Landmark Identification with Wearables for Supporting Spatial Awareness by Blind Persons

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ABSTRACT
This paper describes our research on feedback mechanisms of wearables for supporting indoor landmark identification in the context of blind pedestrians' mobility. It contributes with a promising alternative to audible patterns, which are consistently related to the 'masking phenomenon'. It also contributes with many lessons and insights that could benefit the designer of wearables for blind users. We started from an observational study followed by co-creation workshops with designers and potential users. The resulting prototypes were used in two Case Studies. The first study investigated the occurrence of 'masking', a problem caused by technology that affects negatively the sensorial perception of the wearer. The second study investigated the usefulness of the wearables for the identification of landmarks. The wearable succeeded in both tests for the particular context in which it was used.

Author Keywords
Blind Mobility; Spatial Awareness; Landmark Identification; Wearable Computing.

ACM Classification Keywords
C.3 [**Special-Purpose and Application-Based Systems**]: Real-time and embedded systems

INTRODUCTION
The identification of landmarks plays a crucial role in the locomotion process of blind persons [12][50]: 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 [3,17], 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 [7]. Individuals that acquire blindness usually take some time to accept the cane during their period of mourning, but they finally accept it because the benefits outweigh the hassle associated with the cane.

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 [11,16,30,31]. 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 spatial acquisition by means of landmark identification (for simplification reasons, in this research we usually call 'landmark' the indoor points of reference), this research started with an observational study, followed by co-creation workshops, in which blind subjects and mobility instructors worked together with designers and computer scientists. This method is documented in [18].

We ran two empirical studies after the prototyping stage: one specifically designed for the investigation of masking, and the other to evaluate whether the wearable actually helps blind individuals in the task of identifying landmarks. In total, 36 volunteers participated in the observation, prototyping or testing phases. As a result, the wearable succeeded in both studies and it seems that the reason is the use of verbalized warnings in the wearables, which is the main difference between this and related works. The results are limited by the context in which the studies were made and by the setup used, i.e., quantity of digital landmarks and the distance between them.

This paper is organized in the same sequence of the procedures conducted in our research. We started with the literature review, presented in the next section, in which we discuss the theories of spatial representation and a list of related works. We then present our observational study in the third section, while the fourth describes the co-creation workshops, and the wearable prototypes designed with the help of potential users, experts in blind mobility, designers, and computer engineering students. After presenting the prototypes, we discuss the study we designed to investigate masking. Finally, we dedicated a section to present a study

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in which we assessed the usefulness of the wearable for increasing the number of landmarks explored by the blind participants. The qualitative data were analyzed according to UDUM [40], by means of categorization of quotes, counting of recurrences and chaining of evidences. We present a short version of this in a form of quotes collected from each category. Finally, Conclusion and Future Work sections are presented.

THEORETICAL FOUNDATION

The theories about spatial representation by the blind originally came from Molyneux's Problem. It was described from a letter sent by Molyneux to Locke (both 17th century philosophers), which sparked a discussion in the second edition of his work "An Essay Concerning Human Understanding" [32]. Molyneux proposed a thought experiment in which a globe and a cube (both made from the same material and roughly the same weight and size) are presented to a person who was born blind, so he can learn about them exclusively by touch. After a period of tactile examination, the cube and globe are placed on a table and the person is made to see. One of the main questions is "whether by his sight, before he touched them, he could now distinguish and tell which is the globe, which the cube?" From that question, three answers arose: deficiency, inefficiency, and difference theories [3,17].

The first dominant theory – the **deficiency theory** – says that the man could not distinguish them, as he had not been exposed to the objects through his sight [9]. Locke and Molyneux agreed with the deficiency theory, as Locke responded to Molyneux:

> *I agree with this thinking gentleman, whom I am proud to call my friend, in his answer to this problem; and am of opinion that the blind man, at first sight, would not be able with certainty to say which was the globe, which the cube, whilst he only saw them; though he could unerringly name them by his touch, and certainly distinguish them by the difference of their figures felt.* [32]*(Chapter 9)*

George Berkeley [9] [8] 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 person is considered able to acquire spatial representation, despite the absence of visual information. The inefficiency theory, however, says that 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 [21]. In the 1990's, Loomis *et al.* [33] presented research supporting the inefficiency theory. They investigated internal processes necessary for successful nonvisual navigations, and said that forming or making use of spatial representations is achievable by 'position-based navigation' (also called *pilotage*), 'velocity-based navigation', and 'acceleration-based navigation' (also called *path integration* or *dead reckoning*). Position- and velocity-based navigation rely on external signals (visual, audible or olfactive) while the latter relies on the human vestibular system, which provides information about linear acceleration, rotational velocity and acceleration. A blind person may make use of less external signals when using the position and velocity-based navigation, but the visual cues are only a subset of a family of cues. The authors discuss whether prior visual experience has consequences on tasks performed without vision. They say, from their results, that blindfolded subjects had better performance compared to born blind subjects and, therefore, the absence of vision may cause born blind persons being less efficient in acquiring and making use of spatial representations. The authors discuss related works in which born blind subjects had better performance and the 'inefficiency' subject remained inconclusive.

Nowadays, **difference theory** is the most accepted theory. 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 variable for the blind, but maybe the number of clues or landmarks in the path. Susanna Millar [37,38] and Simon Ungar [47–49] are amongst the researchers that support this theory. Our research draws from the difference theory, although it may also be useful for the ones who support inefficiency theory. Our research 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 [12], in which the problem of locomotion of blind pedestrians is divided in minor problems. The Brambring's Model is illustrated in Fig 1.

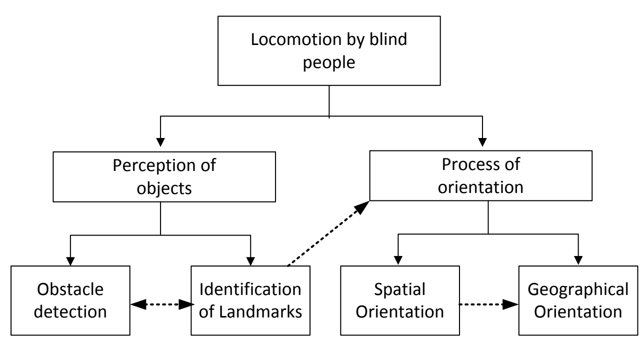

Figure 1. Brambring's decomposition of travel by blind people.

Prototype	Feedback / Sensor	Problem Addressed in Brambring's Model	Users Evaluation?	(B)lind / Blind(F)olded	# Subjects
ENVS [35]	Electro Tactile / Camera	Obstacle Detection	☑	F	?
CyARM [28]	Haptic and Audible / Ultrasound	Obstacle Detection	☑	F	4
Echolocation [27]	Audible / Ultrasound	Obstacle Detection	☑	F	2
Florida Int. Univ. [1]	Audible / Ultrasound	Obstacle Detection	☑	F	4
GuideCane [10]	Direct Force / Ultrasound	Obstacle Detection	☑	B / F	3/7
ITU-ENSAIT [5]	Haptic / Ultrasound	Obstacle Detection	☒	--	--
NavBelt [45]	Audible / Ultrasound	Obstacle Detection	☑	F	?
NAVI [44]	Audible / Camera	Obstacle Detection	☒*	--	--
vOICe [36]	Audible / Camera	Obstacle Detection	☒	--	--
Independence Day [43]	Spatialized Audio and Spoken Info / Beacons	Landmark Identification	☒	--	--
ISAS [41]	Spatialized Audio + Spoken Info / GPS	Landmark Identification	☑	B	6
Virtual Acoustic Space [20]	Audible / Camera	Landmark Identification	☑	B / F	6/6
Eyeled Prototype [19]	Undefined / Bluetooth Beacons	Landmark Identification	☒	--	--
Guelph Project [52]	Haptic /Camera	Geographical Orientation	☒	--	--
Univ. Stuttgart [25]	Audible / Camera	Geographical Orientation	☒	--	--
DRISHTI [42]	GPS, Ultrasound / Spoken Info	Geographical Orientation	☒	--	--

Table 1. Related Works on Blind Mobility

Brambring (Fig 1) divided the locomotion problem in two categories: problems of perception and problems of orientation. Perception problems are related to both the capacity of perceiving and avoiding obstacles, and the capacity of identifying landmarks in a path. Orientation problems are related to both the difficulty of orientation in near-space (spatial orientation) and far-space (geographical orientation).

Hersh and Johnson [22,23], define near-space as the space within the reach of haptic exploration, usually no more distant than 3ft (1 meter). The far-space, however, requires locomotion prior to haptic exploration, and is usually longer than 3ft, most often related to geographical distances.

From the Perception category, Obstacle & Avoidance ETAs have been largely investigated, while Landmark Identification ETAs received little attention so far [5,24,27–29,45]. 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 [24].

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 (as depicted in Brambring's model).

Among these systems, GéoTact [16] 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 works of the Orientation category, like [25,35,52], used an approach of mapping images to auditory or tactile displays. The same mapping approach was used in [44], an ETA designed for obstacle detection.

During the literature review, we found 4 works related to Landmark Identification [19,20,41,43] and also some devices from the Orientation category that could help the blind to identify objects sometimes useful as reference points, like works in [15,26,36,44].

The "Independence Day" [43] is a recent project (2014) from the Landmark Identification category. This system announces landmarks by playing verbalized warnings and it plays a 3D spatialized audio when the wearer approaches a new reference point. The spatialized audio is meant to indicate the distance to the nearest reference point.

Another recent work that uses landmark identification (called by its authors as 'points of interest') for giving users 'Spatial Awareness' is ISAS [41]. The system was designed to answer the following question "What's around me?" by displaying information about surrounding items using speech and spatialized audio. Like the aforementioned project [43], the spatialized audio is designed to help users to find reference points by indicating the distance to them. Holding the phone vertically or horizontally are postures used to activate two important functions of ISAS (namely Stop & Listen and Walking modes). Detailed information is obtained on demand, for example, by tilting the phone. The amount of information that is provided is an important characteristic of such systems, as it may interfere on the use of the remaining senses and may cause cognitive overload.

The masking phenomenon

The harmful interference of ETAs and EOAs in the blind person's ability to pick up environmental cues is called "masking". The masking phenomenon is one of the most frequent side effects of 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 does not 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 relaying 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. The inherent cognitive overload of blindness is illustrated by the words of one of our subjects:

> *A sighted person doesn't understand what it is… a sighted person uses it [pointing to his head] only to work, not to walk. We use it [again, pointing to his head] all the time when walking. I have to pay attention to everything… Our vision passes through here [pointing to his ears].*
> *[Comments from one of our blind subjects]*

The harmful interference that characterizes masking is very often related as 'overwhelming features', 'cognitive overload' and as features that 'block the use of remaining senses' (even partially). For instance, the mapping of images in audible patterns or haptic displays (like [20,25,35,52]) has been consistently related to masking and has been criticized because of the excessive amount of conscious effort required from the wearer to understand the generated pattern and also for blocking the use of wearers' remaining senses. The mapping of images into auditory patterns results in overly complex patterns, requiring too many hours of training and impairing the wearers' pace of gait because they must interpret the audio pattern before they can take action. Borenstein and Ulrich describe this problem after their experimental tests with NavBelt:

> *The problem with this method* (sic) *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.* [10]

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 ours 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 of) with diabetes [39].

The ISAS project [41] is the one most closely related to the present research. The authors did not mention masking specifically, but they were dealing with it all the time. Their users made remarkable comments of how technology interfered negatively in the walking sessions. For instance, they discuss a lot about the ideal quantity of information that should be given to users, as the users considered the current version 'overwhelming' and one said regarding the frequency of audio cues and verbalized warnings: "(...) *But not on, and on, and on... (...) I want to listen to it, when I want to listen to it!*" The authors also discuss the fact that the first version required the use of one hand to hold the phone, and one user said he was instructed (in the mobility course) to always keep one hand free for tactile exploration and for safety reasons.

Our research goal is to support the blind in the identification of Landmarks in order to help spatial representation acquisition. Given that we have to convey sensed information to the wearer, our research may incur on the same risks of masking as the other researches listed in this section. In order to avoid or minimize the occurrence of the masking phenomenon, we prototyped three wearables together with potential users and technical staff. This experience is discussed in the next sections.

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 cannot perceive. The observational study we made is classified as real life observation, non-structured, non-participant, and individual [34]. This phase of the research lasted 8 months and started on July of 2013.

Throughout the whole research we had the support of the Benjamin Constant Institute (IBC: http://www.ibc.gov.br), a 160 years old institution devoted to the education and support of the blind. The institution has its own ethical rules and the research procedure had to be approved previously.

We were only 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 signed a consent form in which they declared that they wanted 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 phase are listed in Table 2.

Concerning postural problems, mobility instructors said that these are the first issues they work on with their students. Some comments are listed in Text 1.

Lesson	Observed individuals	Characterization
Blind individuals are prone to postural inadequacy problems	Born blind, low vision, and late blind individuals	• Round shoulders, • Forward head • Asymmetric feet position
Strategies for the cognitive mapping	Born blind and late blind individuals	• Graphs, linked list, and doubly linked list • Strategies for collecting references • Main difficulties
Difficulties in geographical orientation	Born blind and late blind individuals	• Step counting *vs.* external referencing • Cognitive overload associated
Difficulties in spatial orientation	Born blind and late blind individuals	• Difficulties in walking straight forward, • Difficulties in body centric referencing • Difficulties in external referencing
Difficulties in getting an overview of a scene	Born blind and late blind individuals	• Strategies used by blind persons

Table 2. Lessons from the observational phase of the research

The posture of low vision people is usually bad because they're trying to correct their field of vision. They usually have 'Forward Head' posture or an inclination to one side.
[Thales, 30 y.o., physiotherapist and mobility instructor].

The first things I usually see in my students are 'Round shoulders' and wrong positioning of feet. They usually develop round shoulders to avoid hitting snags.
[Vivian, 31 y.o., mobility instructor]

I think every blind person has some kind of postural inadequacy. We can't see and we can't learn postures from our parents, like every sighted child can. We usually have rounded shoulders because of many accidents and we also tend to incline our heads to be able to hear the cane.
[Manu, 51 y.o., born blind, psychologist and Braille reading teacher]

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 are in the right path or for changing directions, but they also count references sometimes. In that case, reference counting is preferred over step counting (some comments on 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 does not always prefer the shortest path. According to her, it is 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 plenty of references.

How do I choose between two paths? If the longest path is 'better', then I choose it. Someone may say to me: 'ahhh, chose the shortest...' NOOO! (emphasis) ***What if the shortest is too open or has no references? The best path*** *(short pause, pointing to herself)****, for me*** *(short pause)****, 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 floor texture, drafts, walls, fences, and plants among others.

CO-CREATION WORKSHOPS

For the design phase, we used co-creation workshop sessions according to the approach described in [18,46]. These sessions counted with participants ranging from engineering to design students, and from sighted people to blind participants, and mobility instructors. There were 13 participants, as listed on Table 3.

Nickname	Age / Gender / Blindness	Formation
Mary Louise	51yo / Female / Born blind	Psychologist
Gunther B.	20yo / Male / Sighted	Eng. Student
Nathalie	24yo / Female /Sighted	MSc Design Student
Vicky	17yo / Female /Sighted	Eng. Student
Carlson	25yo / Male / Sighted	DSc. Informatics Student
Bertha	28yo / Female /Sighted	Design Student
Brandon	19yo / Male / Sighted	Eng. Student
Vanity	31yo / Female / Sighted	Mobility Instructor
Rachel Green	27yo / Female / Born blind	Master in Literature
Johnny	26yo / Male / Sighted	MSc. Informatics Stu.
Jackie	22yo / Female / Late blind	High School Student
Ian	55yo / Male / Late blind	Attorney
Ryan	25yo / Male / Sighted	Design Student

Table 3. Participants in the co-creation workshop

The workshop started with a brainstorming session on the main problems blind persons face when walking without a sighted guide. 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. In order to balance the number of stakeholders inside each group, the mobility instructor was told to be part of a group with only one blind person. In addition, 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) [4], 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 prototyped for the experimental part of this work. Although most of our participants had already worked with BMP in the past, we gave them instructions on BMP to keep the group on the same page. Fig 2 shows participants during the role-playing session.

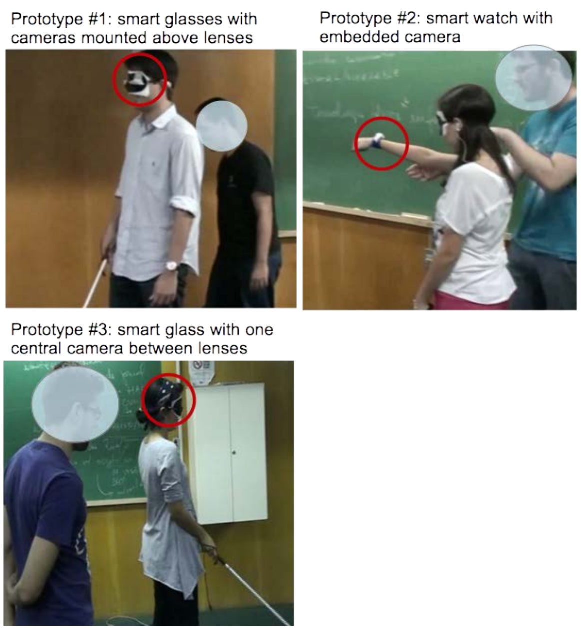

Figure 2. Testing prototypes ideas in a role-play session

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

Many features were discussed and presented during the role-play 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 identifying new landmarks was the same in two prototypes: image processing on images obtained from mounted cameras. Choosing a different solution, Group 2 went for radios and cameras: as a result, the wearable listens to the air trying to identify digital beacons. When it is not possible to identify the digital beacons, the wearer must point the watch to any 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).

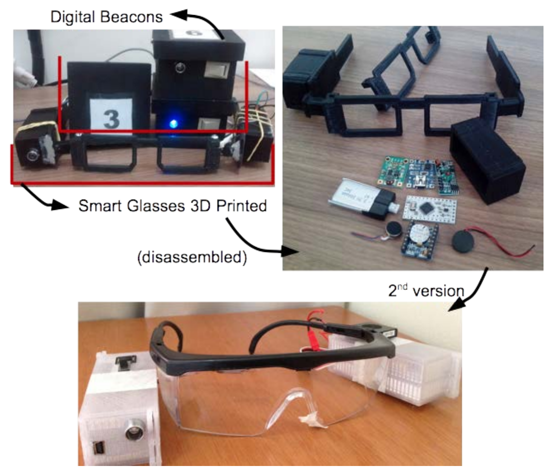

Figure 3. Digital Beacons and Smart Glasses

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 433 MHz radio transmitter. Figure 3 shows a digital beacon, and two versions of the Smart Glasses made to communicate with these beacons.

For the first version, we used a 3D model for printing the glasses, but we changed to manufactured protection glasses (embedding our technology into it) because of ergonomic issues. We also built a glove and a belt with speakers and vibration motors (potential accessories prototyped by the same groups) in order to test different feedback modes, as shown in Figure 4.

The Smart Glasses embedded a microcontroller Arduino Pro Mini 16Mhz 5v, a 433Mhz receiver module, Li-Po batteries 3.7v, voltage regulators (5v and 3.3v), a USB charging module, a WTV020-SD audio module (to provide verbalized warnings for the wearer, every time a new beacon is found). The glove and the belt were made from the same components of our Digital Beacon, with the addition of the following components: a JY-MCU Bluetooth (v1.02), speakers and vibration motors.

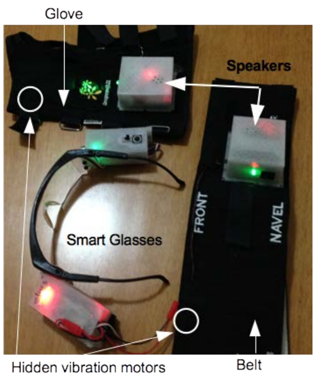

Figure 4. Smart Glasses, Glove and Belt

The Bluetooth component was added to connect with a mobile app, while speakers and vibration motors were added for testing feedback modes with our subjects. The app was used for configuring the current feedback mode during the tests, thus making it possible to perform different tests without reloading the firmware. Finally, the glove and belt were programmed to relay information from our Digital Beacons to the Smart Glasses according to the wearer's commands.

CASE STUDY 1: MASKING

The first Case Study [51] in this research was designed to evaluate whether the proposed feedback mechanisms are related to masking. Masking is an intervenient problem for the hypothesis of this research, as it causes cognitive overload and harms the use of the senses by its wearer.

To investigate the occurrence of masking, the most important data is qualitative. The subjects must say whenever a particular wearable is harmful for them when listening to the environment or whatever characteristics of the wearable feel uncomfortable to them. For collecting qualitative data, we used semi-structured interviews, with a script prepared according to UDUM [40]. For the selection of participants, we accepted all volunteers available for the study at IBC that are blind and have no other deficiency. In addition to the qualitative data, the most important measurement is the pace of gait (quantitative): if the wearer has a significant slower pace when wearing a device, then it may be due to masking and a deeper investigation is needed.

Concerning the pace of gait, Clark-Carter [14] did a comprehensive study of the mobility problems of the blind and how to measure them. According to Clark-Carter, a blind person's performance when wearing a device must be evaluated by comparing its performance when walking with a sighted guide. Interpersonal comparisons have proved wrong, as particular differences in one's disability are not taken into account. Hence, the designer's goal must be to approximate the performance when using the wearable with the performance when guided by a sighted person.

For this study we defined the individual's relative performance by calculating the pace of gait of the blind (steps/minute) when guided compared to the pace of gait of the blind using each one of the five configurations of wearables we prepared. In order to avoid the threat of maturation[1] on the design of this study, we used the Latin Square of order 5 in a cyclic method [6].

We worked with blind students of the mobility course, usually subjects who got blind within the last five years, and we had some born blind volunteers. Table 4 lists participants (pseudonyms) and their profiles.

All participants were asked about how they classify their own mobility skills. From this group, all the late blinds are students of the mobility course and all the born blind are former students of the same course. The study was conducted on IBC's 1st floor, given that all participants knew the place in advance, although they were not able to give detailed information as numbers of doors and the service offered in each room before the study (this is the information given by the beacons to the wearer).

Nickname (pseudo)	Age/Gender	Blindness since	Mobility Skills (self-classification)
Pietro	51yo / Male	3 years ago	Basic
Andrews	46yo / Male	Born blind	Advanced
Donatello	52yo / Male	4 years ago	Advanced
Karlie	33yo / Female	Born blind	Advanced
Monica	53yo / Female	19 years ago	Intermediate
Carlson	21yo / Male	3 years ago	Advanced
Wendy	33yo / Female	Born blind	Advanced
Ross Geller	35yo / Male	Born blind	Intermediate
Rachel Green	27yo / Female	Born blind	Basic
Ian	55yo / Male	5 years ago	Intermediate

Table 4. Case Study 1 participants' profile

The participants were told to perform 5 tests and a control test. The control test consisted in doing the same task as the other tests, but guided by a sighted person. The 5 tests were:

A. (Belt + Beep + Smart Glasses) – In this test, participants wear a belt that rings a beep each time a new beacon is detected. The participant also wears the Smart Glasses, which have an external speaker mounted on it. When a beacon is detected and a beep is heard by the wearer, she may press a button that makes the glasses "tell" the beacon;

B. (Belt + Vibration + Smart Glasses) – In this test, participants wear the same belt, but it is configured to make a vibration warning as a feedback to the wearer each time a beacon is detected (instead of a beep). The wearer must

[1] For this study, the performance may be a function of time, because if the wearer becomes tired, it may worsen his performance or if he has better knowledge of the path, it may improve his performance

press a button on the belt in order to hear her new location, as illustrated in Figure 5;

C. (Glove + Beep + Smart Glasses) – In this test, participants wear a glove configured to ring a beep as a feedback to the wearer each time a beacon is detected. The wearer must press a button on the belt in order to hear her new location;

D. (Glove + Vibration + Smart Glasses) – In this test, participants wear the same glove configured to make a vibration warning as a feedback to the wearer each time a beacon is detected (instead of a beep). The wearer must press a button on the belt in order to hear her new location;

E. (Only wear the Smart Glasses) – In this test, participants wear only the Smart Glasses configured to "tell" the location every time a new beacon is detected. The user does not have a button to press, a beep to listen to, or a vibration to feel.

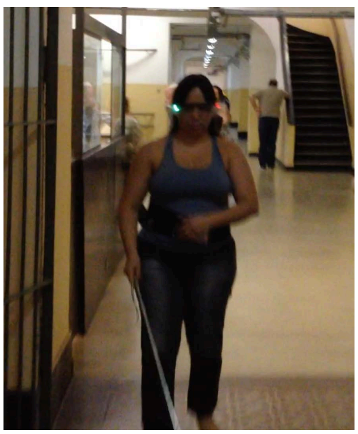

Figure 5. Participant performing test mode B

Considering all the 5 tests, participants were organized in two matrices 5 x 5, according to the Latin Square method.

Verbalized warning as an alternative to audible patterns

We compared the pace of gait when using each one of our 5 wearables with the pace of gait of the participant guided by a sighted person as a first approach for investigating the occurrence of masking. If we found a significant difference, then something went wrong and had to be further investigated. It does not mean that the absence of significant difference implies that the masking did not occur, but this is very uncommon when masking occurs.

Because our samples comprise 10 observations each (each test mode is a sample, and each measure – pace of gait – an observation), it was not possible to determine a Gaussian distribution. Thus, we used the Kruskal-Wallis non-parametric test for k-samples, with alpha of 5%.

All p-values found after the k-samples test (Kruskal-Wallis) and post-hoc tests (Bonferroni) were higher than 0.05, meaning that there is no significant difference between samples. It also means that none of the proposed wearables impaired the wearer's pace of gait.

We used verbalized warnings to relay the location to the wearer, given that the use of audible patterns has been consistently related to masking. The results we've got so far using verbalized warnings give evidences of a more effective way of relaying the location, implying that verbal information does not overload the wearer as much as the mapping of image into audible patterns in the literature [10].

The Wearable Should Infer the Pace of Gait of the Wearer and Behave Accordingly

During the interview process, some participants said they wanted the wearable not to give such detailed information. Instead, they preferred that the wearable relayed only a short message about each Landmark. For instance, for each door it should only tell the number of the door (the wearable was configured to tell all the information presented to the sighted via signs on the doors). In contrast, less experienced participants enjoyed the richness of information and even asked for more information. Some examples from the interviews are illustrated in Text 5.

> *I liked the equipment, but it didn't tell me* [information about location] *at the same pace I walked. Maybe it's because I walk too fast, but the fact is when it says the location I'm already ahead of it. [Carlson, 21yo, late blind]*
>
> *The message is correct, but it should be at the same pace I walk.* ***(…) It should have some kind of sensor that tells me the messages according to my speed, whether it's fast or slow.*** *(…) I like both kinds of messages, but longer messages should be told when in broader spaces, and shorter messages when in a place like this building, with many doors close to each other. If you don't have that kind of sensor, then it should give me short messages by default, and tell me longer messages at my command [Wendy, 33yo, born blind]*

Text 5. Quotes regarding duration of the messages

From the comments of our participants it is clear that the length of the message should be set according to the wearer's walking pace. From the test videos, it seems that the walking pace is a good indicator of the wearer's confidence on the path: when the wearer feels confident, he walks faster; when insecure, walks slower.

These quotes reinforce the need for individualized technologies, instead of global solutions. These results ask designers to prototype smarter wearables that adapt themselves to the wearer and to the current task. In the case of blind mobility, the features of this context-aware device must include awareness of location related to the wearer (the average speed of this wearer at each location, so the speed and duration of messages can be preset).

Limitations

This study is limited by the context in which it was done, like many Case Studies researches. The masking phenomenon has been observed in several contexts and it is clear that it does not depend on the context. However, the effects observed with the technological solution used in this research may be difficult to be reproduced in a different context. Therefore, researchers seeking ultimate solutions to the masking phenomenon may find the present research useful for comparing with the context of their own studies.

Although it is difficult to make a bold statement about the results in using verbalized warnings, it seems reasonable to consider that this approach will perform better than previous approaches for informing wearers because oral communication is the most common way human beings communicate, excluding deaf / non-vocalized persons, and other kinds of impaired persons with no oral communication. Concerning the human ability in recognize phrases, Agus et al. [2] report that human subjects recognize short target phrases within 300 to 450ms, and are able to detect human voices within 4ms. This is a strong argument for using verbal communication instead of audible patterns.

Finally, in addition to the context limitation, we cannot say that verbalized warning itself is the sole responsible for the results we achieved. The number of beacons, for instance, may have influence on the wearer's preferences of feedback. If we double the number of beacons, as asked by some participants, then it may be better to have a vibratory feedback for each new beacon, instead of listening to loads of information one did not ask for. Numerous feedback warnings may be disturbing to the wearer, no matter the kind of feedback. Thus, the ideal number of beacons remains an open research opportunity, as well as their preferable locations (we placed beacons on doors, hallways, entrance halls, bulletin boards, and chairs/banks on the way).

CASE STUDY II: LANDMARK IDENTIFICATION

The second case study was designed to evaluate whether the wearables support the identification of landmarks, since the first one demonstrated it does not cause masking. Table 6 lists participants of this Case Study.

For this study we chose a place unknown by many students of the rehabilitation department: the 3rd floor of the institute. Thus, the criteria for selecting participants included not knowing the 3rd floor and having no other deficiency.

The participants were told to perform two tasks: finding the statue of Dom Pedro II (the second and last Brazilian emperor) and finding the museum door. Our goal with the tasks was to make them move objectively through the space, as we did not evaluate whether they accomplished the task or not.

Participant	Age	Gender	Blindness
Karlie	31	Female	Born blind
Carlson	21	Male	Acquired 3 years ago
Shirley	64	Female	Acquired 7 years ago
Marco	64	Male	Acquired 15 years ago
Selton	53	Male	Acquired 2 years ago
Molina	23	Male	Acquired 1 year ago
Renato	22	Male	Born blind

Table 6. Participants of the Second Case Study

We defined two tests: Test A using only the cane and Test B using the cane and the wearable we provided them. For each test we gave them 5 minutes. The amount of time was set to prevent them from feeling tired or learning about the space. From our observations, a space as large as the 3rd floor takes months to be completely mapped by them. Figure 6 illustrates the haptic exploration that occurred during tests A and B.

Figure 6. Examples of haptic exploration

Next, we defined two events related to the exploration of space: 'Miss' and 'Reach'. Miss occurs when a blind person passes by a landmark (a door, for instance) without noticing it. Reach occurs when a blind person notices a landmark and explores it haptically. Examples of Miss and Reach (Figure 7) can be seen at https://youtu.be/n41ODXzZHDc.

Figure 7. Miss and Reach events

The Miss and Reach events were counted for each test and listed on contingency Table 8.

	Test A	Test B
# Miss	85	46
# Reach	55	94

Table 8. Contingency Table of Events Miss and Reach

The contingency table was analyzed with the Fisher's Test. The result is a p-value of 0.0001, meaning that the alternative hypothesis must be accepted. The alternative hypothesis says there's a link between 'Event' and 'Test' variables, i.e., the event Reach is more likely to occur in Test B (with proposed wearable) and event Miss is more likely to occur in Test A. We also interviewed participants after each test and selected some comments in Text 6.

> *I can say there's an open space and some stuff at its center, but I can't say what it is. I discovered a rounded bench. You saw me when I was using the walls for the exploration and the bench was at the center. I also explored a kind of cabinet and some doors. [Karlie, after Test A]*
>
> *(...) [The wearable] gave me the idea of a place that was unknown to me until now. I thought that it was a cabinet right there, but turns out it is a clock. It surprised me. There are also many things I would have never found out, because it was at the center of this open space... [Karlie, after Test B]*

Text 6. Comments from Karlie after Tests A and B

Because of the Karlie's comments, we also analyzed the strategy of exploration. For the comparison of the exploration strategies, we counted each time a participant passed by each landmark. These data were organized on a histogram (Figure 7) and their distributions were compared with a Kolmogorov-Smirnov test.

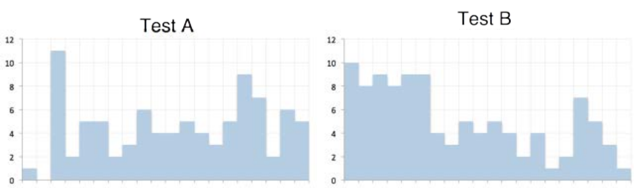

Figure 7. Patterns of exploration

Kolmogorov-Smirnov is a useful test for comparing the shapes of two distributions. We found no significant difference, between these samples, which means their exploration strategy did not change significantly. Actually most participants used the walls for guidance, but in Test B they heard the announcement of each landmark and explored (which produced a higher number of 'reaches' but with no modification on the exploration strategy).

CONCLUSION AND FUTURE WORK

This paper discussed issues concerning the design of wearables for supporting the acquisition of spatial representation by blind people. It contributes with the description and characterization of the masking phenomenon. Related works were discussed and organized according to the Brambring's model for blind locomotion. From this literature review, and according to Brambring's model, Landmark Identification has been less investigated than obstacle & avoidance devices, and less investigated than navigation devices. Landmark identification represents the less explored opportunities of research, especially concerning the spatial representation acquisition.

The present work also contributes with an alternative feedback mechanism for relaying information to the blind as the proposed wearables succeeded in avoiding masking in this particular context. This result, however, is limited by other factors, including: (a) the current task, and (b) the number of beacons and the distance between them. Regarding the current task, consider a Paralympic blind runner from the T11 category: a spoken announcement that she is out of her track takes too much of her time and attention and can even cause an accident. Regarding the number of beacons, the wearer may feel overwhelmed depending on the number of notifications she receives, as experienced in [41]. The authors of the aforementioned paper said that a choice over the quantity of information is crucial and it may be necessary a long-term study to understand it better. For the particular context of our studies, however, the verbalized warning was useful for avoiding masking and helped participants to identify and explore more landmarks. The last task in our study, played an important role evidencing the success in using verbalized warnings, given that its goal was to support learning about the space. Regarding the patterns of exploration, our first results indicate the wearables did not induce any significant modification, but these results are based in the frequency each reference was explored. It did not consider the time used in the exploration, or the different kinds of exploration used. Therefore, more studies are necessary to investigate whether these wearables may have an influence on how blind users explore an unknown space.

Finally, this paper also contributes with some guidelines for designing wearables for blind users, namely: (a) keeping their hands free is crucial (it is also a recommendation from the mobility instructor, for safety reasons); (b) wearables must be preferentially designed embedding technology in accessories already used by the blind (like the white cane, watches and glasses) instead of adding new accessories; (c) never block their ears with earphones - bone inducting phones are preferred, but a loud speaker may be acceptable for a laboratory study (although it is unlikely to be socially acceptable outside the lab).

Future work includes a new version of the Smart Glasses featuring a camera mounted between the lenses. The camera will be used for landmark identification. On the other hand, 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 have an influence on her performance when finding landmarks, her posture, and her social behavior. The investigation on these differences between landmark identification solutions represents our next goal in the following steps of this research.

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