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Exploring Electrovibration on the Palm and the Body

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Abstract

Electrovibration creates tactile sensations by modulating the friction between the skin and an insulated conductive surface powered by time-varying high-voltage signals [1]. This technology has been used extensively with touchscreens and occasionally with everyday objects. We present an exploration of electrovibration beyond the fingertip.

We first explored the design space and feasibility of electrovibrating clothing and wearables, before pivoting to its use on rigid objects that our palms brush against. We then sketched an electrovibrating keyboard that stimulates the palms. To better understand its capabilities, we conducted a psychophysical study to compare the detection thresholds of electrovibration at the palm and the fingertip. We found no statistically significant difference, which suggests that the palm is an appropriate target for electrovibration.

This work was originally published at the 2022 IEEE Haptics Symposium [2].

DESIGN SPACE EXPLORATION

Electrovibrating Clothing and Wearables

Preliminary experimentations with haptic sketches showed that electrovibration is strongest and most perceptible on the palm and fingertips, and slightly weaker on the wrist. We also found that electrovibration is difficult to produce on clothing because of its flexibility and that its feedback is frequently masked by other haptic cues present in clothing and wearables.

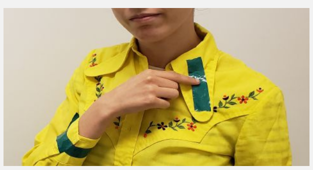

Figure 1. Mock-up of flexible electrovibrating surfaces.

Figure 2. Sketch of electrovibrating watch with cut capacitive plates.

Electrovibrating Objects

We decided to pursue interactive designs in which the palm naturally brushes against the surface of everyday things. We focused our initial inquiry on the surface below a keyboard.

Figure 3. Sketch of electrovibrating keyboard.

PSYCHOPHYSICAL EXPERIMENT

Experimental Apparatus

An electrovibrating surface made of a capacitive touchpad (3M) was driven by a signal generator. A load cell was installed under the electrovibrating surface so that the force applied by the finger or palm could be measured.

Procedure

The study (N=14) followed the same methods as [4] and used an adaptive staircase approach to estimate the absolute detection threshold at 5 frequencies (15, 30, 60, 120, and 240 Hz) on the fingertip and palm.

Results

While we observed a higher threshold at the palm for 10/14 participants, a one-way repeated measures ANOVA failed to show a statistically significant difference between the fingertip and the palm ($F(1, 26) = 2.252$, $p = 0.145$).

Figure 4. Experimental setup.

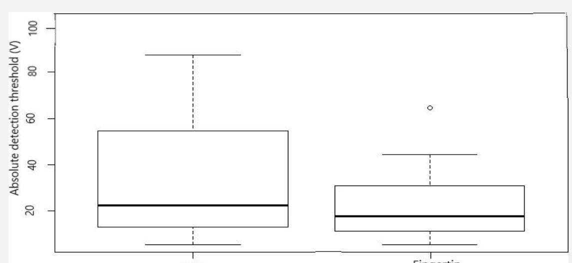

Figure 5. Absolute detection thresholds across participants.

Conclusion

The design space and feasibility of electrovibration on clothing, wearables, and smart items were initially investigated. We discovered that the palm is very sensitive to electrovibration and turned our attention to objects that the palm brushes against, such as a keyboard. We then conducted an experiment to compare the detection threshold of electrovibration at the fingertip and the palm. Our results indicate that the sensitivity of the palm to electrovibration is similar to that of the fingertip.

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Exploring Electrovibration on the Palm and the Body

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ABSTRACT

We present an exploration of electrovibration beyond the fingertip. We first explored the design space and feasibility of electrovibrating clothing and wearables, before pivoting to its use on rigid objects that our palms frequently brush against. We then conceptualized and sketched an electrovibrating keyboard that produces tactile feedback on the palms. To better understand the capabilities of this keyboard, we conducted a psychophysical experiment with 14 participants to compare the detection thresholds of electrovibration at the palm and the fingertip. We found no statistically significant difference between the palm and fingertip, which suggests that the palm is an appropriate target for electrovibration. This work was originally published at the 2022 IEEE Haptics Symposium [4].

1 INTRODUCTION

Tactile sensations are created by modulating friction between the skin and an insulated conductive surface that is powered by time-varying high-voltage signals [3]. This technology has been applied to interactions with everyday objects as well as touchscreens (e.g., [2, 3]). We propose using electrovibration to stimulate areas of the hand and body other than the fingertip via clothing, wearables, and smart objects. We begin with a consideration of the design space and feasibility of incorporating electrovibration into clothing and wearables (Figures 1 and 2). Our attention then moves to rigid objects, with a particular focus on the palm as a sensitive site for electrovibration. We conclude our investigation with a concept for an electrovibrating keyboard that generates tactile feedback when the user's hands brush over its lower surface, either accidentally or intentionally (Figure 3).

While the effect of amplitude [7], frequency [5], and waveform [6] on the tactile perception of electrovibration at the fingertip has already been studied, we are unaware of research that investigates electrovibration perception at the palm. As a result, we conducted an experiment to determine how the electrovibration stimulus is perceived at the palm. For a variety of frequencies, the experiment examines the absolute thresholds of electrovibration perception at the fingertip and palm. Our results suggest that electrovibration should be easily perceived on a keyboard that stimulates the palms.

2 DESIGN SPACE EXPLORATION

2.1 Electrovibrating Clothing and Wearables

To examine the perception of electrovibration on the body, we created haptic sketches using flexible conductive materials such as copper or aluminium foil, as well as conductive textiles such as Velostat (Figure 1). We used a thin layer of insulating paint and 100V signals at frequencies ranging from 15 to 250 Hz to drive the materials. Current-limiting circuits (<5 mA), detachable connectors, and user switches were used as safety precautions.

Fabricating flexible electrovibrating surfaces with reliable insulation and accurate feedback at a voltage of 100V proved difficult. As a result, we experimented with wearables made of multiple rigid surfaces (Figure 2). We found that glass cutting techniques can be used to cut capacitive glass plates (3M MicroTouch) without affecting their electrode structure.

Figure 1: Mock-up of flexible electrovibrating surfaces attached to the outer surface of a collar and cuffs.

Figure 2: Sketch of electrovibrating watch with cut capacitive plates.

Electrovibration is stronger and most perceptible on the palm and fingertips, and slightly weaker on the wrist, based on preliminary experimentations with these sketches. Because of the larger area of contact or the presence of hair, the arms, neck, and thighs produce a more subtle sensation and occasionally an unpleasant tingling.In addition, we have found that the sensations produced by the natural movement of the body against an electrovibrating clothing item or wearable are difficult to distinguish from other tactile cues such as the rubbing of clothing against the skin.

2.2 Electrovibrating Objects

Since the palm appears to respond strongly to electrovibration, we decided to pursue interactive designs in which the palm brushes against the surface of everyday things in a natural way. We focused our initial inquiry on the surface below a keyboard, such as a table beneath a keyboard or the lower surface of a laptop [5]. As we type on a keyboard, our hands often rest or slide on this surface, providing a chance for information to be transmitted via electrovibration. By combining a commercial keyboard (Logitech K380) with two capacitive plates (3M MicroTouch), we created a simple electrovibrating keyboard sketch (Figure 3).

3 EXPERIMENT

To better understand the possibilities of the proposed electrovibrating keyboard, a more extensive investigation comparing the tactile

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Figure 3: Sketch of electrovibrating keyboard made with an off-the-shelf keyboard and two capacitive plates.

perception of electrovibration on the palm and fingertips is required. As a result, we conducted a psychophysical investigation to compare electrovibration perception on the fingertip and palm.

3.1 Experimental Apparatus

The experimental setup is illustrated in Figure 4.The signal generator consisted of a Raspberry Pi, a high precision AD/DA board, and a high-voltage amplifier. An electrovibrating surface made of a capacitive touchpad (3M MicroTouch) was driven by the signal generator. An area was left exposed while the rest was covered with tape to better regulate the location touched. To ensure the safety of the participants, certain safeguards were used. A 20-kΩ high-voltage resistor was used to limit the current to 5 mA. The output could be interrupted by pressing a large push button or releasing a foot pedal.

A load cell was installed under the electrovibrating surface so that the force applied by the finger or palm could be measured. The participants were asked to maintain a force between 0.1 and 0.6 N, which is within the typical range of forces used for tactile exploration [1]. During the experiment, participants used a keypad to enter their responses.

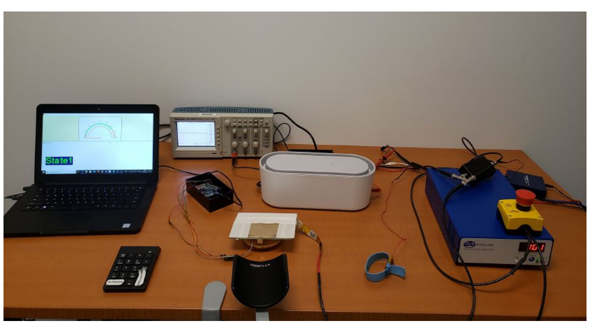

Figure 4: Experimental setup including electrovibrating surface, load cell, signal generator, keypad and computer monitor.

3.2 Procedure

We recruited 14 individuals, seven of which were female, with an average age of 27.5 years. The study, which followed the same methods as [6], involved evaluating the absolute detection thresholds of a sinusoidal signal at five frequencies (15, 30, 60, 120, and 240 Hz) using stimulating at two locations (fingertip and palm). These frequencies were produced randomly. The experiment was carried out utilizing the adaptive staircase method (one up/two down), which gives precise detection and discrimination thresholds with a small number of trials [3, 6].

3.3 Results

While we observed a higher detection threshold at the palm for 10 of the 14 participants, a one-way repeated measures ANOVA failed to show a statistically significant difference in absolute detection threshold between the fingertip and the palm ($F(1, 26) = 2.252$, $p = 0.145$) (Figure 5).

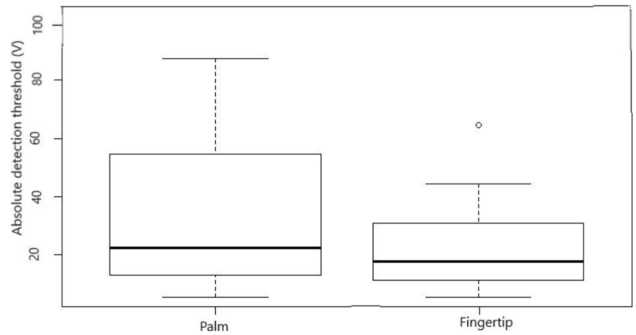

Figure 5: Absolute detection thresholds across participants.

4 Conclusion

The design space and feasibility of electrovibration on clothing, wearables, and smart items were initially investigated in this research. Electrovibration is difficult to properly produce on clothing because of its flexibility and its feedback is frequently masked by other haptic cues present in clothing and wearables. However, we discovered that the palm is very sensitive to electrovibration and turned our attention to objects that the palm brushes against, such as a keyboard.

We then conducted an experiment to compare the detection threshold of electrovibration at the fingertip and the palm to better understand the capabilities of this keyboard. Our results indicate that the hand region has no statistically significant effect on the tactile sense of electrovibration. Implementing a fully functional prototype of the electrovibrating keyboard, creating exemplar applications to demonstrate the extra value of the haptic feedback this will create in real-world scenarios, and verifying the concept with user experiments will be the focus of our future effort.

Acknowledgments

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