Pilot Study on Notification Using Phantom Sensation on Hand

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ABSTRACT

The vocabulary of notifications using vibration that are currently installed in mobile devices is limited, while notifications have many kinds of information that should be informed of the user. In this study, we investigated notifications using the *vibration direction* presented by phantom sensations, which are a type of tactile illusions. We investigated the location and duration of vibrations in which users are most likely to correctly identify notifications using *vibration direction*. Our study results show the best among the investigated conditions for the notification: the locations are the base of the index finger and the wrist; the duration is 1500 ms.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**.

KEYWORDS

vibration pattern, alerts, wearable devices

ACM Reference Format:
Takuma Hidaka, Yusuke Sei, and Buntarou Shizuki. 2021. Pilot Study on Notification Using Phantom Sensation on Hand. In *Asian CHI Symposium 2021 (Asian CHI Symposium 2021), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3429360.3468202

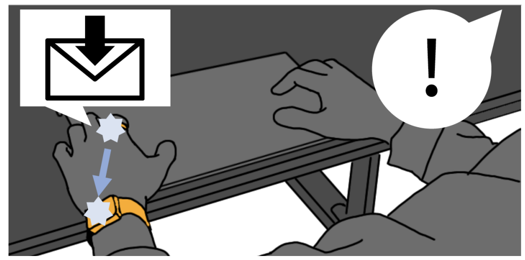

Figure 1: Notifications using *vibration direction*, which is presented by phantom sensations.

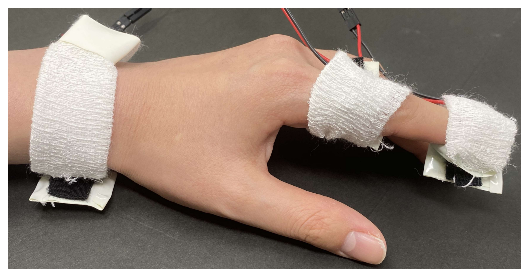

Figure 2: Three devices used to present vibrations; eccentric rotating mass motors were worn on the wrist, base of the index finger, and nail of the index finger.

1 INTRODUCTION

Mobile devices (e.g., smartphones and smartwatches) use notifications to inform the user of incoming calls, receiving messages, and calendar reminders. Notifications using vibrations are attractive because they inform only the user who is wearing a tactile device such as a smartwatch and Nailtactors [2], in contrast to notifications using sound or screen display, which can distract the people around the user during a movie, a lecture, and a conversation. However, the vocabulary of notifications using vibration that are currently installed in mobile devices is limited, while notifications have many kinds of information that should be informed of the user. Previous work has tried to enlarge the vocabulary by vibration patterns (i.e., a combination of the duration that the vibration is presented and the vibration is not presented) [7] and by combining amplitude and vibration patterns [8].

The goal of our work is to create as many identifiable notifications for the mobile device's user as possible. Our idea to achieve the goal is to use the *vibration direction* (Fig. 1) presented by phantom sensations [1]. Phantom sensations [1] are a tactile illusion in which two or more vibration actuators control the perceived location of the vibration. It is also possible to make the user perceive the vibration as if it were moving between the locations where the actuators are worn [3–6]. Specifically, this phenomenon can be generated by gradually increasing the intensity of one vibration while gradually decreasing the intensity of the others simultaneously.

We examined three possible locations on the non-dominant hand for the user to perceive phantom sensations: the wrist, the base of the index finger, and the nail of the index finger. We investigated the conditions in which the user is most likely to perceive the phantom sensations. We considered both the location where the vibration occurs (*vibration location*) and the duration of the vibration (*vibration duration*).

2 USER STUDY

We conducted a user study to investigate the conditions in which the user is most likely to correctly identify notifications. We recruited eight participants (seven male; 22–24 years, M=23.4; all right-handed). Before starting the study, we checked that all participants were able to perceive the vibrations.

Asian CHI Symposium 2021, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8203-8/21/05.
https://doi.org/10.1145/3429360.3468202

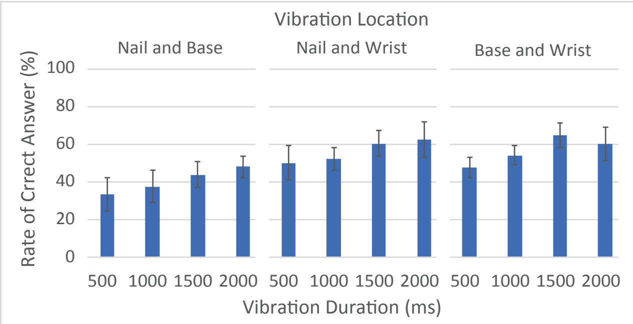

Figure 3: Rate of correct responses. The vertical axis shows the percentage of correct answers. The horizontal axis shows the *vibration duration* for each *vibration location*. The error bars indicate standard deviation.

Table 1: Rate at which participants responded perceiving the *vibration direction* as the opposite of that presented. The vertical axis shows the *vibration duration*. The horizontal axis shows the *vibration location*. Darker colors indicate lower rates of perceived opposite directions.

Vibration Duration	Vibration Location: Nail and Base	Nail and Wrist	Base and Wrist
500 ms	20.8%	18.8%	20.8%
1,000 ms	25.0%	14.6%	10.4%
1,500 ms	16.7%	10.4%	6.3%
2,000 ms	22.9%	10.4%	12.5%

We built three devices to present vibrations to the participants (Fig. 2). In each device, we used an eccentric rotating mass (ERM) motor (LBV10B-009; Silicon Touch Technology Inc.) as the vibration actuator of the device. To ensure that participants perceive the vibrations, the actuators must contact the participant's skin closely. To this end, we used a flexible and elastic cotton bandage, a hook-and-loop fastener, and double-sided adhesive tape. We used a microcontroller (Arduino Uno) to control the ERM motors in the devices.

2.1 Task and Procedure

Participants were presented vibrations in two locations, after which they responded the perceived direction of the vibration (from the elbow to the hand or vice versa). If a participant could not differentiate the direction, they could responded, "I do not know." To prevent participants from basing their response on auditory cues from the ERM motors, participants wore headphones (WH-1000XM3; SONY) playing white noise.

We selected three locations of the non-dominant hand as *vibration location*: wrist (Wrist), the base of the index finger (Base), and the nail of the index finger (Nail). These locations were selected based on those used by other tactile devices. For instance, smartwatches are worn on the wrist, smart rings are worn on the fingers, and a device in a previous study was worn on the fingernails [2]. For each pair of the three locations (e.g., the Base and Wrist), there are two directions (e.g., Wrist to Base and Base to Wrist). To prevent participants from responding by process of elimination, we prepared one dummy condition (Dummy) in which the vibration did not move. In total, there were three *vibration directions* for each combination: Wrist to Base, Base to Wrist, and Dummy.

Throughout the study, each participant conducted 108 tasks (9 tasks × 3 sessions × 4 durations). Participants rested at least 3 minutes every three sessions (i.e., after each duration). It took approximately 30 minutes per participant to complete the study.

2.2 Result

Fig. 3 shows the rate of correct responses from participants. Correct responses indicate that participants correctly identified the *vibration direction* or responded "I do not know" when presented with a Dummy. The highest rate of correct responses (64.6%) was obtained when the *vibration locations* and *vibration duration* were the Base and Wrist and 1,500 ms, respectively. Table 1 shows the rate at which participants responded perceiving the opposite of the presented *vibration direction*. The lowest rate of perceived opposite directions was obtained when the *vibration locations* and *vibration duration* were the Base and Wrist and 1,500 ms, respectively.

3 DISCUSSION AND FUTURE WORK

To prevent the user from identifying the presented notifications as the notifications with the opposite direction, it is necessary to select *vibration locations* and *vibration durations* with the highest rate of correct user responses and the lowest rate of perceived opposite directions. Our results indicated that *vibration locations* on the Base and Wrist with a *vibration duration* of 1,500 ms are optimal.

The highest rate of correct responses in Fig. 3 was low (64.6%), possibly because the perceived vibration intensity varied among *vibration locations*. In addition, participants had difficulty in identifying the *vibration directions* for the Nail and Base in Fig. 3 (33.3%–47.9%) because they perceived vibrations throughout the whole finger. Therefore, future studies should investigate the perceived intensity of vibrations at each *vibration location* before conducting a new user study. Moreover, we plan to recruit eight or more participants to obtain more reliable results.

We used ERM motors to present phantom sensations; however, ERM motors also generate sound, which may distract people near the user. Therefore, we plan to study the effects of ERM motor sound on those nearby.

We found that the Base and Wrist was optimal; this could be used in scenarios in which the user wears a smartwatch and smart ring together. With the two tactile devices (i.e., the Base and Wrist), it would be possible to create six total notifications: two using *vibration direction* (Wrist to Base or Base to Wrist); two using a single tactile device (Wrist only or Base only); and two combining these (Wrist only then Wrist to Base or Base only then Base to Wrist). We plan to investigate the accuracy of identifying them to evaluate their feasibility in a future study.

4 CONCLUSION

To create as many identifiable notifications for the mobile device's user as possible, we used the *vibration direction* presented by phantom sensations. We conducted a user study to investigate the location and duration in which users are most likely to correctly identify notifications using *vibration direction*. The optimal *vibration locations* and *vibration duration* were Base and Write and 1,500 ms, respectively, which could be employed when users wear both smartwatch and smart ring. This combination allows for six notifications using vibration, which we plan to evaluate in a future study.

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