Designing Guides for Blind People

Hugo Nicolau, Tiago Guerreiro, Joaquim Jorge
Instituto Superior Técnico, Departamento de Engenharia Informática, Lisboa, Portugal
Phone: +351 214233565, Fax: +351 213145843, e-mail: {hman, tjvg, jaj}@vimmi.inesc-id.pt

Abstract — **Most blind users frequently need help when visiting unknown places. While the white cane or guide dog can aid the users in their mobility, the major difficulties arise in orientation. The lack of both reference points and visual cues are the main causes. Despite extensive research in orientation interfaces for the blind, their guiding instructions are not aligned with the users' needs and language, resulting in solutions which provide inadequate feedback. We aim to overcome this issue allowing users to walk through unknown places, by receiving a familiar and natural feedback. Our contributions are in understanding, through user studies, how blind users explore an unknown place, their difficulties, capabilities, needs and behaviors. We also analyzed how these users create their own mental maps, verbalize a route and communicate with each other. By structuring and generalizing this information, we were able to create a prototype that generates familiar instructions, behaving like a blind companion, one with similar capabilities that understands their "friend" and speaks the same language. Finally, we evaluated the system with the target population, validating our approach and guidelines. Results show a high degree of overall user satisfaction and provide encouraging cues to further the present line of work.**

I. Introduction

There are approximately 163.000 people with some degree of visual impairment in Portugal, more than 1.6% of the total population, of which about 17.500 are blind. Moreover, there are an estimated 45 million blind people and 135 million visually impaired people worldwide [17].

The autonomy of human beings is essential to their welfare and the ability to move to other places is part of their daily lives. However, for the majority of blind people, walking around unfamiliar places is a very difficult or sometimes impossible task, without help. Indeed, orientation and mobility are essential skills for a blind person, but frequently confused. While mobility depends on skillfully coordinating actions to avoid obstacles in the immediate path, spatial orientation requires coordinating one's actions relative to both the further ranging surroundings and the desired destination. On the other hand, orientation regards the ability to establish and maintain awareness of a person's position in space relative to both landmarks in the surrounding environment and to the intended destination.

The adoption of a white cane or guide dog is the main aid to mobility for the target group. However, major difficulties arise in the orientation task, particularly in places unbeknown to users. The main causes of these problems are the lack of reference points and the inability of blind people to access visual cues.

Well-established orientation and mobility techniques using a cane or guide dog, while effective for following paths and avoiding obstacles, become less helpful when finding specific locations or objects. Even thought tactile maps and Braille signs provide possible solutions, both are insufficient and sometimes inadequate to the users' needs.

Meanwhile, there have been efforts to use technology as a means to help visually impaired people with their spatial orientation tasks. Among these the Sendero GPS and Trekker are two systems commercially available for outdoor environments, as shown in Figure 1. However, owing to use of specialized hardware, their cost and size pose serious obstacles to market penetration.

(a) Sendero GPS (b) Trekker

Fig. 1. Orientation devices for blind people.

On the other hand, mobile phones are part of our daily lives and play an important role in modern society. Due to the constant evolution of mobile devices, particularly in terms of communication and processing capabilities, their range of applications extends well beyond basic communication, ranging from productivity to leisure. Nowadays, most mobile devices already incorporate a wide set of features, such as mp3 players, games, digital cameras, GPS or Internet access, providing a great potential for future mobile applications. Indeed, their availability, low

The authors would like to thank Raquel and Martin Sain Foundation, all the users that participated in our studies and Loquendo. Hugo Nicolau and Tiago Guerreiro were supported by the Portuguese Foundation for Science and Technology, grants SFRH/BD/46748/2008 and SFRH/BD/28110/2006, respectively.

cost, miniaturization and communication capabilities (e.g. WiFi or Bluetooth), makes them suitable to develop mobile guides.

New advances in location-based guides for the blind, have proven too generalist to be useful to the target group. In contrast, by focusing the design on the users, our approach aims at providing blind users with familiar feedback, so they can easily follow and understand all the instructions given and reach their destination successfully. To achieve this goal, we performed studies with a group of blind users and a mobility instructor, gathering a set of guidelines and strategies aligned with the focus group common language, habits and requirements.

Additionally, we developed a prototype that behaves like a blind companion, which speaks users' language and guides them to their desired destinations. Finally, in order to fully evaluate and validate our approach we performed user tests in an indoor building with blind people. Next we present the most relevant works in this research area together with a brief discussion on their advantages and limitations.

II. Related Work

For the past two decades much effort has been applied to developing new orientation systems for the blind and visually impaired. Most these systems focus on adopting technology to estimate the user's position with higher precision [3, 7, 13, 14, 16]. On the other hand, the interaction techniques and, most important, the feedback offered to users are often forgotten.

Tri-dimensional (3D) sounds are frequently used to provide audio cues that seem to come from the same place as the object or waypoint to which they refer. These approaches require the user to wear headphones, in order to present a spatialized sound. The 3D feedback can be presented in either speech or non-speech audio (i.e. earcons or auditory icons) [11]. One such approach is SWAN (System for Wearable Audio Navigation) [9], a navigation and orientation aid for the visually impaired, which represents pertinent data through sonification. However, while using non-speech audio [2, 9, 13] may provide immediately recognizable sounds, it may also lead to a busy and uncomfortable listening experience.

Loomis et al. [5] used 3D speech synthesis to indicate to users either their distance to the next way point or an object name, so that they can follow the sound until they arrive at their destination. The main drawback in using spoken feedback is the high cognitive load that it entails. Indeed, in such systems each spoken message usually lasts more than one second, so the system is often talking. However, this offers the designer a higher expressiveness than non-speech interfaces. Furthermore, speech-based orientation systems can use mono synthesis (e.g. dialogues) to guide blind users, freeing them from the need to wear headphones. Indeed, some users may refuse to wear earbuds [2, 5] because they block out important ambient sounds.

As an alternative to audio interfaces, the vibration modality can also be used to guide a blind user. Van Erp et al. [8] used a belt with eight tactors around the users' waist in order to map the next waypoint direction. Marston et al. [6] were able to perform the same task with a single tactor, which indicates whether the user is on or off track. While this modality is well suited to noisy environments and may be sufficient for route guidance tasks, it lacks the expressiveness of audio interfaces, which can be used to describe places, objects or features.

Speech is the most natural way to communicate. However, current orientation systems that provide spoken feedback to users are not able to fully address their needs and capabilities. The given instructions are often difficult to follow or even to understand [10, 12, 15].

In order to find the most adequate interface to guide the visually impaired, Ross and Blasch [1] evaluated three different interfaces: stereophonic (non-speech), speech output and a shoulder-tapping system. The authors concluded that a multimodal interface featuring tapping and speech was the most adequate. While the shoulder-tapping system was most widely used, the speech interface consisted in announcing the relative position of the destination, once every two seconds (e.g. "*one o'clock … one o'clock …*"). Once again, the speech feedback may be difficult to understand, as it uses a technical and unnatural language for blind users. Additionally, constant audio feedback may prove too intrusive and annoying.

Our main goal and this paper's contribution is to provide blind users with both natural and familiar feedback, by understanding the whats, whens and hows of a guidance system for the blind. We achieved this by studying the users, their needs, habits and using their own orientation abilities to improve both the system familiarity as well as its adequacy to the task on hand.

III. User Centered Design

The main contribution of this paper relies in the results obtained from studies with the target population. User centered design is a philosophy that puts the person in the center and in all stages of the design process, trying to gather as much information from the user and his surroundings as possible, in order to guarantee quality.

Our approach tries to provide familiar feedback by studying the users' capabilities and needs. Indeed, by following a user centered design, we were able to identify common capabilities and behaviors among the target population, when exploring an unknown place. On the other hand, we have also studied the way these users described and guided other blind users, so we could build a virtual guide that offers them an easily understandable set of instructions.

A. Interviews and Questionnaires

On a first stage we performed interviews with eight blind users, allowing us to get a first contact with the target population. These interviews were semi-structured and mainly composed by open questions, leading to an informal and friendly dialogue. After the interviews' analysis, we conducted eighteen questionnaires in order to obtain the users' profile, current limitations, needs, degree of independency and technological knowledge.

According to the questionnaires results, our user group was over forty five years old and had a low educational background (below 12th grade). Indeed, the educational level of most users (39%) was at or below the 4th grade. All users were legally blind, i.e. they needed screen readers to access visual information on their devices. They had at least one cell phone and used it daily to place and receive phone calls, even those without any screen reading software. These results show that the user group has some, albeit very limited, experience with mobile devices.

Finally, according to the questionnaires, despite users walking alone most of their time, 35% always required help to find their intended destination, when visiting a public building. This implies that orientation guides are indeed needed, in this particular case, for indoor environments. However, the remaining question is: How to guide a blind user?

B. Exploration Experiment

In order to efficiently guide the users, an orientation system has to offer them both adequate and easily understandable feedback. Therefore, we needed to analyze their behaviors, difficulties, capabilities, limitations and techniques when exploring an unfamiliar place, so we could build an interface that addresses these requirements. Moreover, we also wanted to identify the most important information for users in an indoor environment and analyze how their mental maps evolve when exploring it. Finally, in order to provide familiar feedback, we have studied how blind users verbalize and communicate routes to blind colleagues.

The chosen place corresponded to a basement with two floors (Figure 2) in a training center for blind users. The first and second floor had approximately 132m^2 (11mx12m) and 80m^2 (10mx8m), respectively. Because this basement was mainly used for storage purposes, the place was not adapted to blind users, i.e. there were diverse obstacles (e.g. broken chairs, tables or old machinery) around the place and some paths were very difficult to navigate.

(a) Second floor (b) First floor

Fig. 2. Map and route chosen. The blue dots represent the reference points chosen by the users.

Three participants volunteered to take the exploratory experiment. Their main goal was to explore and acquire a thorough knowledge of this unfamiliar place, in order to guide a blind colleague through a predefined route.

The route is depicted by footsteps in Figure 2. The starting point was in the second floor, near the room's entrance. The users had to follow the corridor for four meters and then turn right, without entering the room right before the curve. Then they had to go straight ahead for eight meters until they reach the stairs. Already in the first floor, the users had to find a table with a phone, which was approximately five meters away from the stairs and then turn left. After that, they had to go straight ahead for eight meters, avoiding all obstacles, until they reach a door. Finally, to complete the route, the users had to climb up the stairs and find the elevator door.

To assure that all users had a similar knowledge of the place in the end of the experiment, we conducted a set of exploratory tasks (Figure 3) for three days, where each user went through three different sessions lasting 45 minutes each.

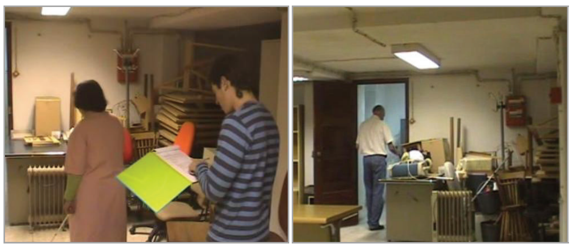

Fig. 3. Users in the exploratory task.

Additionally, the conducted experiment, as well as the users' feedback allowed us to gather a set of conclusions about their behaviors and needs when exploring an unknown place:

Reference points vs. obstacles: All infrastructure elements or other artifacts that cannot be easily moved and allows the users to infer their position are reference points. The remaining artifacts are obstacles.

Trial-and-error approach: In order to explore unfamiliar places blind users adopt a trial-and-error approach, using common mobility techniques. They walk slowly through the place, using their white canes to avoid obstacles, while building a mental map. Through a correct use of mobility techniques, users can easily identify doors, tables, stairs, chairs, walls or pillars by their acoustic and tactile properties.

Obstacles impede the correct perception of reality: The existing obstacles in a room can mislead the user about the place's size or layout. Indeed, they can also impede the correct identification of possible reference points (e.g. a pillar surrounded by chairs). Unfortunately, because obstacles can be easily moved this may be a common problem to blind users.

Users do not like to explore new routes: Despite the users' ability to memorize a route, they confine themselves to a well known path and do not like to explore new ones, unless they are "forced" to.

Incomplete mental map: As a consequence of the previous point, it is likely that users have an incomplete mental map of the place. This may lead to more frequent disorientations when they stray from the path.

When users are lost they turn back: If for some reason users get lost, their first reaction is to turn back in order to identify a well known reference point and then adapt their mental map to that new condition.

Less is better: In the end of each session the users were invited to describe the predefined route, as if they were guiding a blind colleague. From the gathered stories, we noticed a big concern in building a very simple and precise set of instructions, with very few details or long descriptions about the place or route.

C. Group Meeting

After the observation phase, we conducted a group meeting with the three participants and a former instructor of orientation and mobility techniques for blind users, in order to consolidate and discuss all the obtained results.

As all the stories gathered in the exploration experiment were very similar, we decided to build one (the "best") story for the predefined route (Figure 2), which entailed some lively discussions. As mentioned before, there was a big concern in building more precise and simpler stories. Moreover, all participants stated that the instructions should have the minimum amount of detail as possible, so as not to distract users. Therefore, obstacles and other artifacts that are not crucial to the orientation task should not be mentioned (that is the purpose of the white cane). However, they also agreed that a system should allow users to request more detail about an instruction (e.g. number of steps on a flight of stairs) or place (i.e. context) if needed.

When blind users enter an unknown place it is very difficult for them to perceive its environmental flow [1]. Indeed, they may be able to deduce some of its context, through their hearing, smell or the ability to detect heat sources. However, there is information that is inaccessible and may be crucial to the orientation task. In this meeting we were able to identify the main elements that must be present to contextualize the user in an unknown indoor environment: structure - place characteristics (e.g. dimensions, layout or number of floors); interest points - corresponds to all the possible destinies (e.g. shops, offices, building services or toilets).

There was also some discussion about the vocabulary used in the instructions, which may be crucial to user performance. Neither an instruction nor its vocabulary can be ambiguous. For instance, the instruction "go ahead until the end of the ramp and turn right", is clearly ambiguous. The reference point that is given (i.e. the end of the ramp) may be hard to identify, leading the user to unexpected places. Another example is the instruction, "go around the table by the right side and go ahead …" In this case, users do not know how far around the table are they supposed to go.

Finally, throughout the experiment and particularly in the group meeting, it was clear that reference points are crucial to guide blind users. A reference point is some infra-structure element or other artifact that cannot be easily moved and is used to infer the users' position. Through our experiment, it is clear that the usage of reference points to communicate a route is a natural way to guide someone. However these reference points have to be chosen very careful, so blind users can be able to identify them (usually with their white cane) and follow the intended route. Moreover, this is the only way they have to build their mental map of some place. Additionally, when a blind user gets lost, their first reaction is to turn back and try to find a reference point, so they can locate themselves and continue with their path.

The blue dots in Figure 2 correspond to the reference points that were chosen by the users in the exploration task. They were easily identifiable structure elements, such as doors, stairs and metal machines.

IV. PROVIDE FAMILIAR FEEDBACK

In an orientation system, the way the user is guided and the feedback he receives is crucial to his performance. However, this task is often forgotten or inadequate. We aim to overcome this issue by providing a natural and familiar feedback.

A. Elements and Rules

Through a study of how blind users verbalize a route, we were able to identify the main elements and rules for the automatic building of instructions:

Action: this element corresponds to the verb of the instruction (e.g. turn, go, enter or leave).

Direction: some of the previous actions need a direction so they can make sense. For instance, the action turn needs to be complemented with the respective direction, left or right.

Side: sometimes, we need to explicitly identify the side, in which the user should walk, in order to identify a reference point or avoid dangers.

Time/Distance: usually, a reference point is associated to a decision point (i.e. direction shift). The reference to these points is done through time or distance elements. For example, "turn right after you pass a door" or "follow three steps forward ..."

Object: this element can be any artifact existent on the local (e.g. doors, stairs, tables or walls).

To summarize, all the instructions can be defined through the following regular expression [4]:

Action Direction? ([Time Distance Side]) Object?*

B. Algorithm

Our algorithm is an implementation of the rules already defined in the previous section. These rules, just like the algorithm, were defined for the Portuguese language. Next we will present it in more detail.

After the users' position is established, each set of instructions gets starting from the next localizable point along the route. This way, when users reach that point, they can receive a new set of instructions.

Moreover, if there are any reference points or direction shifts in between two localizable points, the instruction is subdivided. In this iterative fashion all the instructions will be built till the user reaches his destination.

If the next point in the route is a reference point, then the instruction is very simple, e.g. Action Direction Object, since the object is easily identifiable. On the other hand, whenever there is a change in direction, the user has no reference point. Therefore, we need to build a reference taking into account the nearest identifiable objects (e.g. doors). This way he can get an instruction like, "turn right when you pass a door". If we cannot build such a reference, then we need to use distances to guide users (e.g. "… and then turn right after three steps"). In either case, using the side element can be necessary to help users find a reference point or identifiable element easily.

If users get lost, stray off the route or need help, the system will ask them to go back to the last reference point. According to our studies, this was the natural behavior of users when they felt disoriented. That is one of the main reasons why correctly identifying reference points is so important. If they cannot go back, the system will try and guide them starting from the nearest localizable position.

V. EVALUATION

To validate the approach presented above, we built a functional prototype and tested it with the target population (Figure 4). The evaluation group was composed by six legally blind users, with ages from 21 to 55 years (three women and three men). Although all users were legally blind, one of them had residual vision, while the others were totally blind. Moreover, none of the users had previous experience either our prototype or the type of spoken feedback provided by it.

Fig. 4. Blind user testing the prototype.

The trials were performed in a controlled environment, in a training facility for blind users. To fully evaluate our approach, we chose both an unfamiliar place and route (Figure 2.b). In this evaluation, we used a Bluetooth localization system, where each beacon, with a one meter range, corresponded to a reference point. The evaluation was performed with a HTC TyTn's mobile device with Windows Mobile 5.0 and a TTS system (Loquendo, Portuguese voice).

During the evaluation, one of the users needed external (i.e. human) help to complete the task. In this particular case, the user had some difficulties distinguishing left and right directions, therefore the need for external help. All the remaining users were able to successfully complete the task without needing any type of help, i.e. they never felt lost.

The mean time needed to complete the route was 146 seconds with a standard deviation of 76 seconds (Figure 5). Moreover, approximately 20% of this time corresponded to the Bluetooth discovery process, where the users had to wait near the last reference point for the next instruction.

Fig. 5. Task completion times, in seconds.

Despite the high waiting time and the difference between times to achieve the final destination, all the users were able to understand all the instructions and clearly identify the reference points, so that they could wait for the next instruction (which indicates that the instructions were adequate). Figure 6 represents the average time that the users spent at each point of the route. Analyzing the obtained results, we can observe that all users followed a similar route and spent most of their time near reference points, waiting for the next instruction.

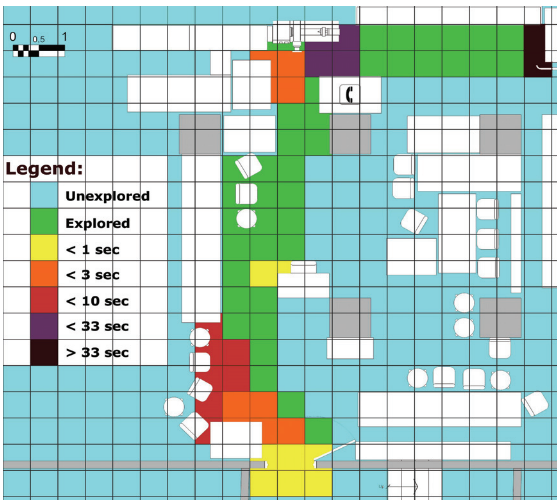

Fig. 6. Thermal map: average time that the users spent in each point of the route.

To assess the users' opinion about the given instructions, we performed a questionnaire in the end of each evaluation session. The obtained results showed an overall user satisfaction of 4.5 in a 5 point Likert scale. All users stated that the instructions were both easily understandable and accurate. Also they demonstrated a high interest in our prototype and in using it in public buildings and outdoor environments. Moreover, one of the users asked if he could repeat the task, but without using his white cane, which demonstrates the confidence that he acquired in using our prototype.

The main complain about our system was the high waiting times when the users arrived at a reference point. They felt the system was too slow to react and could not follow their progress adequately. Most users stated that the system should be able to offer a new instruction immediately after they successfully identified a new reference point.

VI. Conclusions

The actual orientation systems for blind people need appropriate interfaces. Almost all research that has been done aims at locating users with higher precision. Although this is a crucial component, it does not by itself guarantee a successful approach. While there is some research in orientation interfaces for the blind, the feedback they provide to users is mostly inadequate.

New approaches that allow guiding the users and align the interface with their capabilities and needs are required. Therefore, our contribution lies in analyzing blind users' behaviors while exploring unknown places, so that we could build a more appropriate interface and dialogue system. In order to guarantee a familiar feedback we have also studied how these users verbalize a route and communicate it. Moreover, we defined a set of elements and rules so we could generate these instructions automatically.

Our results indicate that generated instructions were easily understandable (without training) and users were able to follow them through a predictable path. To assess each user's opinions we performed a debriefing session. The results thus obtained were very positive showing that users were satisfied with the system and, more importantly happy the audio feedback it provided.

VII. Future Work

In order to efficiently guide a blind user, a good localization system is required. However, this component of our prototype has to be modular enough to easily support different technologies (e.g. RFID, WLAN, Bluetooth …) and take advantage of each one of them. Moreover, we will focus on extending our system to new scenarios. All our studies and research were carried out in a very limited number of indoor buildings. Indeed, our approach needs to be fully evaluated in different indoor/outdoor sceneries with different routes, obstacles and reference points.

One of the main issues present in audio interfaces, particularly in orientation systems manifests itself when they interfere with the general audition (and attention) of the users. We will explore multimodal solutions to this and how different feedback modalities can be used in real life scenarios, typically noisy environments, so users do not need to carry the mobile device in one hand at all times or wear headphones.

References

[1] D. Ross and B. Blasch, "Wearable Interfaces for Orientation and Wayfinding", in *Proc. 4th Int. ACM Conf. on Assistive Technologies*, 2000, 193-200.

[2] F. Tomita et al., "R&D of Versatile 3D Vision System VVV", in *Proc. of SMC'98*, 1998, pp. 4510-4516.

[3] J. Coughlan and R. Manduchi, "Functional Assessment of a Camera Phone-Based Wayfinding System Operated by Blind Users", in *Conference IEEE-BAIS, Research on Assistive Technologies Symposium*, 2007.

[4] J. Friedl, "Mastering Regular Expressions", *O'Reilly Media Inc.*, 2006.

[5] J. Loomis et al., "Personal Guidance System for People with Visual Impairment: A Comparison of Spatial Displays for Route Guidance", in *Journal of Visual Impairment and Blindness*, 2004, pp. 135-147.

[6] J. Marston et al., "Nonvisual Route Following with Guidance from a Simple Haptic or Auditory Display", in *Journal of Visual Impairment and Blindness*, 2007, pp. 203-211.

[7] J. Rajamaki et al., "LaureaPOP Indoor Navigation Service for the Visually Impaired in a WLAN Environment", in *Proc. 6th WSEAS Int. Conf. on Electronics Hardware*, 2007, pp. 96-101.

[8] J. Van Erp et al. "Waypoint Navigation with Vibrotactile Waist Belt", in *ACM Transactions on Applied Perception*, 2005, pp. 106-117.

[9] J. Wilson et al., "SWAN: System for Wearable Audio Navigation", in *11th IEEE Int. Symposium on Wearable Computers*, 2007, pp. 1-8.

[10] L. Ran et al., "Drishti: An Integrated Indoor/Outdoor Blind Navigation System and Service", in *Proc. 2nd IEEE Conf. on Pervasive Computing and Communications*, 2004, pp. 23-30.

[11] M. Blattner et al., "Earcons and Icons: Their Structure and Common Design Principles", *Human Computer Interaction*, 4, 1989, pp. 4-11.

[12] M. Turunen et al., "Mobile Speech-based and Multimodal Public Transport Information Service", in *Proc. of MobileHCI Workshop on Speech in Mobile and Pervasive Environments*, 2006.

[13] M. Turunen et al., "Design of a Rich Multimodal Interface for Mobile Spoken Route Guidance", in *Proc. Interspeech*, 2007, pp. 2193-2196.

[14] S. Bohonos et al., "Universal Real-Time Navigational Assistance (URNA): An Urban Bluetooth Beacon for the Blind", in *Proc. 1st Int. Workshop on Systems and Network Support for Healthcare and Assistive Living Environments*, 2007, pp. 83-88.

[15] S. Helal et al., "Drishti: An Integrated Navigation System for Visually Impaired and Disabled", in *Proc. 5th Int. Symposium on Wearable Computers*, 2001, pp. 149-156.

[16] S. Willis and S. Helal, "RFID Information Grid for Blind Navigation and Wayfinding", in *Proc. 9th IEEE Int. Symposium on Wearable Computers*, 2005, pp. 34-37.

[17] United for Sight, "Global Eye Health Statistics", in http://www.uniteforsight.org/eye_stats.php, last visited in 18/02/2009.