Designing Wearable Haptic Information Displays for People with Vision Impairments

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ABSTRACT
With the ubiquity of wearable computing, an important and emerging challenge is to understand how to design wearable information displays for non-visual, non-auditory interaction. This is particularly relevant to the design of accessible technologies for people with vision impairments. Working towards this aim, we developed a smartwatch prototype that uses variable friction surface haptics to test initial design concepts. Through interviews and iterative prototyping with seven blind users, we identified three key use cases for a haptic smartwatch as well as embodied conceptual models for presenting haptic information. We found that a physical clock face, compass, and numerical keypad are productive representations for presenting information haptically, and these models build on existing tactile and spatial understandings of our target user group.

Author Keywords
Blind; surface haptics; watch; variable friction

ACM Classification Keywords
H.5.2. User Interfaces: Haptic I/O, Screen Design

INTRODUCTION
In recent years, wearable devices have been gaining popularity in the consumer market, with smartwatches, activity tracking wristbands, and other on-body computing accessories becoming more pervasive in everyday life. Past work examines novel interaction techniques for wearable devices and the integration of haptics as a feedback mechanism (e.g., [13,17]). Additionally, a growing body of research focuses on designing wearable devices and mobile computing for people with disabilities, particularly for individuals with vision impairments [1,3,6,7,19,20].

This paper describes a formative study to understand the design and presentation of tactile information on a haptic smartwatch for people with vision impairments. The technology used is a Motorola smartwatch instrumented with a variable friction touchscreen surface (e.g., Tactile Pattern Display) [10,11]. Unlike vibration or vibro-tactile feedback, variable friction surface haptic displays render localized force feedback to the fingertip. As a user's finger slides across the display, the friction between their fingertip and the touchscreen can be dynamically adjusted to give the perception of complex textures and shapes.

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While most research on wearable devices focuses on input or interaction techniques, this paper examines the design of *information presentation* on a small, wearable, haptic display, particularly for blind users. Designing embedded computing experiences for everyday objects can be informed by our embodied and cultural practices with familiar physical devices [9]. During the study, we identify three contexts for watch-based haptic interaction (time telling, navigation, and quantification of activity). Using iterative design and prototyping, we develop an understanding of how to present information through haptics in these contexts. The present work focuses on design for people with vision impairments, but all users stand to benefit from eyes-free, non-auditory access to wearable displays.

RELATED WORK
This research draws on theories of embodiment and related work on wearable and haptic displays to inform the design of a haptic watch for people with vision impairments.

Embodiment and Non-Visual Interaction
Theories of embodiment [2] are particularly relevant when designing information displays for people with vision impairments, who rely on tactile and auditory cues for interaction. William James introduced the concept of the sequential nature of touch and the simultaneous nature of vision. He described that a "seeing baby's eyes take in the whole room at once" in order to discern objects, but the blind child "must form his mental image of the room by the addition, piece to piece, of parts which he learns to know successively" [5]. Such sequential interaction is pervasive in the current design of computing technologies for people with vision impairments. Screen readers (e.g., Apple VoiceOver), which improve non-visual access to graphical displays, rely on sequential auditory cues to help a user build a model of the spatial layout of the display.

In addition to auditory cues, haptic feedback is an important channel through which people with vision impairments come to understand the physical world. Just as a blind person's cane becomes part of their body and sensory experience [12], so too could new haptic technologies. The design of haptic information displays can be informed by examining the embodied nature of interactions. For example, analyzing how blind children produce gestures, including to their blind peers, can indicate their emerging conceptual understandings that may not be visible through talk alone [4]. Similarly, work by Quek and McNeill [15] examines the embodied nature of learning mathematics and how the lack of visual access to the instructor's embodied, spatiotemporal mathematical explanations affects learning for blind students. Based on this analysis, they suggest vibro-tactile gloves and joysticks as feedback displays to help students understand embodied representations in math learning. This phenomenological view guides our work on understanding how to design wearable tactile information displays for people with vision impairments, including our analysis of how users interact with the prototype system.

Wearable and Haptic Displays

Wearable displays present challenges of designing for small screens, noisy environments, and mobile usage scenarios [13,14,16]. For example, Pasquero et al [13] introduced a haptic watch prototype, in which actuators on the bottom of the watch touching the wrist would provide eyes-free haptic communication with an adjacent mobile device. Ye et al. [20] examined the potential of on-body interaction for people with vision impairments by focusing on a wearable wristband prototype to control the screen reader for a linked mobile device. We build on this work through a focused exploration of a haptic watch prototype with localized tactile feedback directly on the display surface.

With respect to haptic interaction, several studies have examined vibro-tactile feedback on mobile phones to increase accessibility [1,3,6], and this work suggests that visually impaired users may outperform sighted users with haptic feedback. The TeslaTouch system [18], which uses electrostatic vibration, demonstrated that blind users were able to sense and create 2D tactile images on a haptic display. Similarly, variable friction surface haptics enabled by tactile pattern displays (TPad) have been explored for improving touchscreen usability [10] and affective communication [11], and the present study examines surface haptics in a mobile context for blind users.

TPAD WATCH HARDWARE

To enable exploration of wearable haptics, we introduce the TPad Watch (Fig. 1), which uses a Motorola MOTOACTV smartwatch with a display of 220 x 176 pixels that runs Android 2.3 Gingerbread. This prototype was developed based on the TPad Tablet technology [10,11]. The haptic surface is a glass plate with an array of piezoelectric actuators along the side. The actuators vibrate the glass at ultrasonic frequencies, causing the fingertip to periodically break contact and reduce the coefficient of friction. This plate is mounted to the watch screen and the level of friction reduction is controlled in real time by a program running on the watch. A more complete description of the TPad system can be found in previous research [11]. The TPad Watch enables new explorations of how to design

Figure 1: Blind participant using TPaD smartwatch.

programmable surface haptics on a wearable digital display. Using the openly available Android SDK for the TPad (www.tpadtablet.org), we developed multiple example applications to understand initial usage scenarios for a haptic watch as well as dedicated haptic visualizations (Fig. 2, right) to explore various techniques for presenting information to users with vision impairments.

METHOD

Seven people with vision impairments (ages 20-62; 2 female; legally blind to light perception only) and two experts in assistive technology who work with people with vision impairments were involved in this study. Two visually impaired people and the two experts participated in early discussions, using initial applications (Fig 1). We then employed an iterative design process. With five visually impaired people, the research team conducted a total of five semi-structured interviews, two paper prototyping activities (Fig. 2, center), and three technology testing sessions. Some participants were involved in more than one session. All visually impaired participants demonstrated how they interact with their current mobile devices and watches.

The TPad Watch prototype was both a probe for understanding potential usage scenarios and a platform for testing early design ideas. Our design process focused on: (1) information gathering about mobile accessibility through discussions and interviews, (2) creating paper prototypes with participants and then developing haptic visualizations for testing, and (3) obtaining feedback on the TPad watch prototype and interface designs. During all parts of the study, the research team took notes to understand current practices, inform design, and capture reactions to early prototypes. Five interviews or prototype testing sessions were audio/video recorded and transcribed. Each session was between 60 and 75 minutes. The research team iteratively coded all notes and transcripts for themes.

FINDINGS

After the early discussions and interviews, we identified three use cases to explore for a haptic watch. While testing our applications, we learned how our participants interact with the TPad Watch. We also uncovered embodied conceptual models to inform the design of a haptic watch.

Use Cases and Value of a Wearable Haptic Display

Three primary use cases for exploration were suggested in early discussions: time telling, navigation, and quantification of activity. During the course of research, engagements with participants supported these use cases. Time telling with haptic interaction is unsurprising since the watch form factor is already associated with this task. All seven visually impaired people saw value in telling time through a tactile interface, particularly when in environments where auditory information may not be appropriate [7]. P2 said, "*When I learned to tell time…I usually use braille watches, then when speech technology came along I would sometimes use a combination [tactile/audio] watch. I've never been one of those people who likes an audio only watch because, every time I want to check the time, the world hears it...*" P3 described similar benefits to haptic only feedback: "*A lot of people have gone to talking watches or they carry some device in their pocket… I'm still old school as far as the watch is concerned… That's why I have my braille watch. I don't have to worry about loud environments.*" For time telling alone, two participants said they would prefer their existing braille watch (Fig. 2, left) to a digital haptic watch.

Building on prior work [7,19], navigation was also an important use case to all seven visually impaired participants: *P4: "It's very important that you have an accessible GPS system because it's how you tell where you are and where you're going and what you want to do."* A haptic watch can provide immediate access and privacy [20]. Finally, quantification of activity was supported as a third area of exploration due to observations of participants' existing practices of counting steps for navigation and counting landmarks to understand spatial layouts. Quantification could work with a compass-like navigation tool to track progress toward a destination or more private data about physical activity (e.g., pedometer or Fitbit feedback). Initial prototypes included percentage-based representations (e.g., screen coverage or pie chart, Fig 2g,h) to represent quantification, although displaying the raw numerical value emerged as an important theme.

Understanding Initial Usage

We observed that physical reference points for device usage were essential for participants during testing. Participants were eager to learn the location of the power button, which served as a marker to properly orient the device on their wrist. All of our interface designs were orientation dependent, and all users successfully learned to orient the device based on physical hardware buttons. When exploring the screen, they tended to start at the top left of the screen, then move up/down or side-to-side rather than a circular motion as we expected based on braille watch usage. Even after lifting a finger, they returned to exploration by starting in this corner. The participants used the hardware as a physical guide for on-screen interaction inside the watch casing similar to descriptions in prior work [8]. Adding physical indentations strategically around the edge of the display (e.g., midpoints) would aid accessibility.

When learning how to detect and interpret the on-screen haptics, one participant offered parallels to prior learned haptic experiences, referencing Optacon and braille. P2 said, *"I guess I'm using the same approach as I would with braille,"* describing his behavior of reading the screen from left to right. This illustrates the sequential nature of exploring inherently spatial haptic representations.

Embodied Conceptual Models for Design

In contrast to the linear presentation of information through a screen reader, with which all participants were familiar, we prototyped a variety of spatial haptic representations to understand which concepts would be most appropriate. An analog clock was a familiar spatial representation for time telling (Fig. 2a-c show clock hand variations) and may work for navigation. P4 uses a clock face as a conceptual model for orientation: *"As I navigate, instead of forward, down, left, and right. I'm thinking in terms of blindness, which would be 12, 3, 6, and 9 [o'clock]."*

In addition to the clock face, all participants understood the concept of a compass and mentioned exposure to an accessible physical compass (e.g., braille magnetic compass). P1 said, *"One of my orientation and mobility instructors had a raised one with raised markings."* For the navigation prototypes, we observed the need to highlight the direction of interest with a textured area near the edge of the display (Fig. 2d-f).

Another spatial representation of which participants had an embodied understanding is a numerical keypad (e.g., on a phone). In the context of activity quantification, presenting information using the spatial layout of digits on a number pad (Fig. 2i) was more appealing than a pie chart representation (Fig. 2h). There were nine positions (1-9) on the number pad, and the strong texture was the "tens" value while the weak texture had the "ones" value. Spaces with textures could be added resulting in a numerical range from zero to 99. In Fig. 2i, the black texture occupies the "6" position and is worth 60, the gray texture is at "3" and is

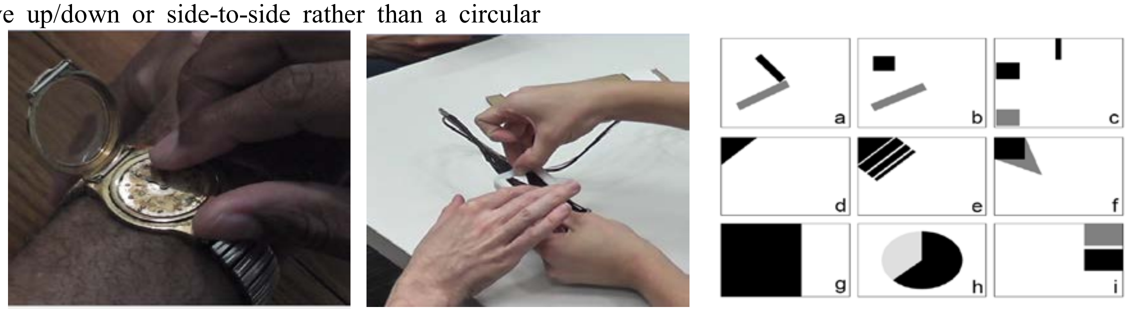

Figure 2: ***Left***: **Blind participant telling time with braille watch.** ***Center***: **paper prototyping haptic representation for the navigation context (i.e., direction of compass).** ***Right***: **Haptic visualizations for clocks (a, b, c), compass navigation (d, e, f), and activity quantification (g, h, i). Black is stronger haptic texture and gray is weaker.**

worth 3 totaling a value of 63. When asked, participants displayed a general preference for the presentation of numerical information on a number pad rather than graphical figures. P2 described his difficulty in learning graphical concepts, *"I can't interpret things that way. Even if you described it, my brain doesn't think that way because there's no technology that allows me to think that way."* Although further evaluation is required, in our initial prototype testing two blind participants were able to discern all nine sections (70 x 50px each) representing a number pad on the watch. While the participants preferred the number pad for reading quantitative values, some appreciated the idea of creating an alternate summary of activity (e.g. percent completed). In our broader discussion, using the concept of a number keypad helped participants orient to the location of haptic areas or targets on the watch.

Naturally, participants' success in understanding the haptic representations depended on their exposure to these visual concepts. One participant excelled in all scenarios, correctly identifying the time on the clock, directions on the compass, and detecting the circular pie chart. This participant had education at a young age in visual reasoning and concepts. In order to draw on embodied conceptual understandings to improve design [2,9], these concepts must be current and well known among the target user group. For example, P2 said, *"I learned math on an abacus…I would not be able to do that now… If someone asked me to do it today I wouldn't know what to do. I'd say give me a calculator."*

CONCLUSION

We have presented an initial exploration of how to design haptic information displays on a smartwatch for people with vision impairments. This work lays the foundation for subsequent development and evaluation of more robust prototypes, providing productive embodied conceptual models for designing for this user group. With the growing ubiquity of wearable computing, understanding how to present information in non-visual, non-auditory contexts is an important research challenge that affects all user groups.

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