Prototyping Wearables for Supporting Cognitive Mapping by the Blind: Lessons from Co-Creation Workshops

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ABSTRACT
This paper describes the co-creation workshops we carried out with three groups composed of blind users, mobility instructors, designers, and computer engineering students. The wearables prototyped by these groups combine verbalized warnings with haptic and audio feedback aiming at supporting blind persons in the task of identifying landmarks. The identification of landmarks is an essential skill required for the cognitive mapping and spatial representation. Since 2013 we have been worked on the investigation of wearables for supporting landmark identification and, thus, the cognitive mapping by the blind. The prototypes we describe in this paper were used in 82 trials in 2 empirical studies and are now being replicated for supporting mobility-training sessions.

Keywords
Blind Mobility, Spatial Representation, Landmark Identification, Wearable Computing.

1. INTRODUCTION
The identification of landmarks plays a crucial role in the locomotion process of blind persons [1]: it helps the orientation process, gives contextual information, helps the planning of routes, and helps avoiding obstacles and hazardous situations. According to the inefficiency and difference theories of spatial representation by blind persons [2], [3], this information is useful for the cognitive mapping.

The problem in providing landmark information to the blind lies not only in detecting landmarks, but also in the way this information is presented to the blind. The negligence with human factors is considered to be one of the main causes blind persons do not adopt new assistive technologies [4]. For instance, individuals that acquire blindness usually take some time to accept the white cane during their period of mourning, but they finally accept it because the benefits outweigh the hassle associated with the cane. For any new technology the golden rule is to minimize the hassle and maximize the benefits.

The masking phenomenon is a problem caused by technology that consists in a cognitive overload and/or the harmful interference of technology in the wearer's ability of sensing the environment [5]–[8]. Avoiding masking is one of the main challenges faced by designers of wearable devices for blind pedestrians when designing Electronic Travel Aids (ETA) and Electronic Orientation Aids (EOA).

In order to develop wearables for supporting landmark identification (and, thus, cognitive mapping), this research used a method - documented in [9] - that combines an ethnographic study with co-creation workshops. During the co-creation workshops, blind subjects and mobility instructors worked together with designers and computer scientists to produce three different low fidelity (lo-fi) prototypes. We then used these lo-fi prototypes to build a high-fidelity (hi-fi) prototype. The hi-fi prototype was used later in 82 trials in two empirical studies (beyond the scope of this paper).

This paper is organized as follows: Section 2 presents the literature review, with a discussion on the theories of spatial representation and a list of related works. Section 3 describes the observational study and the main lessons we learned with these observations. Section 4 describes the co-creation workshops, and the wearable prototypes. Finally, the conclusion and future works are discussed in Section 5.

2. THEORETICAL FOUNDATION
The theories about spatial representation by the blind came from the Molyneux’s Problem [10]. From the initial set of questions, three answers arose: deficiency, inefficiency, and difference theories [2], [3].

The first dominant theory – the deficiency theory – says the blind could not acquire a spatial representation because it depends on the association between sight and other senses [11]. Locke and Molyneux, 16th century philosophers, agreed with the deficiency theory. George Berkeley [11] [12] is another early supporter of the deficiency theory. A particular experiment – conducted by William Cheselden [13] – on a boy born blind, who had surgery for cataracts at 14 years old, initially corroborated the deficiency theory, but many problems in the experiment brought even more discussion and the subject remained inconclusive. Later on, based on observations concerning the sight of newly born animals and babies, another theory took place – the inefficiency theory – in which the blind man is considered able to acquire spatial representation, despite the absence of visual information. The inefficiency theory, however, says this spatial representation is necessarily less efficient in blind than in sighted persons. Some known supporters of this theory are: Johannes Müller, Hermann von Helmholtz, and Adam Smith [14].
Nowadays, difference theory is the most accepted one. It agrees with inefficiency theory concerning the blind's ability to acquire spatial representation, but diverges because it says the difference between blind and sighted person's spatial representation is qualitatively different – and not necessarily less efficient. For instance, a blind person may prefer a longer path as long as it is easier to remember (avoiding cognitive overload). In this case, the “distance” does not seem like the best optimization function for the blind, but maybe the number of clues or landmarks in the path. Susanna Millar [15], [16] and Simon Ungar [17]–[19] are amongst the researchers that support this theory. Our research draws from the difference theory. As a result, it takes as a premise the ability of acquiring spatial representation by the blind and aims at supporting this acquisition by means of wearable devices.

The research on blind mobility may benefit from the framework defined by Michael Brambring [1], in which the problem of locomotion of blind pedestrians is divided in minor problems. Brambring divided the locomotion problem in two categories: problems of perception and problems of orientation. Perception problems are related both to the capacity of perceiving and avoiding obstacles (first minor problem), and the capacity of identifying landmarks in a path (second minor problem). Orientation problems are related both to the difficulty of orientation in near-space (spatial orientation, or the space within the reach of haptic exploration - approx. 3 ft) and far-space (geographical distances orientation) [20], [21].

From the Perception category, Obstacle & Avoidance ETAs have been largely investigated, while Landmark Identification ETAs received little attention so far [22]–[27]. The most common assistive technology for obstacle detection is the white cane, and the most mature ETA for obstacle detection is the Ultra Cane – an electronic cane that uses vibration motors to indicate obstacles both at the level of the ground, hips and head [22]. No specific work on Landmark Identification was found during our literature review, but some EOAs designed for navigation could help the blind identify objects that could serve as Landmarks, like works in [28]–[31]. Devices for navigation using GPS are the most common EOAs investigated in the Orientation category. Very often, these systems try to solve both the Spatial Orientation and Geographical Orientation problem, as the former implicates directly in the latter (this implication is also depicted by Brambring in his model). Among these systems, GeoTact [5] stands out for the way it communicates to the wearer about which directions to take: instead of saying “turn right” (for example), it informs directions by a metaphor of clocks – for instance, 12 o’clock means straight and 2 o’clock means a slight turn to the right. The authors do not say whether this approach is better or worse than the traditional way used by cars.

Some efforts in the Orientation category used an approach of mapping images to auditory or tactile displays [32]–[34] (and also [31] for obstacle detection). This mapping approach has been consistently related to the masking problem, as the auditory pattern takes too much effort from the wearer to be understood. The mapping of images into auditory patterns results in overly complex patterns, requiring too many hours of training and also impairing the wearer’s pace of gait because they must interpret the sound before they can take action. This problem is well described by Borenstein and Ulrich after their experimental tests with NavBelt:

The problem with this method lay in the fact that a considerable conscious effort was required to comprehend the audio cues. Because of the resulting slow response time, our test subjects could not travel faster than roughly 0.3 m/sec (1 foot/sec). And even this marginal level of performance required hundreds of hours of training time. [35] (p.1284)

The mapping of images to tactile displays is also hard to interpret and may be even worse in the matter of communicating to the wearer because the skin’s sensibility varies and the most sensible areas are usually small (like fingertips). In addition, the loss of limb’s sensibility (peripheral neuropathy) is very common in blind persons when blindness comes together (or as a result) with diabetes [36]. The harmful interference of ETAs and EOAs in the blind person’s ability to pick up environmental cues is called “masking”. The masking problem is one of the most frequent side effects of the technology because sight communicates a lot of information in a very efficient way through the optical nerve and no other sense seems to be capable of doing it so efficiently. The ideal solution is to make the blind capable of seeing, but that doesn’t seem achievable in short-term research. To the best of our knowledge, no device is capable of communicating by using the optical nerve, so researchers must rely in different “paths” for giving environment information to the brain. These different paths do not have the necessary “bandwidth”, which requires the designer to be careful when selecting what and how to communicate environmental cues to the wearer. Therefore, “masking” stands as a challenge for designers of wearable assistive technology for the visually impaired.

Our research goal is to support the blind in the identification of Landmarks in order to help spatial representation acquisition. Because we have to communicate sensed information to the wearer, our research relies on the same risks of masking as the research with obstacle detection & avoidance or navigation. In order to avoid or minimize the occurrence of the masking phenomenon, we built three wearables prototyped by potential users and technical staff, as discussed in the subsequent sections.

3. OBSERVATIONAL STUDY

We started this research by observing blind subjects in order to understand how they make spatial references, what elements in space are used as reference, and what elements they can't perceive. The observational study we made is classified as real life observation, non-structured, non-participant, and individual [37]. This phase of the research lasted 8 months and started in July/2013 (selected quotes available at https://youtu.be/SxzPOXb4wzM).

Throughout the whole research we had the support of the Benjamin Constant Institute (IBC), a Brazilian institution that has devoted 160 years to the education and support of the blind. The institution has its own ethical rules and the research procedure was evaluated and approved previously.

We were authorized to work with adult students of the rehabilitation department; most participants are late blind, but we also had some born blind students participating. All participants were asked to authorize us and sign a consent form in which they declare if and how they want to volunteer for the research, as Brazilian laws forbid us to pay for the participation of subjects in research. The lessons we learned during this observational phase are listed in Table 1.
shoulders are usually caused by a protective posture against asymmetric feet position. According to Thales and [38], rounded common postural issues are: round shoulders, forward head and are the first issues he works on with his students. The most Concerning postural problems, one mobility instructor said these sometimes. In that case, reference counting is preferred over step or for changing directions, but they also count references references are used especially for assuring they’re in the right path use walls for helping them to walk in a straight line. The temporary cues as the smell of a grocery store, for instance. They Blind persons use fixed elements as references, but they also use counting (Text 2).

We used pseudonyms for referencing all participants in this paper.

Concerning postural problems, one mobility instructor said these are the first issues he works on with his students. The most common postural issues are: round shoulders, forward head and asymmetric feet position. According to Thales and [38], rounded shoulders are usually caused by a protective posture against unexpected encounters.

**Text 1. Postural problems of the blind**

Blind persons use fixed elements as references, but they also use temporary cues as the smell of a grocery store, for instance. They use walls for helping them to walk in a straight line. The references are used especially for assuring they're in the right path or for changing directions, but they also count references sometimes. In that case, reference counting is preferred over step counting (Text 2).

I don't like counting anything, either references or steps. Counting things makes me sleepy! (...) I think I have all these paths entangled in my 'head' [pointing at her head]. I know that at some point I'll reach references A, B, and C. I know that if I change my path I'll see other references and I know how to reach my destinations through them. I have it all in my mind. [Manu]

**Text 2. Orientation strategies based on references**

One of our blind participants declared she doesn't always prefer the shortest path. According to her, it's not always the best choice as it can be dangerous or have few references to help her orientate herself. The best choice, for her (Text 3), is a path with more references.

How do I choose between two paths? If the longest path is 'better', then I choose it. Someone may say to me: common, choose the shortest... " NOOO! (emphasis) What if the shortest is too open or has no references? The best path, for me, is the one with more references. [Manu]

**Text 3. Preference for paths with more references**

The most common references used in the mobility course are: texture of the floor, drafts, walls, fences, plants among others.

4. **CO-CREATION WORKSHOP**

For the design phase, we used co-creation workshop sessions with participants ranging from engineering to design students, and from sighted people to blind participants, and also mobility instructors. There were 13 participants, as listed on Table 3.

The workshop started with a brainstorming session on the main problems a blind person faces when walking without a sighted guide. During this session, instead of just listing ideas on the board, we decided to read ideas aloud from time to time, in order to make it possible for the blinds to participate.

**Table 3. Participants in the co-creation workshop**

<table>
<thead>
<tr>
<th>Nickname (pseudo)</th>
<th>Age/Gender</th>
<th>Sighted / Blind?</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary Louise</td>
<td>51yo / Female</td>
<td>Born blind</td>
<td>Psychologist</td>
</tr>
<tr>
<td>Gunther B.</td>
<td>20yo / Male</td>
<td>Sighted</td>
<td>Eng. Student</td>
</tr>
<tr>
<td>Nathalie</td>
<td>24yo / Female</td>
<td>Sighted</td>
<td>MSc Design Student</td>
</tr>
<tr>
<td>Vicky</td>
<td>17yo / Female</td>
<td>Sighted</td>
<td>Eng. Student</td>
</tr>
<tr>
<td>Carlson</td>
<td>25yo / Male</td>
<td>Sighted</td>
<td>DSc. Informatics Student</td>
</tr>
<tr>
<td>Bertha</td>
<td>28yo / Female</td>
<td>Sighted</td>
<td>Design Student</td>
</tr>
<tr>
<td>Brandon</td>
<td>19yo / Male</td>
<td>Sighted</td>
<td>Eng. Student</td>
</tr>
<tr>
<td>Vanisty</td>
<td>31yo / Female</td>
<td>Sighted</td>
<td>Mobility Instructor</td>
</tr>
<tr>
<td>Rachel Green</td>
<td>27yo / Female</td>
<td>Born blind</td>
<td>Master in Literature</td>
</tr>
<tr>
<td>Johnny Duque</td>
<td>26yo / Male</td>
<td>Sighted</td>
<td>MSc. Informatics Student</td>
</tr>
<tr>
<td>Jackie</td>
<td>22yo / Female</td>
<td>Late blind</td>
<td>Student</td>
</tr>
<tr>
<td>Ian</td>
<td>55yo / Male</td>
<td>Late blind</td>
<td>Attorney</td>
</tr>
<tr>
<td>Ryan</td>
<td>25yo / Male</td>
<td>Sighted</td>
<td>Design Student</td>
</tr>
</tbody>
</table>

Many problems were listed and the group was told to define guiding criteria for the design. The group decided the main guiding criteria as:

- Using embedded technology in wearables already worn by the blind, like watches, glasses and white canes;
- Keeping their hands free;
- Never blocking their ears with earplugs or something similar.

After defining the guiding criteria, they were divided in 3 groups, each group with – at least – one blind user. The mobility instructor was told to be part of a group with only one blind person, in order to balance the number of stakeholders inside each
group. Also, we chose to put at least one designer and one engineering student in each group.

For the prototyping session, the method used was Blank Model Prototyping (BMP) [39], which requires the participation of potential users (we had 4 blind participants), and design and technology professionals. Blank Model Prototyping is a rapid role-playing technique that uses readily available art and craft materials to construct rough physical representations of a technological concept, according to a predetermined scenario. The method was used with the intent to collect potential user impressions and detailed ideas about the wearable to be built for the experimental part of this work. Although most of our participants had already worked with BMP in the past, we found it important to give them instructions on BMP to keep the group on the same page. Fig 2 shows participants during the role-playing session.

Each group produced their prototypes in 2 hours with their workgroups and then we moved on to the test phase. The role-playing part of the method consists in using the prototypes in a role-playing session (Figure 1). Each group took 10 minutes to present each feature of their prototype.

Many features were discussed and presented during the role-playing sessions. For instance, for the feature “communicate new landmarks to the wearer”, each group chose a different solution: group 1 chose to use beeps and midi sounds (1 sound for each kind of landmark); group 2 decided to use sequences of vibrations with vibration motors mounted on a watch, and group 3 specified a text-to-speech solution.

The technology chosen for the task of identifying new landmarks was the same in 2 prototypes: image processing on images obtained from mounted cameras. Group 2 chose a solution based on radios, which also incorporated cameras. As a result, the wearable would listen to the air trying to identify digital beacons. When it wasn’t possible to identify the digital beacons, the wearer must point the watch to a direction and wait for the analysis of the image.

In order to develop and test each feature, we decided to use an iterative development process. The first step was to evaluate the viability of each solution. Because masking is a frequent phenomenon in ETAs and EOAs, we decided to build a simpler version of the prototypes for investigating the masking effect. For landmark identification, we chose the radio-based solution: it is simpler and faster to develop than machine learning models for computer vision (as it is required in the other prototypes).

A “Digital Beacon” identified each landmark, like a door, chair, entrance halls, hallways, etc. Our beacon is a tangible device made with microcontrollers (we used Arduino Mini Pro), 4 AA batteries, electronic components for voltage regulation, and a 433Mhz radio transmitter. Figure 2 shows a digital beacon, and two versions of the Smart Glasses made to communicate with these beacons.

The wearable consisted in glasses with embedded computing. For the first version, we used a 3D model for printing the glasses, but we changed to manufactured protection glasses (embedding our technology in it) because of ergonomic issues. We also built a glove and a belt with speakers and vibration motors in order to test different modes of feedback with our subjects, as shown in Figure 3.
5. CONCLUSION AND FUTURE WORKS

This paper presented our approach for prototyping wearables for supporting spatial representation acquisition by blind people. The work started with an observational study in which we learned the main problems related to the mobility of blind pedestrians. We were able to correlate the masking phenomenon (described in literature) with the testimonials of our blind participants. We then produced a high-fidelity prototype based on the lessons we got from the previous stages. This prototype is now being used in mobility-training sessions and we keep learning from them. In this way, this work contributes with an approach for prototyping wearables for blind users.

Future works include a new version of the Smart Glasses that will feature a camera mounted between the lenses. The camera will be used for the identification of landmarks. Cameras need to be pointed at the object that is to be sensed, while radio-based solutions (like our beacons) have a perimeter in which the radio waves are captured by antennas. These differences may influence the wearer’s posture and it may influence his performance when finding landmarks, his posture, and also his social behavior. The investigation on these differences represents a second goal in the next steps of this research.

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7. REFERENCES


