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Robustness of apparent tactile motion to frequency mismatches

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Introduction

Most research on haptic illusions assumes that actuators are identical and thus produce vibrations at the same frequency. This may not apply in practical situations where haptic devices are built independently to different specifications.

In this work, we studied whether actuators with mismatched resonance frequencies can generate apparent tactile motion, which produces the illusion of a movement from one actuator to another by precise manipulation of the timing and amplitude of a series of vibrations at two sites on the body [1]. We simulated actuators with diverse characteristics by varying the frequency and amplitude of vibrations produced by a wideband actuator.

This work was originally published in [2].

Methods

The experimental setup consisted of two Haptuator MM3C-HF actuators (Tactile Labs) mounted on the forearm and wrist using custom wristbands designed for comfort, contact with the skin, and transmission of vibrations. The wristbands were worn on the dominant hand's arm, with the actuators separated by 8 cm. We used 9 frequencies ranging from 50 to 250 Hz, with intervals of 25 Hz.

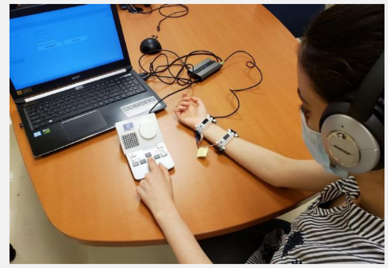

Figure 1. Experimental setup.

Experiment 1: Normalization of Perceived Intensity

Goal: normalize the perceived intensity at all frequencies

Participants received a reference vibration at the frequency (250 Hz) and location (forearm) producing the weakest perceived intensity. They were then presented with another vibration at one of 9 frequencies, on the forearm or the wrist, and asked to adjust its amplitude until it matched the reference vibration. The procedure was repeated three times for each frequency.

Results

This experiment produced normalization factors that can be used to produce a uniform perceived intensity at all frequencies and body locations (Figure 2).

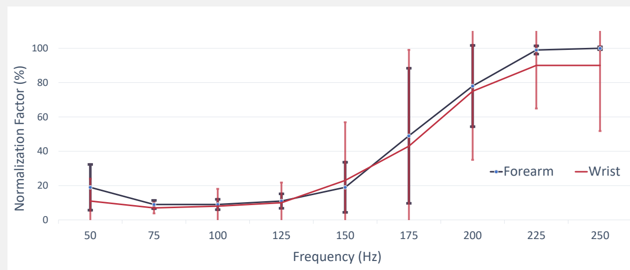

Figure 2. Mean normalization factors selected by participants at different frequencies on the forearm and the wrist[2].

Experiment 2: Detection of Apparent Tactile Motion

Goal: determine the effect of a frequency mismatch on the detection of the direction of apparent tactile motion

One of three reference frequencies (50, 150, or 250 Hz) was used to create the first vibration. The second vibration occurred at one of nine different frequencies (50, 75, 100, 125, 150, 175, 200, 225, or 250 Hz). A total of ten participants took part in the study (3 female; mean age of 30).

Results

Figure 3 shows the detection rate as a function of the absolute difference in frequency between the first and second vibration pulses. No statistically significant effect was observed, which suggests that the difference in frequency has minimal effect on the rate of direction detection.

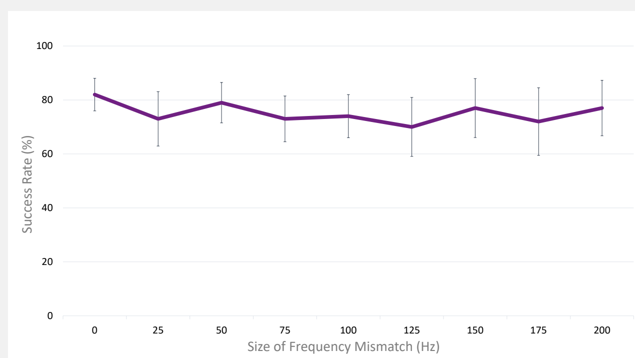

Figure 3. Apparent tactile motion direction detection rate.

Conclusion

This work demonstrates that the illusion of apparent tactile motion can be created with devices with different resonance frequencies, at least when applied to the wrist and forearm with normalized perceived intensity. This suggests that applications of apparent tactile motion may be possible with pairs of commercial devices such as a smartwatch and a game controller (Figure 4).

Figure 4. Application concept with smartwatch and game controller.

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[1] D. S. Alles. Information transmission by phantom sensations. IEEE Transactions on Human-Machine Systems 11(1):85–91, 1970.

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Robustness of apparent tactile motion to frequency mismatches

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ABSTRACT

The majority of haptic illusion research presumes that the actuators employed are identical and so produce the same frequency of vibrations. By varying the frequency and amplitude of vibrations produced by a wideband actuator, we were able to simulate actuators with diverse properties. To normalize the apparent intensity, we changed frequencies from 50 to 250 Hz with appropriate amplitudes. The findings suggest that the apparent tactile motion illusion is robust to mismatches in actuator resonant frequencies and that it can thus be created by haptic devices of varying specifications. This opens the door to novel, rich and complex haptic experiences based on existing consumer devices. This work was originally published at the 2022 IEEE Haptics Symposium [5].

1 INTRODUCTION

We are increasingly engaged with haptic devices in our daily routine. As an example, a user may have a watch on the wrist, hold a game controller in the hand, and wear a haptic jacket, all with sophisticated haptic capabilities. When these haptic devices are used together, they can provide important user experiences and improve our interactions with technology by increasing sensations of immersion. (e.g., [2, 3]).

It is also possible to produce the illusion of a movement from one actuator to another by precisely manipulating the timing and amplitude of a series of vibrations at two sites on the body (apparent tactile motion) [1]. Most previous research, however, assumes that all actuators are identical, which may not apply in a real situation where haptic devices are built independently to different specifications.

We explore whether actuators with mismatched resonance frequencies can generate the illusion of apparent tactile motion and how great of an effect this mismatch has on the quality of the illusion. We hypothesized that as the frequency mismatch between the vibration pulses increases, determining the direction of apparent tactile motion would become more challenging. To test this hypothesis, we conducted two experiments. We simulated having actuators with varying resonant frequencies by altering the frequency between 50 and 250 Hz and normalising the perceived intensity of wideband actuator vibration pulses.

2 EXPERIMENTAL SETUP & METHODOLOGY

With a series of experiments (two main experiments and two pilot tests), we want to know how a frequency variation between the first and second vibrations at the wrist and forearm affected the apparent tactile motion illusion.

The experimental setup (Figure1) consisted of two Haptuator MM3C-HF actuators (Tactile Labs) mounted on the forearm and wrist using custom wristbands designed for comfort, contact with the skin, and transmission of vibrations. It also included an external sound card (Sound BlasterX G6, Creative Labs) for signal generation without interference, a custom interface device for communication with the participants, and a computer. To see if the apparent tactile motion had been perceived, we asked participants to detect the direction of the motion.

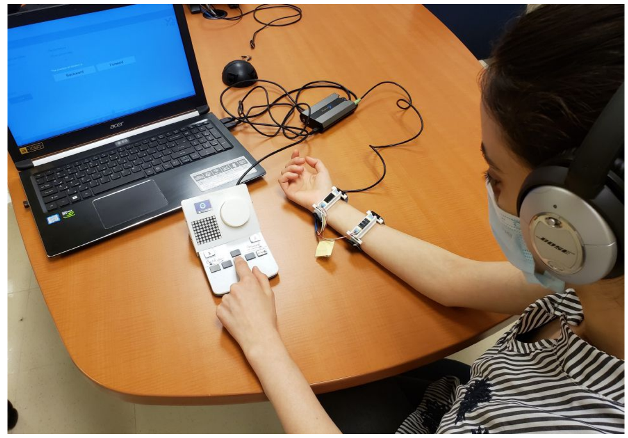

Figure 1: Experimental setup: computer, custom interface de vice, external sound card, and vibrotactile actuators mounted on the wrist and forearm.

The wristbands were worn on the dominant hand's arm, with the actuators separated by 8 cm. The external sound card was used to create the vibration pulses as sinusoidal waveforms. The participants were required to wear headphones that played white noise to drown out any noise made by the actuators or environment.

We chose a stimulus duration (SD) of 200 ms and a stimulus onset asynchrony (SOA) of 111 ms to create a fast apparent tactile motion [4, 6]. We used an SD of 1 s and a SOA of 1.5 s only when a feeling of two separate vibrations was needed.

We used 9 frequencies ranging from 50 to 250 Hz, with intervals of 25 Hz (50, 75, 100, 125, 150, 175, 200, 225, and 250 Hz). This collection of frequencies exceeds the 10% threshold required to perceive a change in vibration frequency, according to [7]. This range includes the most common range of frequencies in commercial vibrotactile actuators, and those with the lowest detection thresholds (200-300 Hz; [8]).

All participants signed a consent form and were compensated with a 20$ gift card. The experiment was approved by the ÉTS Research Ethics Committee.

3 EXPERIMENTS

3.1 Experiment 1: Normalization of Perceived Intensity

The idea was to normalize each frequency's perceived intensity several times. They received the Weakest Frequency on the forearm and normalized the perceived intensity of the frequencies on both the forearm and the wrist. Participants were presented with 9 different frequencies (50, 75, 100, 125, 150, 175, 200, 225, and 250 Hz) on their forearms and later on their wrist, and for each one, the vibration amplitude was reduced until the intensity was the same as the Weakest Frequency. Each participant did the intensity normalization procedure three times for each frequency. We concluded that the frequency range was increased from 50 to 250 Hz, the selected

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amplitude generally increased. Participants most often selected the same normalization amplitude for 200, 225 and 250 Hz at both the forearm and wrist body locations.

3.2 Experiment 2: Detection of Apparent Tactile Motion

We wanted to see how mismatched vibratory frequencies affected apparent tactile motion direction detection. One of three reference frequencies (50, 150, or 250 Hz) was used to create the first vibration. The second vibration occurred at one of nine different frequencies (50, 75, 100, 125, 150, 175, 200, 225, and 250 Hz). A total of 54 vibration pairs were created.

The experiment was organized in 4 blocks, each with 68 trials and a 10-minute break in between. It took about 70 minutes to complete the experiment. A total of ten participants took part in the study (3 females; mean age of 30). They had not taken part in Experiment 1.

4 RESULTS

One-way repeated measure ANOVAs were used to determine the impact of the difference in frequency between the two vibrotactile stimuli on the direction detection rates. No statistically significant effect was observed for the difference in frequency (Figure 2a, 2b and 2c).

We re-encoded the direction detection rates as a function of the absolute difference in frequency between the first and second vibration pulses in a second analysis of the data. The mean direction detection rate across participants for frequency differences ranging from 0 to 200 Hz is shown in Figure 2d.

A Shapiro–Wilks test confirmed that the data was normally distributed. A one-way repeated measure ANOVA revealed that the variation in frequency had no statistically significant influence on the direction detection rate ($F(8,81) = 0.642, p = 0.74$). Based on our observations, the difference in frequency appears to have minimal effect on the rate of direction detection.

5 CONCLUSION

Haptics devices manufactured by different companies are known to differ in their ability to render haptic effects. We hypothesized that a mismatch in stimulus frequency might prove to be detrimental to a system's ability to induce rich cross-device tactile illusions. This work explored the effect of employing such mismatched frequencies on the ability to elicit the illusion of apparent motion between the wrist and forearm. Our two experiments demonstrate that, at least when created with the same perceived intensity between the forearm and the wrist, the illusion of apparent tactile motion can be perceived with a combination of devices set for various resonance frequencies. These findings open the doors to novel and complex cross-device tactile illusions and experiences that have the potential to enrich users' experience.

ACKNOWLEDGMENTS

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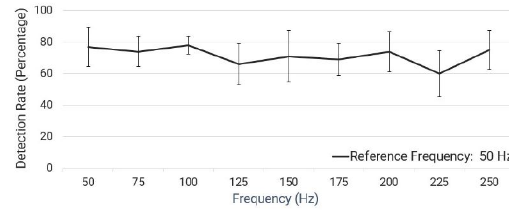
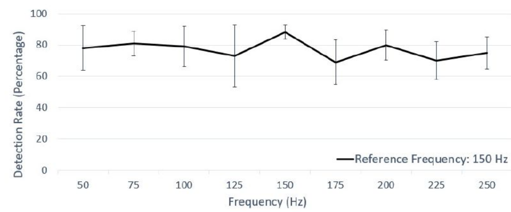


(a)



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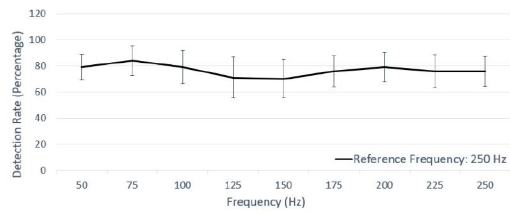
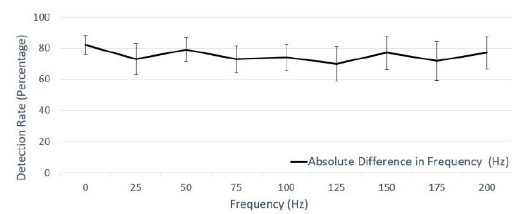


(c)



(d)

Figure 2: Apparent tactile motion direction detection rate as a function of second vibration's frequency for three reference frequencies: (a) 50, (b) 150, (c) 250 Hz and (d) as a function of the absolute difference in frequency between the first and second vibration pulses. Error bars show 95% confidence intervals. The image is from [5].

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