. We selected a definition similar to the latter for rhythm, where two parameters are considered, namely, the duration of one stimulation cycle and its duty ratio given by the rate of stimulation during one cycle. For example, a duration and duty ratio of 100 ms and 75%, respectively, indicate that the one stimulus cycle lasts 75 ms followed by an inactive period of 25 ms.

Therefore, the five parameters we considered for vibrotactile stimuli are waveform (envelope), envelope frequency, amplitude, duration, and duty ratio, whose

Table 1: Parameter specifications of amplitude-modulated vibrotactile stimuli of which carrier frequency is constant i.e. 250 Hz.

Parameter	Specification
Waveform	Reverse sawtooth (R), Triangular (T), Square (S)
Amplitude	Levels: 1, 2, 3, 4 (L1−L4)
Frequency (Hz)	30, 60, 125, 250
Duration (ms)	100, 200, 300, 400
Duty ratio (%)	25, 50, 75, 100

specifications are listed in Table 1. We selected the parameters and their specifications to allow easy generation, even when using low-fidelity vibrotactile actuators.

3.1 Waveform

The waveform of vibrotactile stimuli affects perception. For instance, square waveforms are perceived with more intensity than triangular and sinusoidal waveforms, which elicit only moderate responses [20]. Other waveforms include damped waves and parabolas for modulation [1].

For this study, we tested several types of waveforms, and some of them resulted in similar vibration profiles given the dynamics of voice coil actuators. Specifically, we obtained similar profiles between a damped wave and a reverse sawtooth, and between a sawtooth and a triangular waveform. Consequently, we restricted our study to three types of waveforms, namely, reverse sawtooth, triangular, and square. Figure 3 illustrates a generated triangular wave stimulus, where the stimulus does not completely agree with its ideal envelope.

3.2 Envelope frequency

Vibrotactile perception becomes monotonically more acute as frequency approaches 250 Hz [14, 17, 21]. Hence,

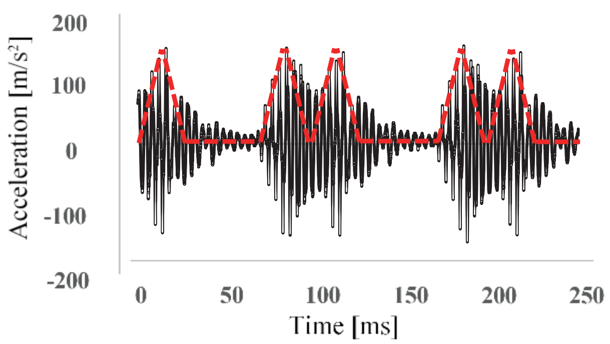

Figure 3: Vibrotactile stimulus measured by an accelerometer (black solid line) and target envelope (red dashed line).

Waveform: triangular. Amplitude: Level 3.
Frequency: 30 Hz. Duration: 100 ms.
Duty ratio: 50%.

Table 2: Stimulus amplitude per frequency

Frequency	Waveform	L1	L2	L3	L4
30 Hz	R	–	89.4	–	199
	T	83.7	99.3	301	–
	S	48.6	77.9	–	291
60 Hz	R	68.3	166	–	330
	T	31.4	–	268	443
	S	–	81.0	–	–
125 Hz	R	52.3	68.5	80.5	86.8
	T	63.3	89.0	245	297
	S	41.8	55.5	198	268
250 Hz	R	50.2	47.6	196	252
	T	–	53.6	–	177
	S	39.2	52.3	71.1	222

L1−L4 represent the amplitude levels, retrieved from an accelerometer in m/s^2. The unspecified values represent levels that were not used for the experiment. L1 stimuli were satisfactorily greater than perceptual threshold levels.

we evaluated four frequency levels constituting a geometric series to generate vibrotactile stimuli: 30 Hz, 60 Hz, 125 Hz, and 250 Hz, with the carrier frequency of 250 Hz, which is illustrated in Figure 2.

3.3 Amplitude

Humans can discriminate up to four levels of vibrotactile stimulus amplitude [20]. Hence, we considered amplitude limits from the lower perceptible vibration to the maximum device output, and linearly divided this range into four levels. The lower limit was determined according to the perception of the authors, and was then verified as perceptible by the study participants. Table 2 lists the peak acceleration values measured by a 2302BW piezoelectric accelerometer (Showa Sokki Corp., Japan) per amplitude level. These values were also dependent on waveform.

3.4 Duration and duty ratio

There must be an interval of at least 10 ms to recognize two subsequent vibrotactile stimuli [20]. From the viewpoint of affective communication through electronic devices, a short time enhances the transference of affective information from vibrotactile stimuli. In addition, unpleasant sensations increase with the duration of vibrotactile stimuli [22]. Considering these aspects, we evaluated four vibrotactile stimulus periods of 100 ms, 200 ms, 300 ms, and 400 ms, as well as four duty ratios of 25%, 50%, 75%, and 100%. Hence, the minimum interval between successive stimuli was 25 ms, which is above the minimum perceptible, and the duty ratio of 100% represented a single continuous stimulus.

4. METHODS

4.1 Vibrotactile stimuli and affective responses

For the experiments, we designed 48 types of vibrotactile stimuli from the combination of the abovementioned parameters. These types were determined using two L24 cross-tables, which allow to avoid an exhaustive search in the parameter space and reduce the number of combinations, whereas independency among parameters is maintained. The stimuli specifications are listed in Table 3, where unfeasible parameter combinations were excluded, e.g., vibrotactile stimulus with envelope frequency of 30 Hz, duration of 100 ms, and 25% duty ratio, where the stimulus duration is shorter than a waveform period.

Table 3: Types of vibrotactile stimuli

No.	Waveform	Amplitude	Frequency (Hz)	Duration (ms)	Duty ratio (%)
1	R	L2	250	100	50
2	R	L3	125	300	25
3	T	L1	30	300	75
4	S	L2	60	200	25
5	T	L2	125	400	25
6	S	L3	250	400	25
7	S	L2	30	400	75
8	R	L1	250	400	100
9	R	L1	60	300	25
10	S	L4	125	400	50
11	R	L1	125	200	75
12	T	L4	60	100	100
13	S	L4	30	300	100
14	S	L1	250	100	75
15	T	L3	30	100	50
16	T	L1	30	200	100
17	R	L4	30	200	25
18	T	L2	250	200	75
19	T	L4	125	200	100
20	T	L1	60	400	50
21	T	L3	125	100	75
22	T	L4	250	300	50
23	S	L2	125	100	25
24	S	L2	125	300	75
25	R	L2	250	300	100
26	S	L2	60	300	50
27	R	L4	60	200	50
28	T	L2	30	200	50
29	S	L4	250	100	100
30	S	L3	125	400	100
31	R	L4	30	400	50
32	S	L2	250	400	50
33	S	L1	250	200	50
34	R	L2	125	200	100
35	T	L2	30	300	25
36	T	L4	60	400	75
37	S	L3	125	200	50
38	R	L4	250	200	75
39	R	L3	250	300	50
40	R	L4	125	100	50
41	T	L2	250	100	25
42	S	L1	125	400	75
43	T	L3	60	300	100
44	R	L2	60	400	100
45	R	L1	60	100	75
46	R	L2	30	100	100
47	S	L1	30	400	25
48	T	L1	125	100	25

The model that uses arousal, comfort (or valence according to the Russell's circumplex model), and dominance to describe affective responses is commonly used to evaluate tactile stimulation [4, 5, 7-10]. Besides these three responses, we added familiarity and preference in our experiment, because these terms can convey useful insights in the design of commercial applications. In fact, terms such as familiarity and approachability are used to determine stimulus acceptability [23, 24].

4.2 Task

Eleven naive male university students (right handed, aged between 21 and 24 years old), participated in the experiment after providing informed consent.

The participants evaluated each vibrotactile stimulus by assigning one out of seven degrees (+3: agree, 0: neutral, –3: disagree) to the five affective responses, after experiencing the stimulus for approximately 5 s. To reproduce a situation where a user is interacting with a touch panel display, we asked every participant to touch the panel with his index finger, as shown in Figure 1.

Overall, the participants rated each of the 48 tactile stimuli, which were randomly presented to prevent the order effect, and responded the questionnaire on affective responses. The experiment took approximately 30 min per participant. During the experiment, the participant was hearing pink noise through noise-cancelling headphones to eliminate the sounds caused by the vibrotactile stimuli generator.

4.3 Analysis

To discover the most effective parameters for vibrotactile stimuli, we applied a multiple regression analysis on the subjective scores. We considered the five parameters of vibrotactile stimuli (i.e., waveform, envelope frequency, amplitude, duration, and duty ratio) as explanatory variables, and each affective response as objective variable. The units of amplitude, envelope frequency, and duration were meters per square second (m/s^2), hertz (Hz), and milliseconds (ms), respectively. The three types of waveforms were represented by combinations of dummy binary variables (x_r, x_t), where r and t denote the reverse sawtooth wave and triangle wave, respectively. Specifically, the reverse sawtooth, triangle, and square waves can be described as $(x_r, x_t) = (1,0), (0,1)$, and $(0,0)$, respectively. A positive correlation between the dummy variable corresponding to a waveform and an affective response expresses an influence from the former on the latter. On the other hand, a negative correlation of both dummy variables with an affective response indicates the effectiveness of the square waveform over that response.

First, we analyzed each participants' subjective scores, which were transformed into z-scores, to investigate individual differences. Then, we collectively analyzed all participants' subjective scores. These analyses enabled to distinguish the parameters having an individual and general influence.

In addition, to investigate the relation among the affective responses, especially in terms of their dimensionality, we computed their principal components, whose scores were determined after applying the promax method.

5. RESULTS

The effective parameters were obtained from the individuals' analysis as listed in Table 4. The regression coefficients obtained by analyzing all the participants' subjective scores are listed in Table 5, and the partial regression coefficients obtained by individuals' analysis are summarized in the appendix. As in Table 5, except for duration, all the parameters showed some impacts on affective responses.

The dummy variable corresponding to the triangle wave negatively influenced comfort, preference, and familiarity for a few participants, as shown in Table 4. In contrast, reverse sawtooth and square wave stimuli were more comfortable, preferred, and familiar than the triangle wave stimulus. On the other hand, the triangle wave influenced arousal negatively in the analysis of all participants' scores, as shown in Table 5. Nonetheless, this effect is inconclusive because it was not confirmed in the individuals' analysis.

Amplitude positively influenced arousal and dominance in the analyses of all participants (Table 5) and each individual (Table 4), whereas it negatively influenced comfort, preference, and familiarity. This effect was consistent among several participants. These results indicate that larger amplitude leads to arousing and dominant responses, as well as discomfort, non-preference, and unfamiliarity.

Envelope frequency negatively influenced arousal and dominance in the analyses of all participants (Table 5) and each individual (Table 4). Moreover, envelope frequency positively influenced comfort, preference, and familiarity in the individual analysis, although some participants exhibited the inverse influence. Arousing and dominant vibrotactile stimuli were delivered by lowering the envelope frequency, and these stimuli were perceived less comfortable, preferred, and familiar by some participants.

Table 4: Summary of positive and negative effects between affective responses and vibrotactile stimuli for each participant

	Triangle *waveform	Amplitude	Envelope frequency	Duration	Duty ratio
Arousal		++++ ++++	−−−−−	+	−−
Comfort	−−	−−−−	+++ −−−	+ −−	++ −−−−
Preference	−	−−−−	++++ −−	+	++ −−−
Familiarity	−−	−−	++++ −	−	+ −−
Dominance		++++ +++	−−−−− −		+ −−

The signs show the effect trend (i.e., +, positive; −, negative) and their number corresponds to the number of participants for whom significant effects were found. Red signs indicate significant effects ($p < .05$) and black signs indicate possibly significant effects ($p < .10$).
*Reverse sawtooth was excluded from this table as it did not show any significant effect.

Table 5: Statistically significant partial regression coefficients obtained from the participants' scores

	Triangle waveform	Amplitude (m/s^2)	Envelope frequency (Hz)	Duration (ms)	Duty ratio
Arousal	−0.46	+6.1E-3	−4.2E-3		−0.74
Comfort		−3.4E-3	(+1.3E-3)		
Preference		−3.2E-3	(+1.4E-3)		
Familiarity		−1.8E-3	+1.7E-3		
Dominance		+3.4E-3	−2.9E-3		(−0.38)

Values in parentheses indicate possibly significant effects ($p < .10$).

Table 6: Principal component coefficients after applying the promax method

Response	Comp. 1	Comp. 2
Arousal	−0.13	0.63
Comfort	0.58	−0.05
Preference	0.58	−0.01
Familiarity	0.55	0.12
Dominance	0.10	0.76

Duty ratio negatively influenced arousal in the analysis of all participants (Table 5) and might have negatively influenced on dominance. For some participants, it influenced comfort, preference, and familiarity, but these effects were not common, as shown in Table 4. When the duty ratio of the stimuli was small, such as impulsive stimuli, they elicited an arousal response.

Two principal components providing a cumulative contribution ratio of 79% were found from the five types of affective responses. Table 6 lists the principal component coefficients after rotation using the promax method. Component 1 was highly related to comfort, preference, and familiarity, whereas component 2 to arousal and dominance. Thus, affective responses during vibrotactile perception can be categorized in a two-dimensional space.

6. DISCUSSION

In this study, we found that vibration amplitude and envelope frequency have a significant influence on affective responses, even under variation of multiple parameters. This suggests that amplitude and envelope frequency are the most important parameters to design affective vibrotactile stimuli. Specifically, amplitude was positively correlated with arousal and dominance, confirming results from previous studies, where amplitude was correlated with arousal [4, 7]. Furthermore, like our work, these studies reported a reduction in comfort due to large amplitudes, which might be perceived as intense and uncomfortable [22].

Unlike amplitude, the envelope frequency negatively influenced arousal and dominance, and positively but moderately influenced comfort, preference, and familiarity. These effects can be explained by the fact that low frequency produces a long and continuous vibration. Then, the temporal accumulation of vibrotactile stimuli [25] might have been perceived as more intense and uncomfortable [22]. In addition, the principal component coefficients indicated that comfort, preference, and familiarity are strongly correlated, and hence their characterization can be considered as semantically similar.

We expressed rhythm by the combination of duration and duty ratio, where the latter influenced arousal negatively, and comfort and preference in an individually different manner in several participants. When the duty ratio is small, the stimuli were impulsive, eliciting arousal and uncomfortable responses [4]. This may explain the negative and positive effects of the duty ratio on arousal and comfort (preference), respectively. Likewise, continuous stimuli (duty ratio: 100%) elicit comfort and less arousing responses compared to intermittent stimuli [8, 9]. However, when the duty ratio is large, participants are exposed to longer stimuli. Some participants might have evaluated such continued stimuli as intense and uncomfortable by the temporal accumulation of vibrotactile stimuli [7, 25], which undermined comfort. Hence, the perceptual effects of the duty ratio can vary among participants. These individual differences of the effects of rhythm have been also reported in previous studies [9]. Nevertheless, Akshita et al. [4] reported the inexistence of affective responses to rhythm when varying multiple parameters. Our results suggest that the effects of rhythm on human affective responses are notably weaker than those of amplitude and frequency. However, rhythm can present clearer effects when it influences amplitude and carrier frequency [7]. Likewise, rhythm may be useful for discriminating different vibrotactile stimuli [15].

We did not find general effects of the waveform on the evaluated affective responses. In an earlier study [4], the effect of waveforms, except for that of impulse trains, was not prominent. Hence, it appears that unless the waveforms are clearly distinguishable, such as impulses compared to continuous waveforms, their elicited affective responses may be insignificant. In addition, the difference among waveforms can be distinguished only at low frequencies [26]. Moreover, the ineffectiveness of waveform may be due to the difficulty of reproducing it with high fidelity. In fact, despite using highly responsive voice coil actuators, we were not able to completely control the waveform envelope given the actuator and system dynamics, as illustrated in Figure 3.

Although the number of participants may not be sufficient in the present study, most part of our results stated above are consistent with previous studies. Especially, the effects of amplitude and envelope frequency on arousal and comfort, respectively, were also found in [4, 7, 10]. Nevertheless, further investigation with a larger number of participants would be helpful to clarify the individuality of the effect of rhythm.

Overall, the analyses suggest that affective responses

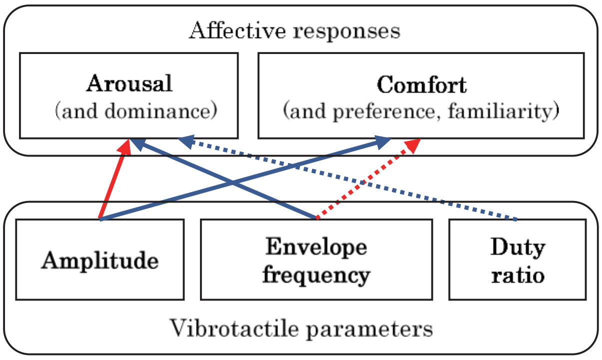

Figure 4: Effect of vibrotactile parameters on two-dimensional affective responses

Red and blue lines indicate positive and negative effects, respectively. Dotted lines indicate effects that depend on the individual.

elicited by vibrotactile stimuli vary over two dimensions, namely, arousal (dominance) and comfort. Arousal and dominance can be merged, as well as comfort, preference, and familiarity.

The results from this study provided us insights to recommend the following guidelines for designing vibrotactile stimuli evoking two-dimensional affective responses, as illustrated in Figure 4. First, the effect on comfort can be tuned by the amplitude of the stimuli, which has also some influence on arousal. Next, the effect on arousal can be tuned by the envelope frequency or duty ratio. For instance, comfortable and arousing stimuli can be designed using low envelope frequency and small amplitude. However, the effects of affective stimuli designed by this method include individual differences. Envelope frequency influenced arousal and comfort inversely for some participants (Table 4). Thus, the effects of these two parameters are dependent for some individuals. Concretely, only two types of affective stimuli, either uncomfortable and arousing or comfortable and less arousing can be elicited by changing these two parameters for such individuals. To design two-dimensional affective stimuli, we need at least two parameters that independently influence the affective responses. We may need to seek another parameter to control the affective aspects of vibrotactile stimuli with more independency and clarity.

7. CONCLUSION

We investigated the effects of five parameters of vibrotactile stimuli, namely, waveform, amplitude, envelope frequency, duration, and duty ratio, on affective responses. This kind of research is scarce, especially with respect to the number of evaluated parameters. To determine the most effective parameters, we asked 11 participants to evaluate 48 amplitude-modulated vibrotactile stimuli, which were generated from different parameter combinations, by providing their affective responses to each stimulus. The responses included arousal, comfort, preference, familiarity, and dominance. We found that amplitude and envelope frequency of the vibrotactile stimuli were the most effective parameters to influence human affective responses. Especially, amplitude influenced arousal and dominance positively, and comfort, preference, and familiarity negatively. On the other hand, envelope frequency influenced arousal and dominance negatively. We expressed rhythm by the combination of duration and duty ratio, and it influenced some participants. Especially, duty ratio influenced arousal negatively. However, such effect was not consistent among participants and smaller than the effects of amplitude and envelope frequency.

The principal component analysis on the subjective scores revealed a two-dimensional model for affective responses composed by arousal (and dominance) and comfort elicited by vibrotactile stimuli. Hence, it may be sufficient to design affective vibrotactile stimuli by using two parameters, namely, amplitude and envelope frequency. However, the effects of these two parameters were not independent from each other for some participants. Thus, other parameter should be studied to suitably design affectively attractive vibrotactile stimuli.

This study provided a guideline for designing affective vibrotactile stimuli for commercial electronic devices such as touch panel displays and suggests the direction for future studies on the relationship between vibrotactile stimuli and affective responses.

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APPENDIX

Partial regression coefficients from multiple regression analysis of individual participants

		Participant A	Participant B	Participant C	Participant D	Participant E	Participant F	Participant G	Participant H	Participant I	Participant J	Participant K
Arousal	Triangle	−0.20 (*p* = .44)	8.3E-2 (*p* = .74)	0.10 (*p* = .66)	−0.18 (*p* = .56)	−0.32 (*p* = .28)	−0.27 (*p* = .36)	−0.36 (*p* = .16)	−2.3E-3 (*p* = .94)	−0.26 (*p* = .40)	−0.47 (*p* = .13)	−0.41 (*p* = .19)
	Amplitude [m/s^2]	2.9E-3	4.1E-3	3.6E-3	1.8E-3 (*p* = .16)	2.0E-3 (*p* = .09)	4.1E-3	5.5E-3	3.2E-3	1.6E-3 (*p* = .21)	3.3E-3	1.6E-3 (*p* = .23)
	Frequency [Hz]	−5.8E-3	−4.1E-3	−6.5E-3	1.3E-3 (*p* = .45)	−4.5E-3	−2.2E-3 (*p* = .16)	−2.3E-3 (*p* = .11)	−3.2E-3	2.2E-3 (*p* = .19)	1.6E-3 (*p* = .33)	−2.7E-3 (*p* = .12)
	Duration [ms]	−3.4E-4 (*p* = .73)	−3.0E-4 (*p* = .77)	−3.5E-4 (*p* = .68)	1.0E-3 (*p* = .44)	−1.6E-3 (*p* = .17)	5.4E-5 (*p* = .96)	4.9E-5 (*p* = .96)	−5.1E-4 (*p* = .65)	2.4E-3	1.4E-3 (*p* = .24)	7.4E-4 (*p* = .56)
	Duty ratio	0.16 (*p* = .70)	−1.4	0.16 (*p* = .65)	−7.9E-2 (*p* = .88)	0.25 (*p* = .62)	−0.54 (*p* = .28)	−1.4	−0.48 (*p* = .32)	0.31 (*p* = .56)	−0.29 (*p* = .58)	−0.16 (*p* = .76)
Comfort	Triangle	−6.0E-2 (*p* = .70)	−0.35 (*p* = .25)	−0.42	−0.12 (*p* = .70)	0.24 (*p* = .38)	0.36 (*p* = .24)	−4.8E-2 (*p* = .86)	−5.1E-2 (*p* = .86)	−6.2E-2 (*p* = .84)	0.19 (*p* = .55)	−0.54 (*p* = .08)
	Amplitude [m/s^2]	−4.8E-3	−1.1E-3 (*p* = .41)	−6.4E-4 (*p* = .53)	−8.1E-5 (*p* = .95)	−1.4E-3 (*p* = .26)	−6.5E-4 (*p* = .62)	−4.9E-3	−4.8E-3	−2.5E-3 (*p* = .06)	−1.5E-3 (*p* = .26)	−2.0E-3 (*p* = .16)
	Frequency [Hz]	4.5E-3	−8.8E-4 (*p* = .61)	7.6E-3	−4.9E-4 (*p* = .78)	−5.4E-3	1.2E-3 (*p* = .48)	−4.5E-3	2.6E-3 (*p* = .09)	−3.7E-3	−1.0E-3 (*p* =.56)	2.3E-3 (*p* = .19)
	Duration [ms]	−1.1E-3 (*p* = .21)	−2.4E-3 (*p* = .06)	−4.5E-5 (*p* = .96)	4.1E-4 (*p* = .75)	−2.6E-3	−1.5E-3 (*p* = .25)	−3.2E-4 (*p* = .77)	−1.6E-4 (*p* = 89)	−1.6E-3 (*p* = .21)	−1.5E-3 (*p* = .23)	2.3E-3 (*p* = .07)
	Duty ratio	0.10 (*p* = .81)	−0.81 (*p* = .13)	−1.0	0.13 (*p* = .80)	0.87 (*p* = .06)	0.74 (*p* = .16)	−0.80 (*p* = .08)	1.3	−0.82 (*p* = .10)	−0.36 (*p* = .49)	−0.96 (*p* = .07)
Preference	Triangle	0.27 (*p* = .27)	−0.40 (*p* = .19)	−0.30 (*p* = .19)	−7.9E-17 (*p* = 1.0)	0.21 (*p* = .42)	0.26 (*p* = .40)	−0.30 (*p* = .27)	−0.16 (*p* = .59)	−3.6E-2 (*p* = .91)	−9.0E-2 (*p* = .79)	−0.95
	Amplitude [m/s^2]	−4.5E-3	−2.0E-3 (*p* = .13)	−9.0E-4 (*p* = .40)	−1.4E-3 (*p* = .30)	−1.1E-3 (*p* = .37)	−8.4E-4 (*p* = .52)	−4.0E-3	−4.4E-3	−1.9E-3 (*p* = .15)	−1.3E-3 (*p* = .32)	−2.1E-3 (*p* = .09)
	Frequency [Hz]	4.2E-3	9.0E-4 (*p* = .60)	6.6E-3	−9.9E-4 (*p* = .57)	5.0E-3	9.1E-4 (*p* = .60)	−3.6E-3	2.8E-3 (*p* = .08)	−3.1E-3 (*p* = .07)	−1.2E-3 (*p* = .47)	2.5E-3 (*p* = .11)
	Duration [ms]	−7.9E-4 (*p* = .40)	−1.7E-3 (*p* = .19)	4.2E-4 (*p* = .66)	−5.9E-4 (*p* = .65)	3.3E-3	−8.4E-4 (*p* = .52)	−4.0E-4 (*p* = .71)	3.7E-4 (*p* = .74)	−1.5E-3 (*p* =.26)	−8.1E-4 (*p* = .51)	7.2E-4 (*p* = .54)
	Duty ratio	−9.7E-2 (*p* = .81)	−0.47 (*p* = .37)	−1.4	0.46 (*p* = .39)	0.91	0.53 (*p* = .32)	−1.0	1.3	−0.90 (*p* = .09)	−5.6E-2 (*p* = .91)	−0.55 (*p* = .25)
Familiarity	Triangle	−2.3E-2 (*p* = .93)	0.44 (*p* = .16)	−0.26 (*p* = .21)	−0.19 (*p* = .53)	−0.17 (*p* = .57)	6.1E-2 (*p* = .84)	−0.51 (*p* = .07)	−5.7E-2 (*p* = .83)	−0.34 (*p* = .32)	−0.33 (*p* = .28)	−0.72
	Amplitude [m/s^2]	−2.3E-3 (*p* = .06)	8.0E-4 (*p* = .54)	−1.5E-3 (*p* = .11)	1.6E-3 (*p* = .20)	−9.0E-4 (*p* = .48)	−3.4E-4 (*p* = .78)	−3.5E-4 (*p* = .80)	−5.3E-3	−5.3E-5 (*p* = .68)	−1.1E-3 (*p* =.40)	−1.1E-3 (*p* = .40)
	Frequency [Hz]	6.0E-3	−2.4E-3 (*p* = .17)	8.4E-3	4.5E-3	4.4E-3	7.9E-4 (*p* = .63)	−3.2E-3	−1.1E-3 (*p* = .45)	−2.2E-3 (*p* = .18)	−1.7E-3 (*p* = .32)	2.3E-3 (*p* = .16)
	Duration [ms]	−6.6E-6 (*p* = .99)	−1.6E-3 (*p* = .20)	3.0E-4 (*p* = .73)	8.0E-4 (*p* = .51)	1.8E-3 (*p* = .14)	−2.8E-3	7.3E-5 (*p* = .95)	1.5E-3 (*p* = .16)	6.5E-4 (*p* = .60)	−3.9E-4 (*p* = .76)	1.0E-3 (*p* = .41)
	Duty ratio	0.24 (*p* = .61)	−0.50 (*p* = .34)	−0.90	−9.3E-2 (*p* = .85)	−0.26 (*p* = .60)	5.2E-2 (*p* = .92)	−1.3	1.3	−0.17 (*p* = .75)	−0.32 (*p* = .55)	−0.41 (*p* = .42)
Dominance	Triangle	−6.0E-2 (*p* = 0.84)	0.12 (*p* = .65)	0.10 (*p* = .70)	−1.5E-17 (*p* = 1.0)	−0.14 (*p* = .62)	0.35 (*p* = .16)	−0.44 (*p* = .12)	−1.3E-2 (*p* = .96)	2.0E-2 (*p* = .95)	−0.41 (*p* = .18)	−0.29 (*p* = .36)
	Amplitude [m/s^2]	−2.1E-3 (*p* = .11)	2.3E-3	3.0E-3	−3.1E-4 (*p* = .82)	1.7E-3 (*p* = .16)	5.8E-3	4.5E-3	3.5E-3	−8.9E-5 (*p* = .95)	3.2E-3	2.4E-3
	Frequency [Hz]	4.5E-3	−6.0E-3	−4.2E-3	4.8E-4 (*p* = .78)	−5.8E-3	−4.0E-4 (*p* = .80)	−3.0E-3 (*p* = .06)	−3.9E-3	−3.8E-4 (*p* = .83)	5.6E-4 (*p* = .74)	−1.6E-3 (*p* = .36)
	Duration [ms]	−1.3E-3 (*p* = .29)	−1.8E-4 (*p* = .86)	−8.0E-4 (*p* = .44)	8.4E-4 (*p* = .52)	−7.5E-4 (*p* = .51)	−3.3E-4 (*p* = .74)	−6.6E-4 (*p* = .56)	1.0E-4 (*p* = .92)	2.8E-4 (*p* = .83)	1.7E-3 (*p* = .16)	−6.8E-4 (*p* = .60)
	Duty ratio	−0.66 (*p* = .18)	−0.60 (*p* = .17)	−1.3	−0.70 (*p* = .19)	9.2E-2 (*p* = .84)	−0.60 (*p* = .16)	−0.88 (*p* = .06)	−0.46 (*p* = .32)	0.13 (*p* = .80)	0.24 (*p* = .65)	0.93 (*p* = .08)

The cells in orange and gray contain statistically significant values at $p < .05$ and $p < .10$, respectively.

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