Evaluating the Usability of Vibrotactile Navigation

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ABSTRACT

The user experience of navigation has almost always required that the user glue their eyes to a map (or screen) to navigate. However, devoting so much attention to this activity can endanger oneself through the loss of spatial and environmental awareness. Ubiquitous computing has the opportunity to transform this space by bringing navigation into the periphery. Accomplishing this would free our cognitive resources to pay greater attention to our environment and navigate more safely through unfamiliar spaces. This paper will evaluate the usability of one promising solution: vibrotactile navigation. During our research, we conducted walking trials with participants and sought to use a combination of self-reported feedback and emotional data to evaluate the quality of the vibrotactile user experience. Our research showed that in general, users enjoy using vibrotactile systems, and this technology could be deployable to a wide consumer base.

ACM Reference format:
Alex Quian and Josh Hong. 2020. Evaluating the Usability of Vibrotactile Navigation. In *Proceedings of ACM Conference, Washington, DC, USA, July 2017 (Conference'17),* 6 pages.
https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

How humans navigate the world - and how effectively they do it - has been a crucial skill for our species. Yet over the many centuries that humans have been finding their way through unfamiliar spaces, the method by which we do it has remained largely unchanged: looking at a map. Though the explorers of ages past relied on paper and physical instruments, functionally, the modern traveler relying on Google or Apple maps and their phone's suite of sensors is not all that different, as our eyes are just as glued to the visual aids utilize.

Though navigating in this manner is undeniably effective, using Google Maps, Apple Maps, or other comparable applications on our phones present some drawbacks. One such limitation is that relying on navigational methods that require the user to pay attention to their phones significantly reduces the user's situational awareness, which presents safety issues. Studies comparing the situational awareness of pedestrians occupied on their phones and pedestrians who were not showed that the former group was less likely to recall aspects of the environment around them, more prone to engaging in unsafe behavior, and at higher risk for crime victimization[16].

Alternative approaches to navigation utilizing modern technology do exist - both Google Maps and Apple Maps provide users the option to have directions spoken to them, and researchers have evaluated a number of other possible solutions.

One promising solution is vibrotactile navigation. Research studies have explored various ways to provide users with navigational vibration signals, utilizing devices such as a vibration belt[20], smartphone[17], and smartwatch[7]. These studies have shown that regardless of the specific implementation, users are able to effectively navigate routes and unfamiliar spaces using only the vibration signals received from these devices.

Despite the proven effectiveness of vibrotactile navigation systems, few examples of this technology exist "in the wild." As of 2018, the only consumer-grade products incorporating vibrotactile navigation is Navibration[19] and smrtGRiPS[2], a set of bike grips that vibrate to let the rider know when to make a turn. Research addressing vibrotactile navigation systems have largely not explored the usability of the technology or how consumers would interact with it, and thus cannot provide insight into why a seemingly useful technology has not transitioned into a consumer product.

This paper seeks to evaluate the potential benefits vibrotactile navigation systems pose and investigate the feasibility of deploying this technology onto the consumer market. In examining vibrotactile navigation systems, our research study will evaluate the following metrics.:

(1) The effect of vibrotactile navigation on user's situational awareness.

Conference'17, July 2017, Washington, DC, USA

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM…$15.00
https://doi.org/10.1145/nnnnnnn.nnnnnnn

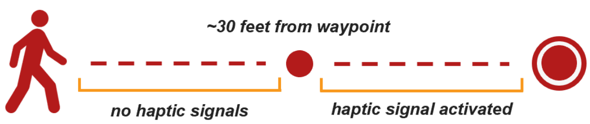

Figure 1: The vibrotactile system used in this study provides haptic turn signals to the user whenever they are within 30 feet of an upcoming waypoint along their route.

(2) How readily users learn and trust vibrotactile navigation systems.
(3) The emotional responses of users while using vibrotactile navigation.

Our research paper will focus on exploring these metrics for several reasons. For one, enhancing users'situational awareness while navigating is one of the largest benefits of pursuing non-visual navigation, so analyzing this area is crucial to evaluating the usability of vibrotactile navigation. Secondly, assessing how intuitive the system is to use is an important consideration in determining whether any new technology is viable for deploying to the broad consumer market. Lastly, examining the users'emotional state while utilizing a vibrotactile navigation system provides important information about the user experience and can indicate whether users are likely to enjoy (and therefore use) such a system.

2 RELATED WORK

Vibrotactile navigation systems are not a novel concept. Many researchers have explored this topic, and have produced a variety of systems that incorporate this technology. This research has been able to reliably demonstrate that vibrotactile systems are effective at guiding users to their destination.

A variety of implementations for vibrotactile navigation have been explored. Most research has focused on using haptic signals as a directional "compass," where users are continuously fed signals that inform them where the next waypoint is and how far away it is [17] [20] [12]. Other implementations of vibrotactile navigation systems rely on "turn-by-turn" navigation, providing haptic signals whenever the user needs to change their direction[15]. These examples have, as mentioned previously, fed haptic signals through a variety of apparatuses, such as belts, smartwatches, shoes, and phones.

3 OUR IMPLEMENTATION

Given the lack of widely available vibrotactile systems, we set out to create our own vibrotactile navigation system. Because of our objective of assessing the usability of such a system in the consumer market, our design decisions were guided by the goal of creating a prototype that could easily be deployed as widely as possible and be readily integrated into existing application frameworks.

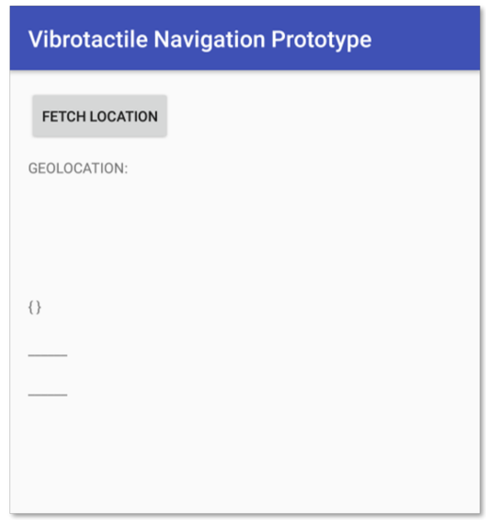

Figure 2: Screenshot of the vibrotactile navigation application built for this study.

With this goal in mind, we decided to use a Samsung Galaxy A5 running Android 7.0 for our system. As of January 2018, approximately 77 percent of Americans own a smartphone[4]. If actually seeking to deploy this system to consumers, adding vibrotactile navigation functionality to an already widely-used platform rather than creating a new product that would need to be purchased would ensure that this system would be available to as many consumers as possible.

Additionally, our implementation utilized a turn-by-turn directional scheme. Users were provided haptic signals as they approached a waypoint (i.e. a set of coordinates along a route where the user would need to turn). Once the user was within approximately 30 feet of this waypoint, our application activated the appropriate haptic signal to indicate a left (two long vibrations, repeated) or right turn (four rapid vibrations, repeated). Once the user passed the waypoint, the vibration would stop, and the device would not send any more haptic signals until the user was within 30 feet of the next waypoint, as seen in Figure 1.

We decided to use a turn-by-turn directional scheme because we believed that this would be easily integrable into existing navigational applications, which rely on turn-by-turn instructions. We envision that vibrotactile navigation can serve as a complement to existing navigation applications, so creating a prototype that could easily be integrated into existing application ecosystems was an important consideration.

4 RESEARCH METHODOLOGY

To evaluate the three metrics by which we will assess the usability of vibrotactile navigation, we utilized two primary data collection methods: self-reported user feedback surveys and emotional data collected by an Empatica E4.

Analyzing Emotion Data

We set out to collect physiological data from an Empatica E4 for the purpose of analyzing the emotional state of users. Understanding the emotional state of users would provide qualitative data to inform our conclusions about the user experience of interacting with a vibrotactile navigation system.

Previous research into emotional analysis has identified that the levels of arousal and valence reflected by physiological data roughly correlates to human emotions. [5] [11] [14] [21]. Figure 3 illustrates the correlation between arousal, valence, and emotions[9], which was utilized in analyzing the physiological data collected.

There has been extensive research done on the correlation between EDA data and arousal [3], so for this reason, EDA data was chosen to determine the level of arousal in research participants. Once EDA data was collected, it was analyzed using a script developed by the Affective Computing Group at the MIT Media Lab [10].

Analyzing EDA data to assess levels of arousal involves identifying peaks in the collected data. Six parameters were defined in the EDA data to facilitate analysis: minimum peak amplitude, offset, filter frequency, filter order, max rise time and max decay time. The following values were set for each parameter:

- **Minimum peak amplitude:** 0.01 microseconds
- **Offset:** 1.0 seconds
- **Filter frequency:** 0.5 hertz
- **Filter order:** 6
- **Max rise time**: 4 seconds
- **Max decay time:** 4 seconds

These values were utilized due because they are relatively sensitive when identifying peaks, a useful trait due to the short amount of data that would be acquired from each trial. Previous literature affirmed that these values were valid and would result in accurate analysis [3].

"High arousal" was defined to mean any period where at least 8 peaks were identified in a 100 - 120 second time span; any period which did not fit this description indicated low arousal. This classification system has been utilized in prior research[1].

For analyzing valence levels, HRV data was chosen because it provides a relatively accurate indication of an individual's stress levels[13][18]. Evaluating the power of the low-frequency band associated with HRV was the most significant indicator of an individual's mental stress[6]. However, physical activity is associated with lower levels of stress[8] - given that the HRV data will be collected while participants are walking, this will be taken into account when analyzing the data.

Categorizing emotions requires plotting the data along the graph found in Figure 3. The arousal found from the analyzed EDA data will be plotted on the y-axis. Valence data will be plotted utilizing HRV data and subjective observations.

Participant Interviews

To facilitate accurate analysis of the physiological data collected by the Empatica E4, we conducted interviews to elicit and measure specific emotional reactions from participants. Our goal was to trigger specific emotions in participants (nervousness, happiness, calmness) in a controlled setting so that we could more easily identify these same emotions from the Empatica E4 data in the later walking trials.

Each participant was brought in for an interview prior to their walking trial. A facilitator, who administered the tasks to the participant, and a note taker also was present for each interview. At the start of each interview, the participant was briefed about the objectives of the study and given an Empatica E4, but were not told that their emotions would be analyzed during the interview so that they were not preoccupied with them and our data would not be influenced.

Each interview began by asking the participant to prepare and give a five minute oral presentation. This situation was meant to make the participant nervous and help us establish a baseline for this emotional response. This exercise was

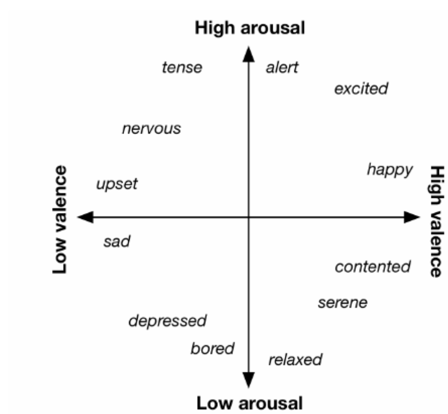

Figure 3: An arousal/valence graph, which shows the emotions which correspond to varying levels of arousal and valence. Collecting and identifying levels of arousal and valence is key to analyze participant's emotions.

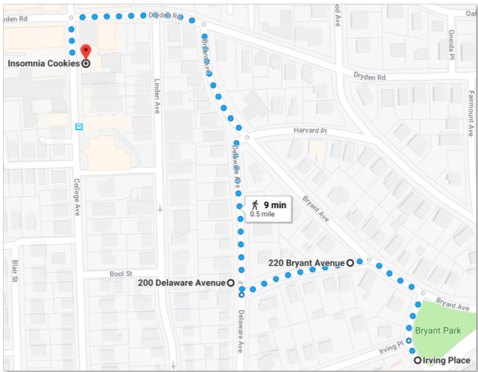

Figure 4: Screenshot of the route users were asked to navigate during each walking trial.

followed by praising the participant and engaging them in light-hearted conversation to elicit happiness. Lastly, we asked the participant to meditate by utilizing a commercially available meditation application to put them in a state of calmness. In total, each interview lasted no more than 30 minutes.

Walking Trials

To perform analysis of the vibrotactile navigation system, we devised a two-part walking trial where each participant would walk a pre-determined route - once with our vibrotactile navigation app and once with Google Maps.

In addition to the data that was planned to be collected from the Empatica E4, we also administered user feedback surveys. These surveys were designed to assess the emotional state of users and their experience using vibrotactile navigation and Google Maps.

The pre-trial survey asked the user to indicate how happy, nervous, calm, and sad they were before conducting the trial. The post-trial survey asked the user to again indicate their emotional state and also provide insight into how they normally navigate unfamiliar routes, how confident they felt that the directions they were receiving were accurate, and how aware they felt they were of their surroundings during the trial. Additionally, after every vibrotactile navigation trial, we asked for feedback on the system and how likely they would use a system like this in their own lives.

Prior to each trial, the participant was once again given the Empatica E4 and asked to complete the pre-trial survey. After completing the survey, the participant began navigating the test route (Figure 4), which took approximately 10 minutes to complete for each participant.

After the individual navigated the route, they were immediately asked to complete the post-trial survey. Once this survey was complete, the Empatica E4 was turned off, and the trial was completed. If the participant had not yet completed their second trial, then the Empatica E4 was turned back on, and they were asked to complete another pre-trial survey to start the process again.

The route was specifically selected to ensure that no participant was already familiar with it. Every participant was taken to the start of the route by our research team, and care was taken that the participant was not able to familiarize themselves with the route prior to the trial.

5 RESULTS

During our walking trials, 100 percent of users were correctly guided to their destination. Our pre-trial and post-trial surveys showed that in general, the majority of users felt confident that the vibrotactile navigation system was effective at guiding them to their destination. This was expected, given results from previous research.

Although it was effective, almost all users expressed dissatisfaction at the inability to preview their route while using the system, as their typical approach to navigating involves memorizing a route before actively using navigational aids for guidance. Additionally, every user noted that they felt more aware of their surroundings than they did using Google Maps. Some users reported difficulty distinguishing between the particular vibration signals our system implemented to indicate a left or right turn.

This data suggested the following:

(1) To ensure users feel confident in a vibrotactile navigation system, it should allow users to preview and view a route. This will increase the user's confidence that the system is providing accurate directions. It will also allow the haptic signals to utilize and complement the user's memory, rather than providing blind navigation.
(2) The success of vibrotactile navigation depends largely on the distinctness of the haptic signals used for navigation and the user's ability to quickly become familiar with them. Providing a tutorial or ability to experience the haptic signals on command could help improve user's familiarity with the signals.
(3) In general, vibrotactile navigation systems do allow the users to pay more attention to their environment, which suggests that this system could address concerns regarding the potential dangers of relying on visual navigation.

An initial goal of our research was to analyze the emotional state of users while using vibrotactile navigation systems in order to provide qualitative data and insight about the user experience. Unfortunately, initial physiological emotional data collection from users failed to capture enough data to construct comprehensive models.

One difficulty encountered was that complications with the Empatica meant that adequate EDA and HRV data was

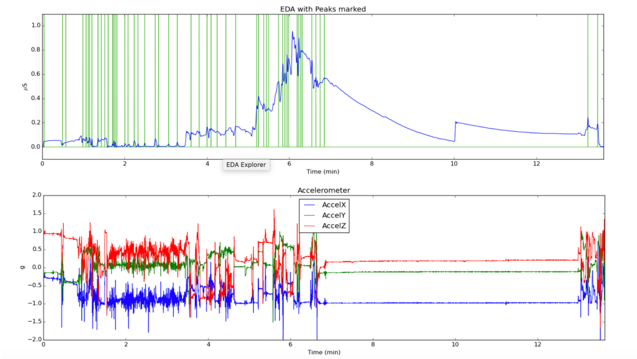

Figure 5: A collection of one participants' analyzed data. Top: EDA measurements with peaks indicated. Bottom: Measurements of acceleration in each direction experienced by the Empatica.

not captured from some participants to conduct proper analysis. Additionally, we realized that more baseline data needed to be collected in order to properly plot arousal and valence data on the graph seen in Figure 3. More trials needed to be conducted to record numerous sets of EDA and HRV data from each participant in order to analyze and identify the minute differences in data sets.

Despite these shortcomings, the EDA data collected was adequate enough to infer levels of arousal in most participants. Examining this data shows that 3 out of 5 users experienced high levels of arousal during the vibrotactile walking trial - indicating that they were happy/alert or upset/nervous. Combining this data with the self-reported responses of the pre-trial and post-trial surveys for these particular participants, we are able to infer that these users generally enjoyed using the vibrotactile navigation system. Although we would need to conduct far more trials and collect more emotional data, this does begin to show promising results for vibrotactile navigation.

6 CONCLUSION AND FUTURE WORK

Based on this preliminary research, there is a compelling argument for the deployment of vibrotactile navigation systems to the consumer market as an alternative to traditional, visual based systems. This research, supported by previous work, shows that vibrotactile navigation is effective, intuitive, and promotes greater situational awareness.

Given the feedback we received from test participants, we believe that vibrotactile navigation would best be implemented by integrating it into existing navigational platforms (such as Google Maps) as a system option that can be toggled, much like audio guidance. This would address finding (1) of our results, and pairing the technology with an already trusted application like Google Maps would lend a high degree of initial trust to the system.

Our findings suggest that users generally have a positive user experience with vibrotactile navigation systems, and that it would be a viable, non-intrusive alternative to visual navigation. Deploying vibrotactile navigation systems to a wider market would likely find use with users who already use navigation applications to navigate through unfamiliar environments, but may be hesitant to use them in potentially dangerous environments.

To further evaluate the usability of vibrotactile navigation, we would need to refine and conduct this experiment on a much larger scale. We additionally would need to recruit a broader range of test participants than were used in this experiment.

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