
Communicating Multimodal Wayfinding Messages for Visually Impaired People via Wearables

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ABSTRACT

People with a visual impairment (PVI) often experience difficulties with wayfinding. Current navigation applications have limited communication channels and do not provide detailed enough information to support PVI. By transmitting wayfinding information via multimodal channels and combining these with wearables, we can provide tailored information for wayfinding and reduce the cognitive load. This study presents a framework for multimodal wayfinding communication via smartwatch. The framework consists of four modalities: audio, voice, tactile and visual. Audio and voice messages are transmitted using a bone conduction headphone, keeping the ears free to focus on the environment. With a smartwatch vibrations are directed to a sensitive part of the body (i.e., the wrist), making it

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easier to sense the vibrations. Icons and short textual feedback are viewed on the display of the watch, allowing for hands-free navigation.

CCS CONCEPTS

• **Social and professional topics** → **Assistive technologies**; • **Human-centered computing** → **User interface design**; **Haptic devices**; **Sound-based input / output**; **Ubiquitous and mobile devices**; *Smartphones*; User studies; • **Information systems** → Geographic information systems; Location based services.

KEYWORDS

Wayfinding, Visually impaired, Assistive technology, Smartphone, Smartwatch, Multimodal feedback, Tactile, Bone conduction, Ubiquitous computing

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INTRODUCTION

People with a visual impairment (PVI) often experience difficulties with navigation and orientation [5]. By using technological aids like wayfinding apps, some independence is regained [12]. However, most apps are not optimized for PVI resulting in inaccessible communication methods and insufficient information transmission. For example, traditional apps usually convey wayfinding information via instructions on the smartphone screen and via text-to-speech voice messages. While these voice messages improve wayfinding [4], in busy urban environments spoken feedback can be distracting and ineffective [5, 17]. Different modalities can be used to allow for more tailored and effective communication. By using vibrations, PVI can put more focus on the environment and their cognitive load is reduced [10]. This work presents how communication of wayfinding information to PVI can be improved by utilizing four modalities: audio, voice, tactile and visual. We propose a communication framework that provides guidelines for these modalities and further extend this by optimizing it for commercially available wearables, such as smartwatches.

RELATED RESEARCH

Audio and Voice

Current wayfinding apps usually provide wayfinding information via voice messages using text-to-speech audio. PVI prefer this method over other modalities, such as tactile, non-voice audio [17] or

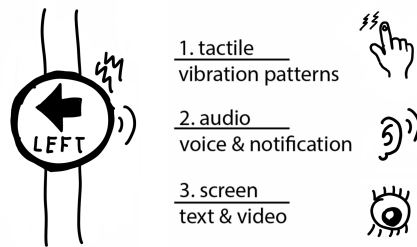


Figure 1: Multimodal message framework transmitted via the smartwatch and smartphone.



Figure 2: Smartwatch screen in different color contrasts.

sonification [6][1]. While voice messages are the preferred method, PVI also suggest to apply different modalities for different tasks [17]. Sonification or sounds can be useful for certain tasks, such as indicating the distance in a stressful situation (e.g., crossing a road) [9]. Furthermore, sonification has been effectively used to provide information about objects, often combined with different forms of tactile feedback [3].

Tactile

Tactile feedback in the form of vibrations can be used to complement or even replace voice messages. Navigation instructions translated into vibration patterns have been applied on different parts of the body, such as the chest [1], feet [15], hand and waist [10]. These studies either use vibration patterns to communicate an instruction (e.g., turn left) or use vibration frequency or intensity to communicate distance.

Visual

While voice messages are important, many PVI are not fully blind and use the screen to access visual wayfinding information when needed [12]. However, the map interface used by traditional navigation apps is often inaccessible for PVI [12]. In contrast, a simpler interface with navigation instructions, arrows and images of the environments seems to be more effective [11, 14].

Information content

Traditional apps omit important wayfinding information PVI need. Road layout, obstacles and detailed information of the environment (e.g., landmarks) is usually not provided [4]. Apps can be improved by optimizing the given information [14]. The app BlindSquare is specifically designed for PVI and provides some of this missing information [2]. Wayfindr is a standard to stimulate proper integration of environmental information in traditional wayfinding apps [16]. This standard contains guidelines on what information to provide and when to provide it. It proposes the usage of sounds in combination with text-to-speech messages to indicate different type of alerts.

MESSAGE FRAMEWORK

Our framework combines the different approaches in one complementary message framework. All messages are constructed using the Sidewalk wayfinding syntax, a modular wayfinding message syntax allowing for detailed and short wayfinding messages [13]. A distinct notification for each message is given before the actual information is transmitted. To lower the learning curve for the different notification signals and to allow for more selective attention, the messages are sorted in four different categories according to their content and importance: navigation instructions, orientation messages, accessibility messages and alerts. Navigation instructions contain information similar to

Table 1: Description of modalities for each message category.

Message type	Navigation	Orientation	Accessibility	Alert
Tactile	Two vibrations	Two long vibrations	One vibration	Three vibrations
Audio/ Voice	Confirmation sound before message	One short note before message	Fast rising sound before message	Bell sound before message
Visual	Arrow, image (optional), short tekst	Image or icon, short text	Image or icon, short text	Image or icon, short text

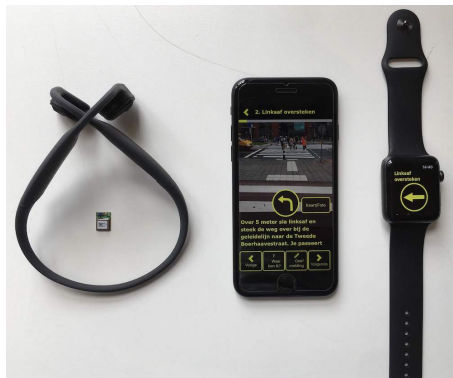


Figure 3: The EyeBeacons system with bone conduction headset, smartphone and smartwatch.

turn-by-turn navigation that is currently available in wayfinding apps. Orientation messages convey information about the environment. Accessibility messages provide information about tactile paving, audible traffic lights, or the easiest way to access the stairs. Alerts are messages that are of immediate importance for the user, such as road constructions. The notification is provided in the discussed modalities: an audio tune is played with a corresponding vibration pattern. On the screen an icon or image is displayed indicating the type of message. The audio and vibration signals indicate the level of importance, allowing the PVI to decide how much attention should be paid to the message. For example, an alert should have immediate attention, while an orientation message can be ignored. If the user misses a notification, the screen can be accessed to get an indication of the type of message by looking at the indication icon. The full implementation for each different message category is shown in Table 1.

WEARABLES

For transmitting the messages to the user, a smartphone can be used. However, the form-factor and position of the smartphone is not ideal for wayfinding. PVI often do not have their hands free to interact with the device because of the usage of other assistive tools like a guide dog or a white cane [17][11]. Commercially available wearables such as a bone-conduction headphones and a smartwatch are likely to improve the wayfinding experience. For conveying audio/voice feedback PVI often use headphones [17]. However, the use of headphones can be undesirable for wayfinding, as they disconnect the user from the environment. Several sources consider wireless bone conduction headphones to be an effective solution to this problem [3][16]. These headphones communicate the messages via vibrations on the bone, while keeping the ear free to listen to the environment. Moreover, there are no extra wires extending from the phone. Vibration signals of smartphones go often unnoticed when walking, due to their position on the body. Machida et al. found the ear, wrist, hand or feet to be a suitable location for vibration feedback on the body while walking [8]. PVI are potentially willing to wear a wristband or glasses for audio/voice or tactile feedback, but the wearable should look like a mainstream device



Figure 4: Examples of different situations encountered on the test route: stairs, obstacle and road with crossing.

[17]. A smartwatch can be used to communicate the envisioned modalities (audio, voice, tactile and visual) and allows for interaction gestures via finger or arm. Despite the screen size being small, the watch can transmit the essence of a wayfinding message like an icon and a short text in high contrast (see Figure 2).

METHOD

The effectiveness of the framework was tested in an urban setting in Amsterdam, the Netherlands. We designed the route to include situations users typically encounter in an urban environment (noisy roads, stairs, road crossings, squares, construction work and obstacles on the road), figure 4. We incorporated our framework in a wizard-of-Oz iPhone and Apple Watch wayfinding app via Bluetooth connected to a bone conduction headphone, figure 3. After an indoor introduction, users walked the predetermined route of 1 kilometre and received a total of 23 wayfinding instructions via the headphone (audio/voice), smartwatch (visual) and smartphone (tactile (vibration)). While the smartwatch was envisioned to deliver the vibrations, limitations of the smartwatch did not allow us to communicate the desired patterns. Hence, it was decided to use the smartphone mounted on the arm to transmit the vibrations. Users were accompanied by a trained researcher to prevent accidents. The user experience was measured through the System Usability Scale (SUS) [?], the Raw NASA Task Load Index (RTLX) [7] and through open questions about the different modalities. Written informed consent was obtained from all participants. The study protocol was evaluated by the Medical Ethical Board of the Free University of Amsterdam and received the indication that the Medical Research Involving Human Subjects Act does not apply for this study.

RESULTS

Four PVI participated: one female, three males, age between 25 and 46 and visual acuity between 2% and 30%. SUS scores were high with an average of 89.4 (SD = 6.5). RTLX score average was 14.7 (SD = 12.3) (see Table 2). Perceived mental load of walking the route varied per participant. P1 and P3 experienced almost no mental load, while P2 experienced moderate load and P4 experienced high mental load. P4 also experienced a higher physical effort (moderate) than the other participants (low). All other task load experiences were rated close to the other participants. From the open questions we learned that all participants found the Apple watch to be comfortable and easy to use next to their existing assistive devices.

The experience with the bone conducting headset varied: P1 and P2 were positive, while P3 was not satisfied with the device. P4 could not use the headset because of a Bluetooth hearing aid. P1, P3 and P4 were satisfied with the amount of feedback from the system. P4 wanted to receive less messages and shorter voice messages. The timing of the messages was experienced as sufficient by all participants. The vibrations were felt by all participants. However, P1 and P2 had trouble distinguishing

Table 2: Participant scores of the System Usability Scale and the Raw NASA Task-Load Index.

Participant	SUS	RTLX
P1	97,5	15
P2	80	20
P3	92,5	18
P4	87,5	35
Average	89,4	14,7
STD	6,5	12,1

the different vibration patterns, while P3 and P4 found the difference sufficient. All participants had trouble recognizing the different audio tunes belonging to the different messages, and recommended to change this indication. P3 suggested to expand the explanation about the tunes. Looking at the effectiveness of the system, none of the participants had trouble focusing on the environment while using the system. The researchers also observed a quick and adequate navigation response to the messages. Overall, the participants appreciated the hands free option of on-body wearables, were satisfied with the different features of the system and would recommend it to their peers.

DISCUSSION

We created a multimodal communication framework for transmitting wayfinding messages to PVI via wearables. Our approach was tested in a small user study. Participants walked a predetermined route through urban Amsterdam, receiving vibrations on the arm via smartphone, screen messages via the smartwatch and audio and voice feedback via a bone conducting headset. Both vibrations and audio tunes were recognized by all participants, but were difficult to distinguish. It is unknown if this was caused by the chosen indicators, or that users could not recollect the meaning of the different indicators. Before the field test, it was confirmed that participants remembered the different patterns. However, for future research we plan to extend the learning experience, ensuring users know the different patterns by heart before starting the field test. In conclusion, participants were satisfied with the communication framework. However, they had trouble distinguishing between different vibration patterns and audio tunes. Nevertheless, even without recognizing message types by their indicators, users responded to the patterns, indicating a notifier before the voice message is still valuable.

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