



# Evaluating Smartphone Vibration Patterns and Evoked Feelings using Semantic Differential Method

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**Abstract.** Vibration patterns or tactile patterns are widely used as user interfaces to alert users about messages from mobile devices. Previous studies suggested that elderly users can understand the meanings of up to three vibration patterns. However, if a vibration pattern evokes a sensory image or emotion, it can carry the message relating to that image or emotion; therefore, users are not required to learn more vibrational patterns associated with declarative knowledge. To confirm this hypothesis, we aimed to clarify the user feelings evoked by vibration patterns using the semantic differential method (SDM) and, as the first step, created six vibration patterns for investigation. SDM can quantify the feelings evoked by a subject, image, and concept. Questionnaire items were designed as fifteen adjective pairs using a seven-point Likert scale. Eighteen healthy male students participated. An analysis of the questionnaire data by exploratory factor analysis revealed three factors affecting the subjective feelings of vibration patterns, including dominant ones named “Nervousness” and “Calmness.” A verification experiment confirmed the validity of the two dominant factors using three vibration patterns characterized more by “Nervousness” and/or “Calmness.” Consequently, the method that characterized vibration patterns by dominant factors was useful for designing patterns that evoke common feelings.

**Keywords:** Tactile Interface, Vibration Pattern, Semantic Differential Method

## 1 Introduction

Mobile terminals like smartphones can convey information to users through vibration. User interfaces that provide vibrotactile stimulation through vibrations are referred to as tactile interfaces, and they can convey a variety of information, such as incoming phone calls or e-mails, to users through vibrations.

Research on the use of tactile interfaces to convey information dates back to the 1950s. Frank conducted pioneering research on the role played by the sense of touch in human communication [1]. Many studies have emerged in recent years owing to the widespread use of smartphones and wearable devices. For example, a study involving a “Vibration Mouse,” equipped with a built-in motor for input, revealed that a challenge to adding meaningful information to vibration patterns was that people had to

remember multiple patterns and the information they contained. Therefore, people could not memorize more than three vibration patterns [2]. Louise et al. conducted a study on vibrotactile feedback to assist the visually impaired in controlling their power wheelchairs. They tried to assist the driver of an electric wheelchair by using a vibrating device attached to the arm to provide information about the location of obstacles [3]. Mohammadreza et al. researched using vibrotactile feedback to assist deaf people with task processing. Participants were asked to perform tasks in a virtual environment, and the speed of performing the tasks was evaluated in the presence of vibrotactile stimulation [4]. Ji-Won and Kee-Ho conducted a study on supporting drone pilots with vibrotactile stimulation. In addition to the pilot's visual information, the researchers were trying to provide information about obstacles in the drone's path using vibrotactile stimulation [5]. Thus, studies on vibrotactile stimulation have been actively conducted. However, we focused on feelings based on the differences in the types of vibrotactile stimulation rather than their presence or absence. If a vibration pattern allows people to imagine the meaning, there is no need to store the vibration pattern and its information, and the transmission of specific information by the vibration pattern may be facilitated. In this study, we clarified the characteristics of vibration patterns that evoke specific feelings, such as "Crisis," independent of people's memory.

To clarify the characteristics of vibration patterns that evoke specific feelings, the feelings evoked by people for different vibration patterns need to be measured. Participants were asked to respond to 85 different impressions of vibration patterns on a 5-point interval scale using a semantic differential method (SDM) rating form with 15 adjective pairs [6]. The SDM method describes and expresses the mutual differences and relationships among the implicit and affective meanings of various concepts objectively and quantitatively [7]. It measures people's mental responses, and by using factor analysis, the feelings that people experience from vibration patterns can be visualized in a feeling space.

Research is needed to clarify the characteristics of vibration patterns that should be incorporated to evoke certain feelings in people and demonstrates the practical application of the research results in people's lives. This study investigated the characteristics of vibration patterns that evoke a particular feeling based on the questionnaire results, where participants were asked to respond to feelings of a vibration pattern, and proposed a vibration pattern designed to incorporate these characteristics.

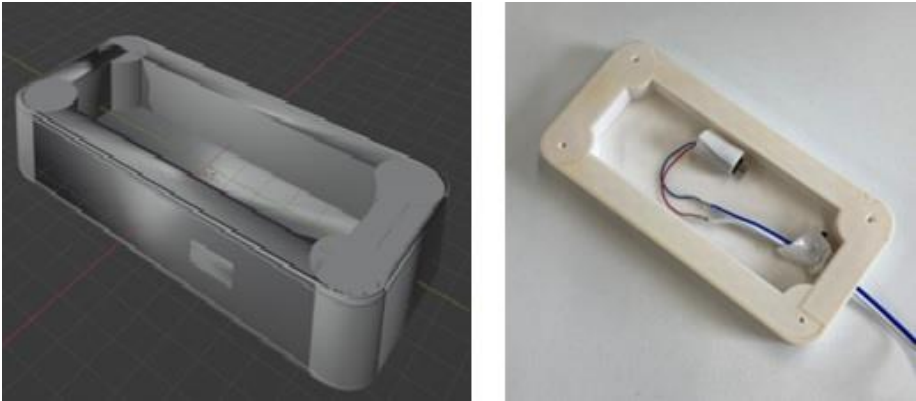
## **2 Method**

### **2.1 Participants**

Eighteen healthy male students aged 20 to 24 (mean = 21.7, SD = 0.9) participated in the study. We focused on differences in feelings experienced after vibrotactile stimulation. Therefore, participants were selected from among young people with vibrotactile perception. The Research Ethics Committee of the Chitose Institute of Science and Technology (Reception No. 2022-7) approved and reviewed this study. Informed consent was obtained from the participants before the experiment.

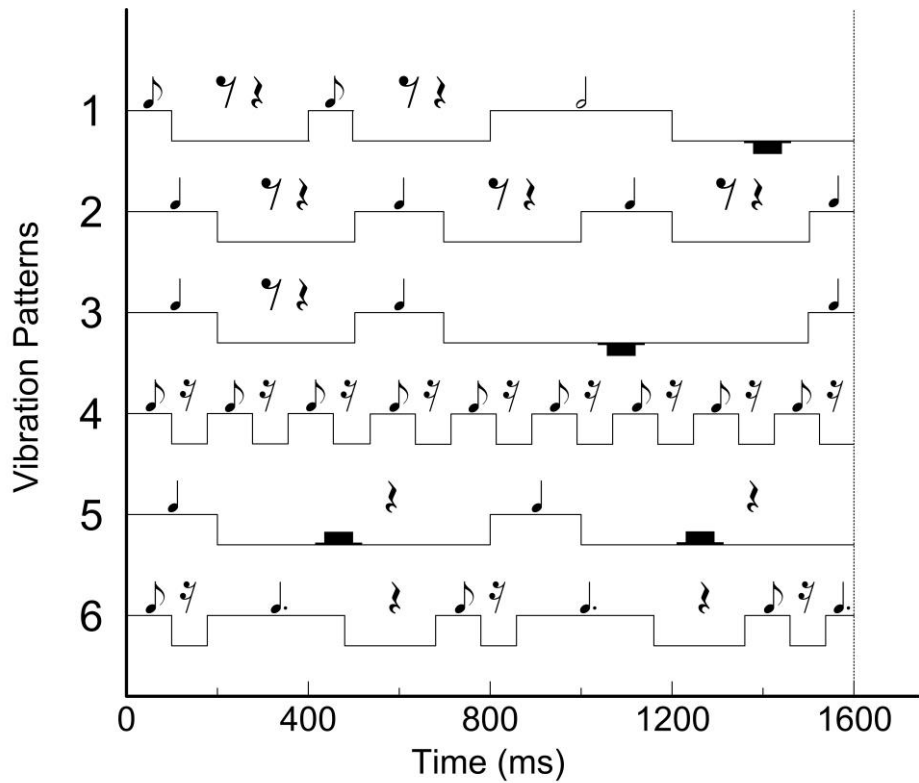
## 2.2 Apparatus

The device used to present multiple vibration patterns to participants was made using a 3D printer (Adventurer 3X by FLASHFORGE), and the housing of the device mimicked the shape and form factor of smartphones (Fig. 1). A vibration motor (CL-0614-13103-3 by S.T.L.JAPAN) was embedded in this device and was covered with a rubber cover (RC-VM612 by S.T.L.JAPAN).



**Fig. 1.** 3D model of the vibration device (left panel) and the smartphone-like shape (right panel).

The device presented six different vibration patterns (Fig. 2). The vertical axis indicates the type of vibration pattern, and the horizontal axis indicates time (in milliseconds). The patterns used in the experiment were composed by combining musical notes and rests: Half Note, Dotted Quarter Note, Quarter Note, Eighth Note, Whole Rest, Half Rest, Quarter Rest, Eighth Rest, and Sixteenth Rest. The notes represent the duration of vibration, while the rests are periods of silence. Table. 1 shows the time and frequency of each note and rest that are common to the created vibration pattern.



**Fig. 2.** Six different vibration patterns.

**Table 1.** Time and frequency of notes and rests.

Notes and Rests		Time (ms)	Frequency (Hz)
	Half Note	400	0.0025
	Dotted Quarter Note	300	0.0033
	Quarter Note	200	0.005
	Eighth Note	100	0.01
	Whole Rest	800	0.00125
	Half Rest	400	0.0025
	Quarter Rest	200	0.005
	Eighth Rest	100	0.01
	Sixteenth Rest	50	0.02

### 2.3 Selecting Adjectives

We repeatedly presented six vibration patterns to two participants for 15 s to produce a rating paper experimentally, to which they responded based on their perception of the

vibration patterns. Each vibration pattern was presented once. Participants described the feeling presented by the vibration pattern, and adjective pairs were selected to describe these feelings. As Table 2 shows, fifteen adjective pairs were picked out.

**Table 2.** Fifteen selected adjective pairs.

No.	Adjectives	
1	Chilled	Nervousness
2	Light	Heavy
3	Placid	Boisterous
4	Comfortable	Uncomfortable
5	Laugh	Bored
No.	Adjectives	
6	Reassured	Scary
7	Refreshed	Down
8	General	Special
9	Cheerful	Gloomy
10	Calm	Heart-beating
No.	Adjectives	
11	Soft	Hard
12	Safe	Precarious
13	Loose	Tight
14	Pleased	Unpleased
15	Powerless	Powerful

## 2.4 Evaluation of Feelings from Vibration Patterns

**Overview.** Participants replied to feelings of different vibration patterns using the fifteen adjective pairs in Table 1. Each of the eighteen participants experienced six different vibration patterns once in random order.

**Procedure.** A voltage of 1.2 V, which is the maximum voltage for the vibration motor, was applied through a high-precision analog input/output terminal (AIO-160802AY-USB by CONTEC) to the vibration motor embedded in the device held by each participant. Fig. 3 displays an application that showed six different vibration patterns. Participants wore earmuffs to block out the sounds produced by the vibrating motors.



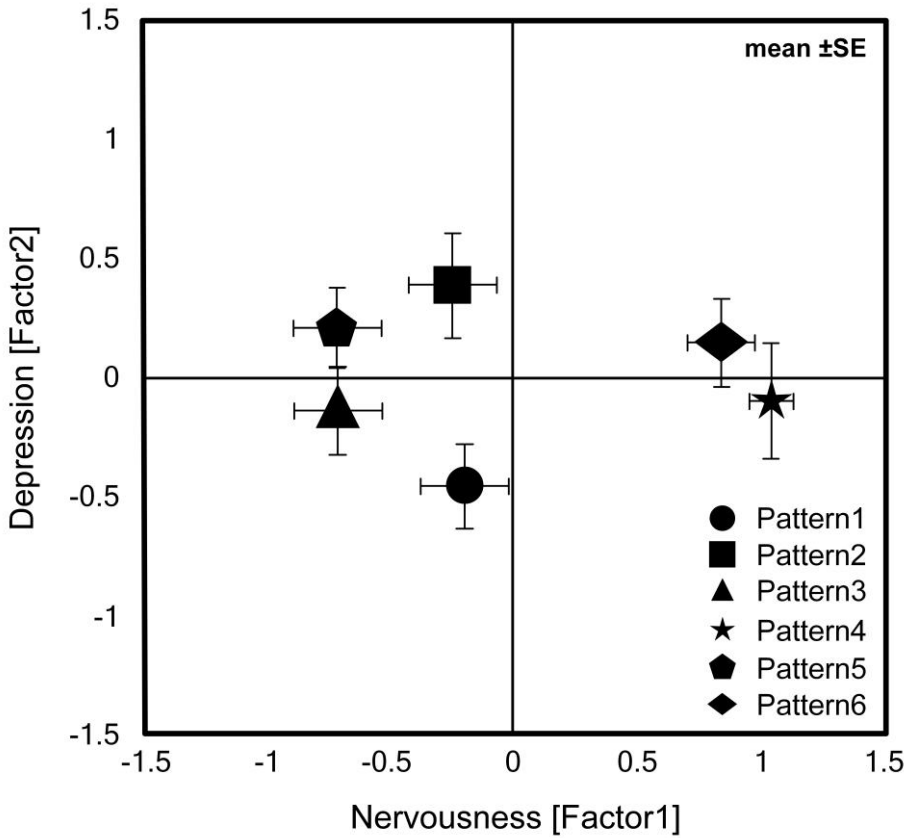
**Fig. 3.** Experiment (left panel) and application showing six different vibration patterns (right panel).

### 3 Results

#### 3.1 Factor Analysis of Feelings

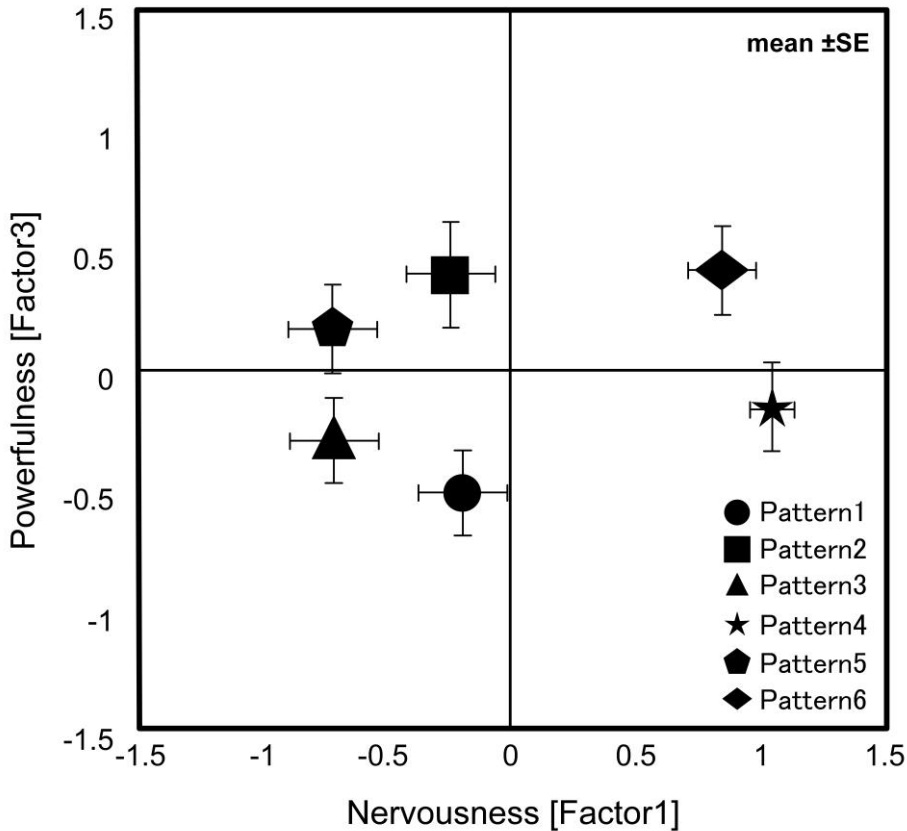
The results of the Kaiser-Meyer-Olkin (KMO) test and Bartlett’s sphericity test showed a sample validity measure of  $p = .917$ . The factor analysis was validated. Bartlett’s sphericity test significantly inferred common factors by factor analysis ( $p = .001$ ). In other words, there is a common factor in the feelings evoked by vibration patterns.

In terms of the adjective pairs with factor loadings of 0.5 or higher for each factor, the first was named “Nervousness,” the second “Depression,” and the third “Powerfulness.” The image space is displayed using the first and second factors as axes, with representation based on the factor scores of six different vibration patterns, in Fig. 4.



**Fig. 4.** Feeling space of “Nervousness” and “Depression”

Patterns 4 and 6, which featured fast-tempo patterns with rests of 50 ms, received high ratings for “Nervousness.” Conversely, patterns 3 and 5, characterized by slow-tempo patterns with rests lasting 600–800 ms, received low ratings. Therefore, a fast-tempo vibration pattern made participants nervous, while a slow-tempo vibration pattern made them calm. The image space is displayed with the first and third factors as axes, represented by the factor scores of six different vibration patterns, in Fig. 5.



**Fig. 5.** Feeling space of “Nervousness” and “Powerfulness.”

There were no significant differences in the factor scores for “Powerfulness,” the third factor among the six vibration patterns. In other words, none of the six types of vibration patterns elicited a pronounced sense of “Nervousness.”

### 3.2 One-way Analysis of Variance and Multiple Comparison

One-way analysis of variance is an analytical technique that can be performed on the assumption that the variances of each level are equal. Therefore, it is essential to test for equal variances before conducting the analysis. We conducted equivariance tests on the results for the first factor, i.e., “Nervousness.” The results indicated that the variances at each level were equal ( $p = .051$ ). Consequently, we performed a one-way analysis of variance.

The result of the one-way analysis of variance showed that a significant main effect was observed in the average ratings across the six vibration patterns. Consequently, specific vibration patterns among the six patterns strongly induced feelings of “Nervousness.”

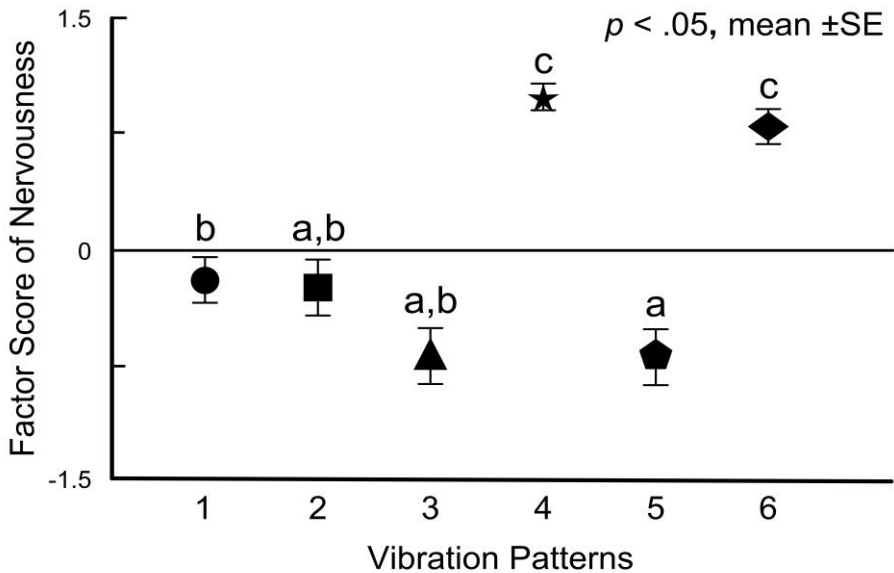


We conducted multiple comparisons using the Ryan-Einot-Gabriel-Welsch F test to identify the vibration patterns that elicited a sense of “Nervousness” (Table. 3). The differences between the vibration patterns (PATT.) are shown in the equality subgroups (Fig. 6).

**Table 3.** Multiple comparisons of “Nervousness” using the Ryan-Einot-Gabriel-Welsch F test.

PATT.	PATT.	<i>p</i>	signifi- cance	PATT.	PATT.	<i>p</i>	signifi- cance
1	2	0.998	n.s.	4	1	0.002	**
	3	0.275	n.s.		2	<.001	***
	4	0.002	**		3	<.001	***
	5	0.379	n.s.		5	<.001	***
	6	0.027	*		6	0.997	n.s.
2	1	0.998	n.s.	5	1	0.379	n.s.
	3	0.949	n.s.		2	0.989	n.s.
	4	<.001	***		3	1	n.s.
	5	0.989	n.s.		4	<.001	***
	6	0.004	**		6	<.001	***
3	1	0.275	n.s.	6	1	0.027	*
	2	0.949	n.s.		2	0.004	**
	4	<.001	***		3	<.001	***
	5	1	n.s.		4	0.997	n.s.
	6	<.001	***		5	<.001	***

\*:  $p < .05$ , \*\*:  $p < .01$ , \*\*\*:  $p < .001$



**Fig. 6.** Differences between vibration patterns are shown in the equality subgroups.

In Fig. 6, symbols “a” to “c” represent equality subgroups, indicating no significant difference between vibration patterns within the same subgroup at a 5% significance level. Patterns 2 and 5, which feature no inflection in tempo, belong to subgroup “a,” 1 and 3, characterized by 800 ms rests and a slow tempo, to “b” and 4 and 6, featuring 50 ms rests and a fast tempo, to “c.” No significant differences between vibration patterns 1, 2, and 3 or 2, 3, and 5 were found. However, 4 and 6 were significantly higher than 3 and 5 ( $p < .001$ ). Pattern 4 was significantly higher than pattern 1 ( $p < .01$ ) and pattern 2 ( $p < .001$ ). Similarly, Pattern 6 was significantly higher than pattern 1 ( $p < .05$ ) and pattern 2 ( $p < .01$ ). Therefore, Patterns 4 and 6 stood out as those that induced the highest level of nervousness among the six patterns.

By contrast, a one-way analysis of variance for the second factor, “Depression,” and third factor, “Powerfulness,” revealed no significant main effect across the average ratings of the six vibration patterns. Therefore, strong feelings of “Depression” or “Powerfulness” cannot be attributed to any of the six vibration patterns.

## 4 Discussion

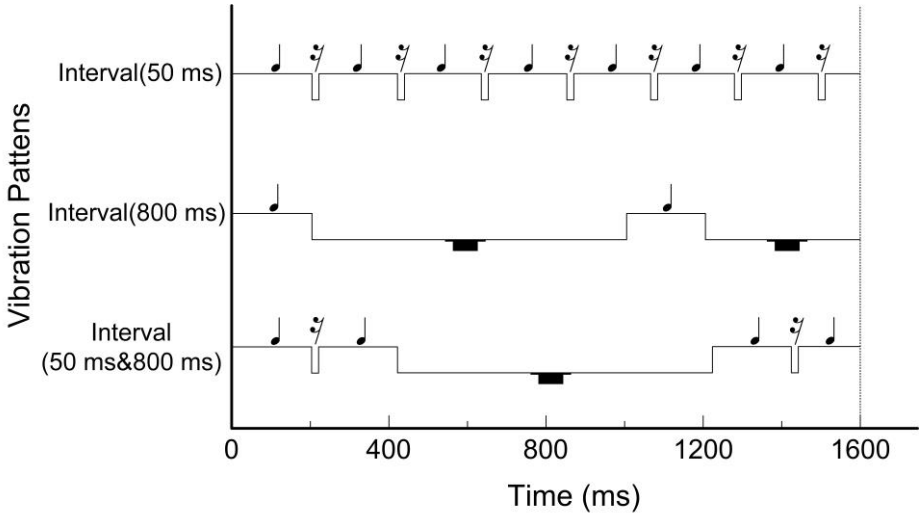
### 4.1 Feelings of Vibration Patterns

Participants described the fast-tempo vibration pattern as “a very impatient vibration” and the slow-tempo as “having a relaxed tempo with a calming feeling,” suggesting that a fast-tempo vibration pattern is suitable when creating a sense of crisis. By contrast, a slow-tempo suits calmness.

From the above, the fast-tempo vibration pattern is suitable for signaling an emergency in a noisy environment, while the slow-tempo suits a quiet place.

### 4.2 Designing Vibration Patterns

We designed vibration patterns to include characteristics that easily induce “Nervousness” and characteristics that readily evoke “Calmness.” Three different vibration patterns designed to incorporate features that elicit specific emotional responses are displayed (Fig. 7). We standardized the vibration duration to 200 ms and asked participants whether “Nervousness” was elicited using these vibration patterns.



**Fig. 7.** Three different vibration patterns designed to incorporate characteristics to give a particular feeling.

After experiencing vibration patterns at intervals of 50 ms, most participants reported feeling “Nervousness.” By contrast, for vibration patterns with 800 ms intervals, most participants reported not feeling “Nervousness.” Furthermore, when participants experienced vibration patterns with alternating intervals of 50 and 800 ms, many reported feeling “Nervousness.” Sainsbury and Gibson reported that an increase in innervation of skeletal muscles accompanies anxiety, causing greater muscle tension in anxious individuals trying to relax compared with healthy subjects [8]. Caterina described that perceptions of touch, temperature, and pain provide information about our bodies’ condition and the world around us, playing critical roles in our functionality, self-protection, comfort, and social interactions [9].

Therefore, classifying vibration patterns by “Nervousness” and “Calmness” is considered appropriate.

## 5 Conclusion

In this study, we investigated the relationship between the structure of vibration patterns and the feeling they elicit. As a result, differences in the feelings held according to the speed of the tempo, such as fast-tempo and slow-tempo vibration patterns, became apparent. Specifically, the participants felt a sense of urgency with fast-tempo vibration patterns and calmness with slow-tempo vibration patterns. However, it is necessary to present more vibration patterns and to identify in detail the characteristics of vibration patterns that induce “Nervousness” and “Calmness.”

In addition, adjusting the amplitude of the presented vibration was impossible owing to the components used in the vibration presentation device. Yoshida et al. described that vibrations with an amplitude of 0.5–0.7 mm and a frequency of approximately 2

Hz have a pleasant effect on the human body [10]. However, the threshold for amplitude, differentiating between pleasant and tense vibrations, remains undefined. Therefore, future studies may investigate variations in feelings when altering the vibration amplitude.

Furthermore, since the vibration patterns were presented to participants for only 15 s, examining the potential effects of stress on the autonomic nervous system responses and feelings they may have when the same vibration patterns are presented for an extended duration is necessary.

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