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# Large-Scale Survey on Adjectival Representation of Vibrotactile Stimuli

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***Abstract*— Objective descriptions of the perceptual impression of vibrotactile sensations have become an important issue for designing haptic interaction. In this study, we conducted a large-scale survey on adjectival representations of vibrotactile stimuli with 520 participants using 16 adjective pairs to find naturally associated words to vibrotactile stimuli. The vibrotactile stimuli used were designed to result in the perception of sequentially varying frequency (vibrotactile pitch) using single-frequency sinusoidal vibrations and dual-frequency superimposed vibrations. In results, metaphoric adjective pairs of 'heavy–light' and 'thick–thin' were most frequently used for single-frequency vibrations. In contrast, dual-frequency superimposed vibrations were largely attributed to three adjective pairs that bear more physical meanings, 'slow–fast', 'sparse–dense', and 'bumpy–even'.**

## I. Introduction

Vibrotactile stimuli are used in a wide variety of applications in order to deliver physical or abstract information or improve user experiences [1]. However, it is difficult to express the sensations of vibrotactile stimuli using objective and standard terms unlike other sensory modalities. For example, terms representing visual colors, textures, and brightness have long been established and used in daily life. The 12-semitone octave scale is standard for describing auditory pitch perception.

In haptics, researchers have studied to find perceptual dimensions underlying vibrotactile perception and match those perceptual dimensions with appropriate adjectives. For instance, van Erp and Spapé evaluated the suitability of 16 words for explaining the sensations of 59 vibrotactile melodies extracted from diverse music pieces [6]. Kyung and Kwon looked at perceived roughness as a function of vibration frequency and amplitude using a vibrotactile pin array [3]. MacLean's group investigated perceptual dimensions using vibrations of various rhythms, and they found two prominent dimensions of evenness and duration [5]. Our group studied adjectival representations of sinusoidal vibrations in the context of mobile applications [2], as well as consonance perception (perceived degree of harmony) of dual-frequency superimposed vibrations [8].

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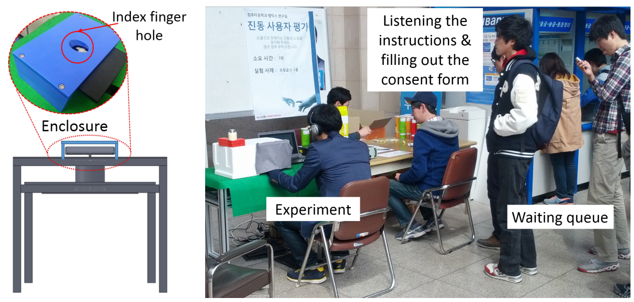


Fig. 1. Experimental apparatus and setup.

Despite these endeavors, a well-established vocabulary for vibrotactile sensations does not exist, especially for vibrations that are spectrally complex. In this work-in-progress paper, we report a large-scale user survey that was carried out with 520 participants to associate adjectives to vibrotactile sensations. Emphasis was on the effects of the frequency content of vibrations and the immediate, natural responses of general non-expert users. Other salient features such as rhythm, envelope, and amplitude were not considered.

## II. Methods

### A. Apparatus

This work was part of a large research project on the use of vibrotactile feedback for a tablet computer. Participants perceived vibrations by touching a tablet mockup (teflon-coated metal plate; $16 \times 16 \times 0.8$ cm) with a finger. The mockup was driven by a mini-shaker (4809, Brüel & Kjær; bandwidth dc–18 kHz) and an amplifier (2719, Brüel & Kjær). The total mass of the moving part including the mockup and assembly was 550 g. The shaker was controlled by a PC through a data acquisition card (USB-6251, National Instruments) at 10-kHz sampling rate.

The tablet mockup and shaker were enclosed by a plastic cover and placed within a custom-made table to provide a comfortable posture with stable contact (Fig. 1, left). Participants inserted an index finger to the hole in the plastic cover to touch the mockup. A curtain covered the entire vibration apparatus to preclude any visual information (Fig. 1, right). Participants also wore noise-canceling headphones to block faint sound produced by the shaker.

### B. Stimuli

This user survey used 13 sets of vibrations. Six of them included single-frequency sinusoidal vibrations. The other

TABLE I

SINGLE-FREQUENCY VIBRATION SETS.

| Set | Duration (ms) | Frequencies (Hz) |
|---|---|---|
| S-L-1000 | 1000 | 50, 56, 63, 70, 78, 88, 98, 110 |
| S-L-100 | 100 | 50, 56, 63, 70, 78, 88, 98, 110 |
| S-L-25 | 25 | 50, 56, 63, 70, 78, 88, 98, 110 |
| S-H-1000 | 1000 | 100, 114, 130, 148, 169, 193, 219, 250 |
| S-H-100 | 100 | 100, 114, 130, 148, 169, 193, 219, 250 |
| S-H-25 | 25 | 100, 114, 130, 148, 169, 193, 219, 250 |

TABLE II

DUAL-FREQUENCY VIBRATION SETS.

| Set | Mix Ratio | Base Frequencies (Hz) |
|---|---|---|
| D-L-1.2 | 1.20 | 50, 58, 66, 76, 87 |
| D-L-2.0 | 2.00 | 50, 58, 66, 76, 87 |
| D-H-1.2 | 1.20 | 100, 115, 132, 152, 175 |
| D-H-2.0 | 2.00 | 100, 115, 132, 152, 175 |
| Set | Base Freq. (Hz) | Mix Ratios |
| D-50-MR | 50 | 1.10, 1.22, 1.35, 1.49, 1.64, 1.81, 2.00 |
| D-92-MR | 92 | 1.10, 1.22, 1.35, 1.49, 1.64, 1.81, 2.00 |
| D-175-MR | 175 | 1.10, 1.22, 1.35, 1.49, 1.64, 1.81, 2.00 |

* For example, base frequency 50 Hz and mix ratio 1.2 mean that the vibration consists of two frequency components, 50 Hz and 60 Hz (50 Hz×1.2), with the same amplitudes.

seven sets included dual-frequency superimposed vibrations.

For single-frequency vibrations (Table I), the effects of frequency and duration were investigated. The frequency range was divided into low (L; 50–110 Hz) and high (H; 100–250 Hz) ranges. The sensations of such low- and high-frequency vibrations are considerably different [1], [2]. Each set included eight vibrations with different frequencies. For duration, we chose three different values: 1000 ms (long), 100 ms (medium), and 25 ms (short), considering the temporal summation characteristics of the Pacinian channel [7].

For dual-frequency vibrations (Table II), we changed the base frequency and the mix ratio between the two frequencies. These two variables determine the perceptual properties of superimposed vibrations [8]. In four sets, two sets (low and high) of five base frequencies were combined with two mix ratios (1.2 and 2.0). In the other three sets, seven mix ratios were applied to three base frequencies (50, 92, and 175 Hz). All the dual-frequency vibrations had the same duration of 1000 ms.

The perceived intensities of all the vibrations were equalized by another experiment that used the method of adjustment with 10 participants. The reference stimulus was a sinusoidal vibration (100 Hz, 1000 ms, 1 *g*).

In the survey, vibrations in each set was presented sequentially with an inter-stimulus interval of 0.5 s. Participants were expected to perceive the continuous changes in the spectral content of the vibrations.

### C. Selection of Adjectives

We also conducted a pilot experiment with 16 participants (all native Koreans; 10 male, 6 female; M 21.2 years) to find an appropriate set of adjectives to use in the survey. Participants perceived the 13 vibration sets in Table I and II repeatedly (more than five times) and described their sensations in words. Based on these results and also referring to the previous work [2], [8], we selected 16 adjective pairs, and their English translations are shown in Table III.

TABLE III

ADJECTIVE PAIRS USED IN THE SURVEY.

| | | | |
|---|---|---|---|
| slow–fast | deep–shallow | thick–thin | muddy–clear |
| heavy–light | sharp–blunt | warm–cold | dark–bright |
| thick–light | fluttering–(not) | solid–soft | rough–smooth |
| bumpy–even | vague–distinct | sparse–dense | jagged–even |

* thick–thin: extent, heavy–light: weight, thick–light: color
*'fluttering–(not)' represents 'fluttering–not fluttering.'

### D. Procedure and Participants

For this survey, we set up an experimental site in the students' union building at POSTECH (Fig. 1, right). Prior to the experiment, participants were asked to read written instructions carefully, and then they signed on a consent form. Afterwards each participant sat in front of the shaker table and lightly touched on the center of the tablet mockup using their left index finger. Then vibrations in one of the 13 vibrations sets were presented to the participant. The participant perceived the vibration set repeatedly (more than five times) and then selected three most adequate adjective pairs from Table III for describing the changes in the sensations. This procedure took approximately 5 minutes. This design allowed each participant to experience vibrations briefly in order to obtain their immediate responses. Instead, each vibration set was tested with a large number (40) of participants.

In total, 520 students (all native Korean; 411 male, 109 female; M 22.0 years; 40 for each of the 13 vibration sets) participated in the survey. All of them were recruited at the experimental site. They received a snack (≈ 2 USD) for compensation. Nobody reported any sensory disorder.

## III. RESULTS AND DISCUSSIONS

Table IV and V summarize the top five adjective pairs that were most frequently selected by the participants for each vibration set. Due to the limited space, we focus on the most important results in this section. Further details will be reported elsewhere in a full journal article.

### A. Single-Frequency Vibrations

The most noticeable result in Table IV is that the adjective pair 'heavy–light' was most frequently selected for all of the six single-frequency vibration sets. To our knowledge, this adjective pair was not reported in the literature to describe vibrotactile sensations. Literally 'heavy-light' is about weight, and it does not implicate a physical property of vibration. However, 'heavy-light' is also used for many metaphoric meanings, e.g., color, music, mood, etc. This wide use of the 'heavy-light' pair may account for its popularity as an immediate response to the continuous changes of vibration frequency, which were a new experience to most of the participants. This finding, however, may has two limitations.

TABLE IV

TOP FIVE ADJECTIVE PAIRS FOR SINGLE-FREQUENCY VIBRATION SETS

| S-L-1000 | S-L-100 | S-L-25 | S-H-1000 | S-H-100 | S-H-25 |
|---|---|---|---|---|---|
| heavy–light (17) | heavy–light (15) | heavy–light (21) | heavy–light (18) | heavy–light (16) | heavy–light (23) |
| bumpy–even (15) | thick–thin (14) | deep–shallow (16) | thick–thin (14) | thick–thin (14) | thick–light (19) |
| thick–thin (10) | muddy–clear (14) | thick–thin (14) | sharp–blunt (12) | thick–light (13) | thick–thin (16) |
| sharp–blunt (10) | bumpy–even (12) | sharp–blunt (12) | deep–shallow (11) | sharp – blunt (12) | deep–shallow (15) |
| slow–fast (9) | deep–shallow (11) | thick–light (11) | thick–light (10) | deep–shallow (11) | sharp–blunt (10) |

TABLE V

TOP FIVE ADJECTIVE PAIRS FOR DUAL-FREQUENCY VIBRATION SETS

| B-L-1.2 | B-L-2.0 | B-H-1.2 | B-H-2.0 | B-50-MR | B-92-MR | B-175-MR |
|---|---|---|---|---|---|---|
| sharp–blunt (16) | heavy–light (16) | thick–thin (16) | heavy–light (18) | sparse–dense (22) | sparse–dense (19) | rough–smooth (16) |
| vague–distinct (14) | thick–light (13) | slow–fast (11) | thick–thin (17) | slow–fast (20) | bumpy–even (17) | slow–fast (15) |
| sparse–dense (14) | slow–fast (11) | bumpy–even (11) | vague–distinct (13) | bumpy–even (19) | slow–fast (16) | sparse–dense (15) |
| bumpy–even (13) | thick–thin (11) | muddy–clear (10) | thick–light (12) | thick–thin (13) | rough–smooth (13) | bumpy–even (13) |
| slow–fast (10) | bumpy–even (10) | rough–smooth (9) | slow–fast (9) | heavy–light (9) | fluttering–(not) (8) | deep–shallow (9) |
| heavy–light (10) | | fluttering–(not) (9) | sparse–dense (9) | | | fluttering–(not) (9) |

First, the percentages of the participants who selected 'heavy-light' was 37.5% to 57.5%, which is not very high. Second, this result might depend on language and culture since it appears to be a metaphoric use. Also, the adjective pair 'thick–thin' was voted for frequently for all the single-frequency vibration sets.

It is worth to mention that the adjective pair 'bumpy–even' was in the top five list for only the two low-frequency vibration sets with sufficient durations (100 and 1000 ms). This is consistent with the previous study that reported rough, fluttering and bumpy sensations for low-frequency vibrations [2], [8] as a contribution of the RA1 (Rapidly Adapting 1) channel in vibrotactile perception [4]. 'Bumpy–even' was not selected frequently for the short (25 ms) low-frequency vibration set.

### B. Dual-Frequency Vibrations

Counting the number of occurrences of each adjective pair in Table V led to an observation that three adjective pairs, 'slow–fast', 'bumpy–even', and 'sparse–dense', were mostly frequently selected for the dual-frequency superimposed vibrations (7, 6, and 5 times, respectively, out of the seven vibration sets). Although the three adjective pairs describe different qualities in their original meanings, they may orginate from the same physical phenomenon of superimposed vibrations. A superimposed vibration generally delivers a clear sensation of beat, which has the frequency equal to the difference between the two superimposed frequencies [8]. Hence, the beat frequency is (often much) lower than the two component frequencies. For example, a $50\,\mathrm{Hz} + 60\,\mathrm{Hz}$ superimposed vibration has a 10-Hz beat. The three adjective pairs were consistently ranked very high especially for the three vibrations sets in which the beat frequency was changed sequentially (the three right columns in Table V). It seems that participants associated the sensations of low-frequency beat to the speed of pulse-like sensations ('slow–fast') or the density ('sparse–dense'). The beat sensations are also analogous to those perceived when scanning a bumpy surface ('bumpy–even').

The results of the other four vibrations sets (the four left columns in Table V) did not share additional apparent insights. However, we noticed that the results of the vibration sets with the mix ratio 2.0 were very similar to those of the single-frequency vibrations; it seems that the effects of superposition (beat) disappeared.

There were no adjective pairs that had been voted for by a majority of the participants (the highest 57.5%), similarly to the single-frequency vibration data.

## IV. CONCLUSIONS AND FUTURE WORK

In this study, we investigated the adjectival representations appropriate for describing the subjective quality of vibrotactile stimuli in a large-scale user survey with 520 participants. Main findings are twofold: 1) metaphoric adjective pairs of 'heavy–light' and 'thick–thin' were most frequently used for single-frequency vibrations and 2) dual-frequency superimposed vibrations were largely attributed to three adjective pairs that bear a more physical meaning, 'slow–fast', 'sparse–dense', and 'bumpy–even'. Topics for our future work include a scaling experiment of the subjective quality of vibration using the adjective pairs found in this study as perceptual metrics, as well as vibrotactile pattern authoring using adjectival scales.

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