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Technology Enhanced Vision in Blind and Visually Impaired Individuals

Synoptik Foundation research project

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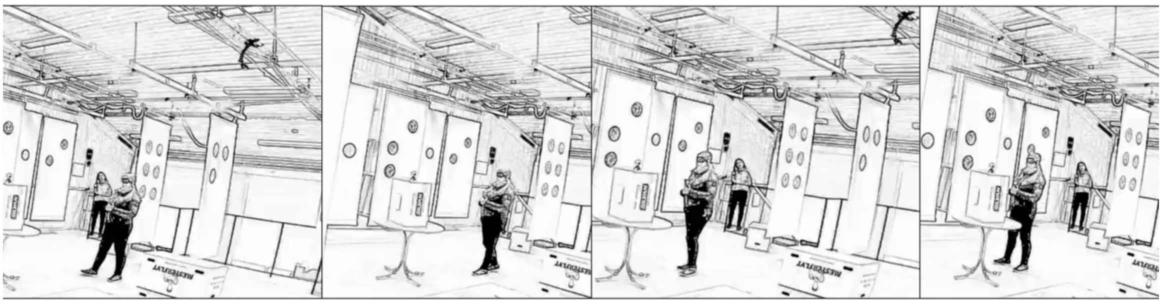

2017

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1. Introduction

This report provides a final overview of the activities and findings of the multidisciplinary research project ”Technology Enhanced Vision for Blind and Visually Impaired Individuals”. The project was funded by the Synoptik Foundation and ran from January 2016 to October 2017. The aims of the project were to collect data on how blind people navigate in urban environments, and to investigate the potential of computer vision technology for blind and visually impaired individuals in everyday life. The project focused on activities that are difficult in conditions of visual impairment such as spatial navigation, reading and object recognition. We developed and tested different types of technologies throughout the grant period.

The goal was to increase our understanding of the behaviour of blind people with respect to the obstacles and challenges they meet during navigation, and to use this information as basis for input to new technology. The original goal was to provide a prototype head-worn device that allows to detect obstacles. We started with Google Glass, but quickly realized that it did not work as expected, which made us switch to the Google Tango platform. In this project, we only touched upon the basics of the of this new technology: more research and further funding resources are needed to fully exploit the huge potential of this very promising technology.

2. Background and organisation of the project

The project was a collaborative and interdisciplinary research project between Brian Due, Ron Kupers and Maurice Ptito. Simon Bierring Lange was employed as a research assistant from January 2016 till February 2017. Sebastian Brun Simonsen was hired as a part-time assistant starting from mid January 2017. Furthermore, we collaborated with two software companies that contributed significantly to the development and communication throughout the project. Nextwork A/S contributed to dissemination, PR, stakeholder management and facilitation of research seminars. Jacob Funch (Jafu ApS) was involved with digital innovation and counseling on technological aspects of the project and communication with the programmers of the navigational prototype. Finally, SignalGarden, an American software company, developed the Google Tango prototype that we used and that will be described in further detail.

3. Project activities

January-March 2016: Establishing the team. Identifying the relevant technology to work with. Collaboration with different industrial partners. Stakeholder mapping. First contact with blind subjects. Interviews with experts in the field of blind navigation and early workshops with users.

April-June 2016: Video-ethnographic data collection. Following 7 blind people in their everyday lives. Interviews, observations, video recordings. Participating in Google conference I/O at San Francisco. Establishing first contact with SignalGarden and with the Oxford research group working on the VA-ST smart glasses. First test of the VA-ST glasses in the wild.

July-September 2016: Deciding to not include the VA-ST technology in the project following tests of 6 visually impaired people. Establishing development agreement and NDA with SignalGarden. Analysing the video ethnographic material and analysing the first findings. Providing user-feedback to the software developers at SignalGarden. Visiting King's College in London and presenting initial findings on blind navigation. Organising workshops in Denmark on vision aids.

October-December 2016: Participating in conferences with paper on findings from video ethnographic studies:

- B. Due & S. Lange. Substituting sight with other modalities: A video ethnographic study of blind people's uses of different semiotic resources for navigating in urban areas. Presented at XI International Conference on Semiotics, Thessaloniki, Greece, on October 14-16, 2016.
- B. Due & S. Lange. Doing being a blind-man-navigating: The orderliness and joint accomplishment of co-constructing a blind-man-navigating. Presented at NORDISCO 2016. The 4th Nordic Interdisciplinary Conference on Discourse and Interaction. Oslo, 23-25 November 2016
- B. Due & S. Lange. The turn-taking dog - and other extended semiotic resources used by blind people when navigating. Presented at Multimodality Day Copenhagen, November 18, 2016.

Providing continuous feedback to the software developers. Preparing for the experimental setup. Contacting more blind subjects.

January-March 2017: Semi-experimental testing of the first and second versions of the Google Tango technology. First testing with the old hardware at The Institute for the Blind and Partially Sighted (IBOS) and the Blindecenter Bredegaard. Second testing with the new hardware at the same places. Testing of 10 blind subjects and documenting the results through video and interviews. Providing feedback to the software developers.

One key note presentation:

- Due, B. Storming the body. Practices for Enacting Embodied Prototyping based on insights from multimodal EMCA analysis. 10 February 2017, QUT Design Lab, Queensland University of Technology, Brisbane, Australia

Disseminating findings to stakeholders:

- Lange, S. B & Simonsen, S. "Test af smart glasses til svagsynede". Foredrag om smartglass-teknologi og test VA-ST smart specs på Retinitis Pigmentosa-gruppens årsmøde og artikel i RP Nyt. 28. januar 2017, Fuglsangcentret, Fredericia.

April-June 2017: Designing the experimental setup. Learning from the semi-experimental setup. Disseminating findings and status of the project to practitioners through conferences like:

- Due, B. Status on the project: “Technology enhanced vision in blind and visually impaired individuals”. Syn og hjælpemidler 17.5, 2017, IBOS

Writing up articles on the video ethnographic material:

- Due, B. & Lange, S. (2017) The Moses Effect: The Spatial Hierarchy and Joint Accomplishment of a Blind Person Navigating. *Space and Culture*. 1-16. DOI 10.1177/1206331217734541
- Due, B. & Lange, S. (2018). Semiotic resources for navigation: a video ethnographic study of blind people’s uses of the white cane and a guide dog for navigating in urban areas. *Semiotica*.
- Due, B. & Lange, S. (forth). Annoying Things: Unpacking unpredictable trouble sources in blind navigation using video ethnography and ethnomethodology. *Sociological Research Online*.

Preparing the experimental setup for the quantitative data collection. Finding proper location for constructing a life-size experimental walk-way. Deciding on the type of obstacles, their number, size and spatial configuration. Constructing head mount for the Tango device, deciding on the type of behavioural measures. Continuous testing of various beta versions and daily interactions with software developers.

July-October 2017: Finishing up the experimental study and frequent communication with software developers about further refinements of the app. Organisation of the conference: "Enhancing spatial navigation in blind and visually-impaired individuals". The conference took place on September 22, 2017 and was held at the Auditorium of the Psykiatrisk Center København, Rigshospitalet, Copenhagen. More than 70 persons attended the meeting, including researchers and practitioners. A description of the conference and the video recordings of each presentation can be found on http://circd.ku.dk/projects/enhancedvision/

- Kupers, R. Don't get lost: from tongue stimulation to tango with a smart hand-held
- Funch, J. Technological aids for the visually impaired: Our way to Tango
- Due, B. Ethnographic knowledge of blind individual's behaviour and insight in the technological development.

4. Learning from the video ethnographic study of blind behaviour

We wanted to base the technology development on the real needs of blind people with respect to navigation. There is of course already a lot of knowledge about these needs, which are described in the literature. However, the main part of these descriptions is based on interviews and biographical notes, which primarily serve as reflections about practice. Many of the small details that play an important role when navigating in the physical world are unknown, even to blind people. Therefore, we decided to map out in detail the navigational practices in order to better understand their problems and to get clues as to which issues new technology should be able to deal with. We begin by shortly defining the theoretical background for this line of research, and then we highlight some of our findings.

4.1. Theoretical position

We are specifically interested in approaches describing member's methods for accomplishing walking. Other approaches deal with e.g. interview- and survey-based methods (Hayhoe, 2012), experimental methods (Giudice & Legge, 2008), or auto-ethnographic methods (Saerberg, 2010). We applied ethnomethodology (Garfinkel, 1967, 2002a; Heritage, 1984; Maynard & Clayman, 1991, 2003) to get a better understanding of how blind people, as members of our society, perform everyday activities like walking to work. Ryave and Schenkein were the first ethnomethodologists to describe the orderliness of the art of walking (1974). Garfinkel also studied walking behaviour (2002b) and Lee and Watson focused on interaction in public spaces (1993). These authors showed how participants orient toward each other and the material circumstances while walking. Later studies have focused in more detail on how participants use space and material structure as resources for playing (M. H. Goodwin, 1980), visiting museums (Lehn, 2013), interrogating suspects (LeBaron & Streeck, 1997), using mobile phones (Arminen & Weilenmann, 2009), and dance lessons (Keevallik, 2013). While there exist studies investigating mobility, there is only limited detailed understanding of blind navigation from an ethnomethodological approach, except studies by Psathas (1992), Relieu (1994), Kreplak and Mondémé (2014) and Lehn (2010). This project contributes to this growing body of interactional studies focused on walking in sociomaterial urban environments, thereby showing how specific obstacles may cause trouble for the blind person trying to navigate.

Our data on blind people's real issues concerning navigation, mobility and obstacle detection is 'naturally occurring' and collected by using video ethnography (Heath, Hindmarsh, & Luff, 2010; B. L. Due, 2017). The data analysed were collected over a one-year period. The data pool consists of 15 hours of video recorded walks with seven different legally blind participants using a white cane and sometime a guide dog. The participants' behaviour was recorded with a semi-concealed go-pro camera. Thereto, the researcher followed the blind pedestrian at a distance – close enough to capture the activity in detail, and far enough to be hardly recognizable. Apart from the video recordings of blind navigation, ethnographic background knowledge was obtained through 25 hours of interviews with blind persons, mobility trainers and mobility aids developers, and field work, e.g. visits to different institutions for the blind, and orientation and mobility training with the white cane after being blindfolded.

4.2 Studies of actual blind navigational behaviour

The video ethnography was employed to learn from actual behaviors how the Google Tango device should be designed, and what it should be able to do? We wanted to learn what kind of relevant information should be provided to the software developers, thereby taking the following three perspectives:

- Learning from the basic tools: the white cane and the guide dog
- Learning from what the white cane *cannot* detect before collision
- Learning from initial semi-experimental testing

The approach we apply in this part of the study aims to examine in detail the orderly features of the navigational behavior and the resources involved in the activities. The findings presented below are backed by a corpus of typically +5 similar kind of examples, but we will only provide a single example of each finding. We will not go through detailed analysis but only highlight the reflections about the learning potential of the findings. More detailed analysis can be found in Due & Lange (forth., 2018; 2017).

4.3 Learning from the basic tools: the white cane and the guide dog

The white cane is the most widely used aid for navigation by blind people. It has many functions. One of them is to provides tactile feedback and detailed information about the object touched, thus functioning as an extended part of the body. Figure 1 shows a simple example.

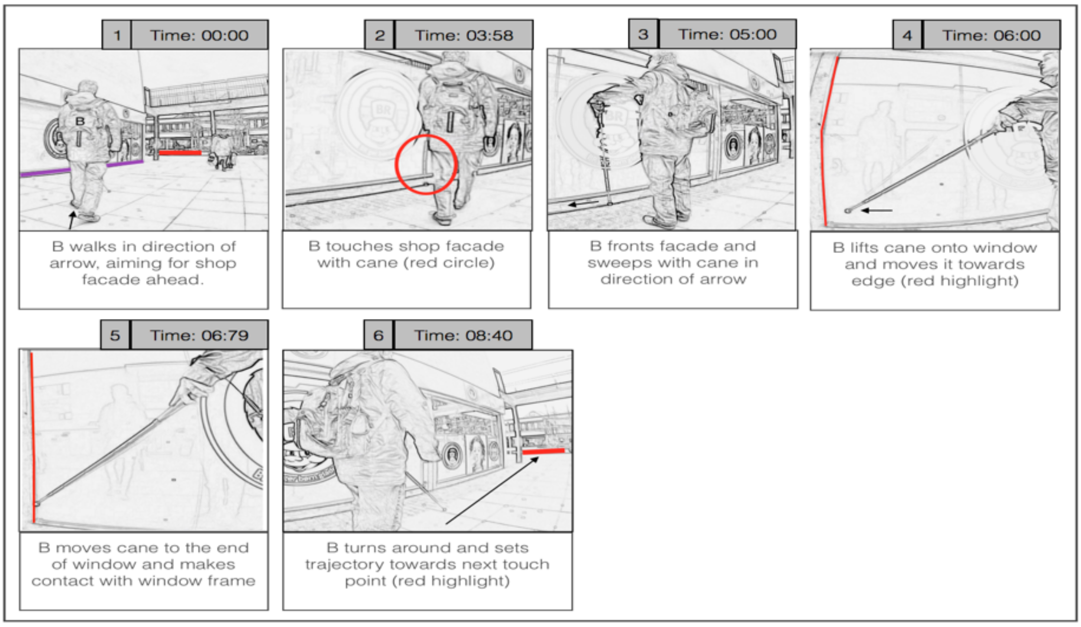

Figure 1: A detailed transcription of a typical example where a blind person uses the white cane for detection.

<u>Learning reflection and potential</u>: Should technology provide the blind with tactile input at an extended level and that is flexible relative to the type of relevant input from the surroundings (e.g. concrete/glass/wood)? It would be nice if the Tango device could handle not only information about the presence of an obstacle, but also about its texture.

The white cane also functions as an echolocation device, providing the blind with sound information about the surrounding. This is typically used in closed spaces like tunnels (Figure 2).

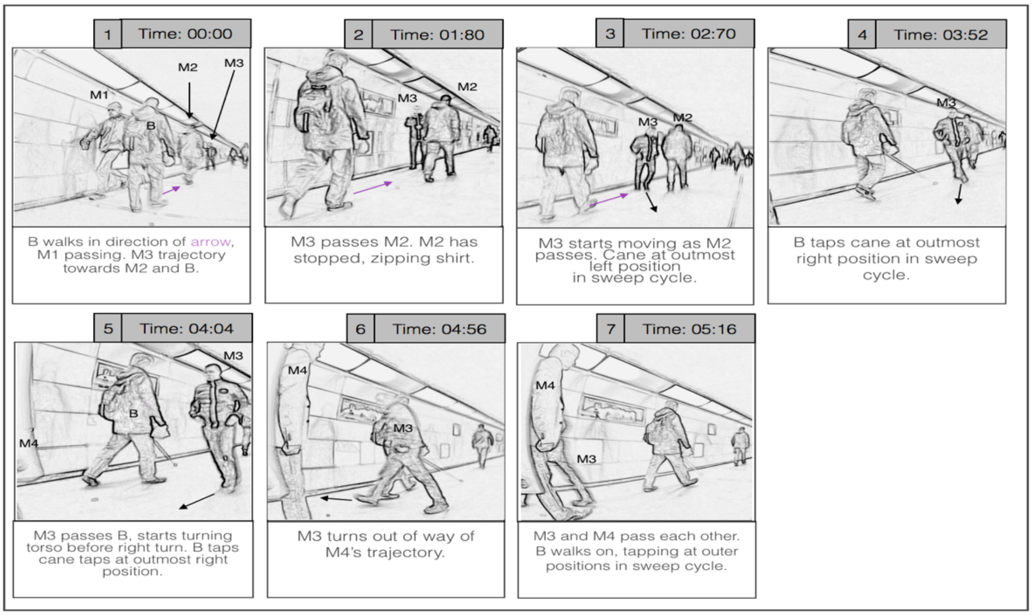

Figure 2: A detailed transcription of a blind person walking in a tunnel using the white cane to produce high sounds while tapping on the sidewalk.

<u>Learning reflection and potential:</u> Should technology provide the blind with the ability of echolocation? It could be designed with the ability of sending out sound signals that would bounce on the walls and thus provide information. Another issue concerns how far should a wall be away in order to provide relevant information? The findings so far show that it is typically 2-3 meters.

The white cane is not only helping the blind person to detect obstacles, it also functions as a symbol to other pedestrians, informing them that they should navigate around the blind person. We have called this the *Moses effect* (Figure 3).

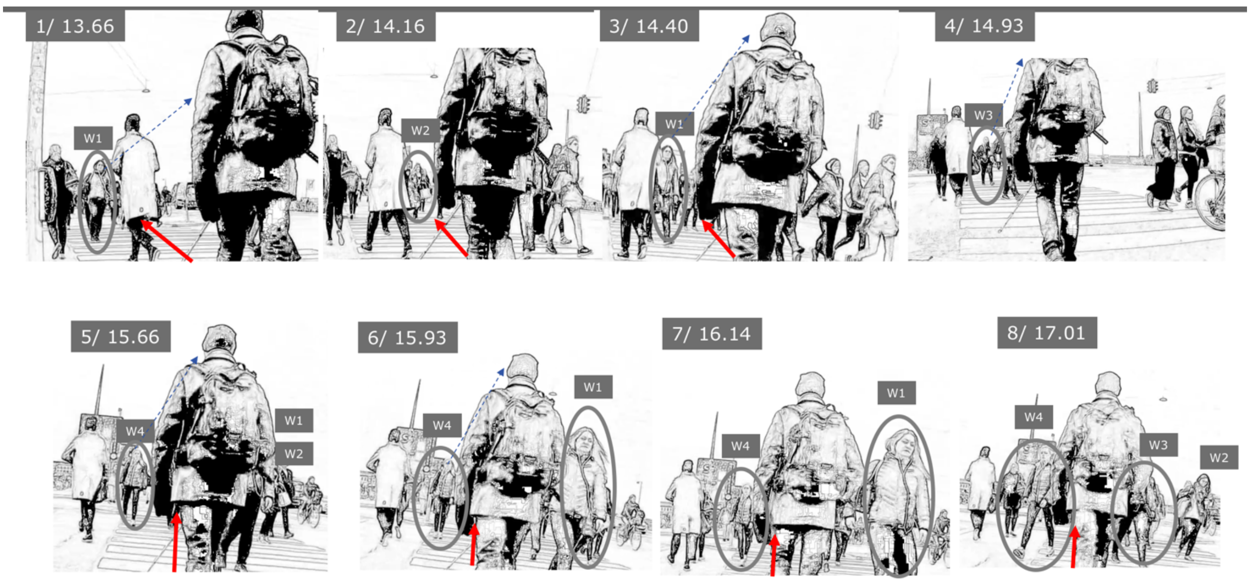

Figure 3: A detailed transcription of a blind person walking in a crowded crossing, keeping a straight trajectory and the white cane in a steady position in front of him.

Learning reflection and potential: Other pedestrians orient to the blind by recognizing him/her as blind, predominantly because of the white cane. Consequently they step out of the way, thus reducing the potential for collision. How could technology signal to others that there is a blind person walking, and that they should try to avoid getting in the way? Should the Tango software be designed as a stand-alone device – or as a supplement to the white cane?

The white cane is also used as a movability tool to do a gentle nudge. This may not be intentional, nor something that is learned in mobility schools, but we learned that blind people sometimes (accidently) use their cane to hit other people to make them move out of the way.

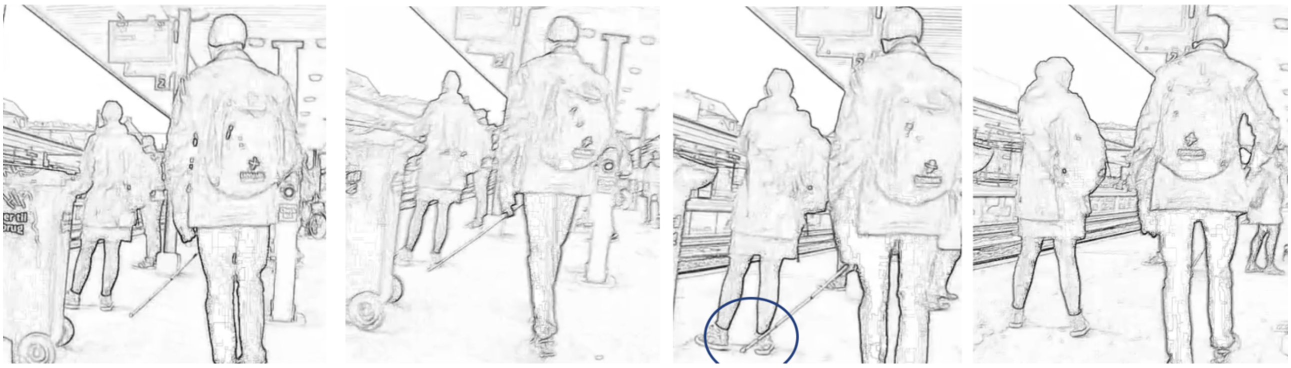

Figure 4: A detailed transcription of a blind person approaching a train platform and accidently hitting a bystander, who moves out of the way.

Learning reflection and potential: The white cane is a very palpable device for communicating to bystanders, thus avoiding colliding with them. Whenever other people are hit, they turn to see what it is, and when recognizing the blind stepping out of the way. This enables the blind a clear path. How could technology help the blind "nudge people away"? Or should the technology be completely invisible and without the ability to communicate? These questions are at the moment not completely clarified and need more data and in-depth analysis.

Whereas the white cane detects obstacles and problems when navigating, the guide dog leads the way around the obstacles without ever letting the blind person know what the obstacle is. Thus, the white cane is *problem-oriented* and the dog is *solution-oriented*. Figure 5 shows an example.

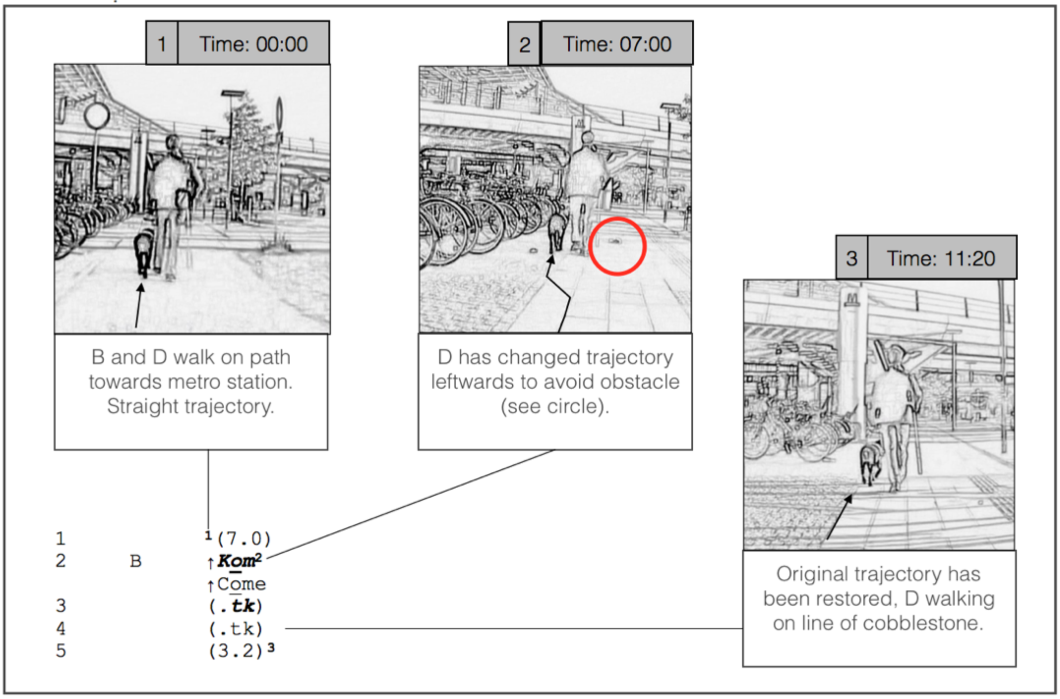

Figure 5: A detailed transcription of a blind person approaching a train station together with his guide dog. The dog leads him around a small obstacle.

Learning reflection and potential: The dog helps the blind to avoid an obstacle before it becomes a problem, and the blind person doesn't know what the potential problem was. How could technology help the blind to move around obstacles without being disturbed? How could the Tango software help navigate by only providing the most critical information, and additionally only provide it as tactile steering input? How can the device be trusted the same way the dog is trusted? Should the blind be able to interact with the software verbally? What kind of response would be relevant? More testing is needed to determine this in detail.

4.4 Learning from the things the white cane does *not* detect before collision

As shown, the white cane detects a lot of obstacles and is also a useful resource for communication. Thus, blind people will probably continue using the cane, even when new technologies may help in other ways. However, there are also many obstacles in public environments that the white cane does not detect, thus causing the blind to bump into things. Like e.g. the problem with hip level obstacles like bikes (figure 6).

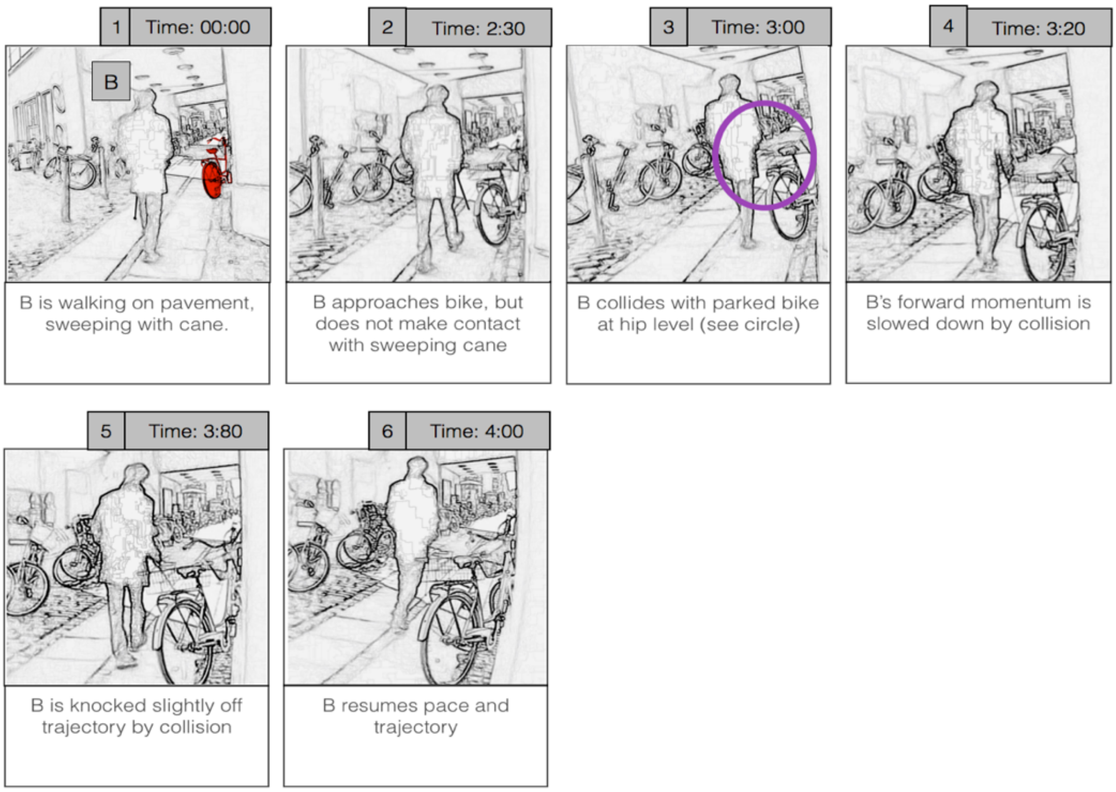

Figure 6: A detailed transcription of a blind person approaching a narrow part of the sidewalk, were many bikes are placed. Although sweeping the cane, he still bumps into a standing bike.

Learning reflection and potential: Although the blind sweeps the white cane accordingly, he still hits the standing bike on his hip. How could technology inform about that kind of obstacles and the type and shape of obstacles? – And not just the object but details of the object? How could technology distinguish between moveable people and irregular shapes like signs?

There are also problems with knee level obstacles like shown in Figure 7.

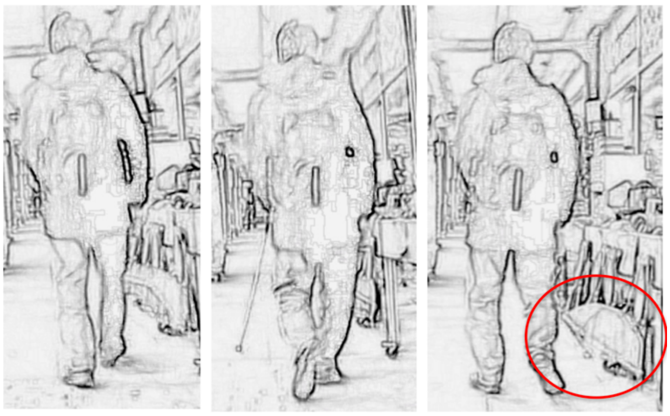

Figure 7: An example of a blind person walking on a pedestrian street and bumps into a hanging object

Learning reflection and potential: Although the blind sweeps his white cane and has detected the bicycle racks to his right, a small protruding object goes undetected and he bumps into it. How could technology detect this and distinguish between "acceptable" things and "annoying" things?

4.5 Summing up: the key features

The white cane is the most widely used aid for navigation. Although it detects many obstacles, some remain undetected, particularly those at or above waist-level, and may cause injury. Thus, technology should be an ad-on providing information about the surrounding that is not provided by the white cane. How could technology detect (irregular) obstacles at or above waist level? What is relevant and irrelevant information and at what distance?

Figure 8: An illustration of a blind person using the white cane, showing which areas the white cane possibly detects.

These are some of the final thoughts on the input to the development of the Tango software:

Problem-oriented features: lessons from the white cane

- Provide tactile or haptic feedback.
- Provide information about the type of the surroundings, e.g. concrete, glass, wood. Possibly through sound feedback.
- Provide specific information about an object.
- Identify obstacles before they come within the egocentric space, but not too many meters away. What is a precise relevant range?
- Act as a symbol to indicate that a blind person is navigating. Be recognizable from a distance.
- Inform others of presence, e.g. make them move out of the way.

Solution-oriented features: lessons from the guide dog

- Provide tactile and haptic feedback (directional steering without extra information)
- Be trustworthy
- Reduce environmental complexity, and reduce obstacles by tacitly leading around them
- Be a companion and provide the ability for verbal commands and negotiation in a natural language processing mode.

Lessons from the limitations of the white cane

- Detect the irregular and dynamic physical structure
- Distinguish between people and objects and the relevance of one type of obstacle compared to another
- Be a supplement to the white cane

5. Findings from initial semi-experimental testing of Tango early versions

The development of the Tango software progressed simultaneously as the findings from the project were disseminated to the developers. Both the first and second version of the hardware and initial software versions were tested in semi-experimental setups in collaboration with instructors at Blindecenter Bredegaard and The Institute for the Blind and Partially Sighted (IBOS).

Figure 9: Two versions of the hardware we used to test the Tango software.

In short, the hardware is equipped with different cameras and sensor technologies. The software uses the sensors to create a 3D mapping whereby it can detect obstacles at distance providing sound feedback to the user. A more technical and thorough description of the technology can be found in the appendix. Figures 10 and 11 illustrate two of the key findings during the early phase of the project.

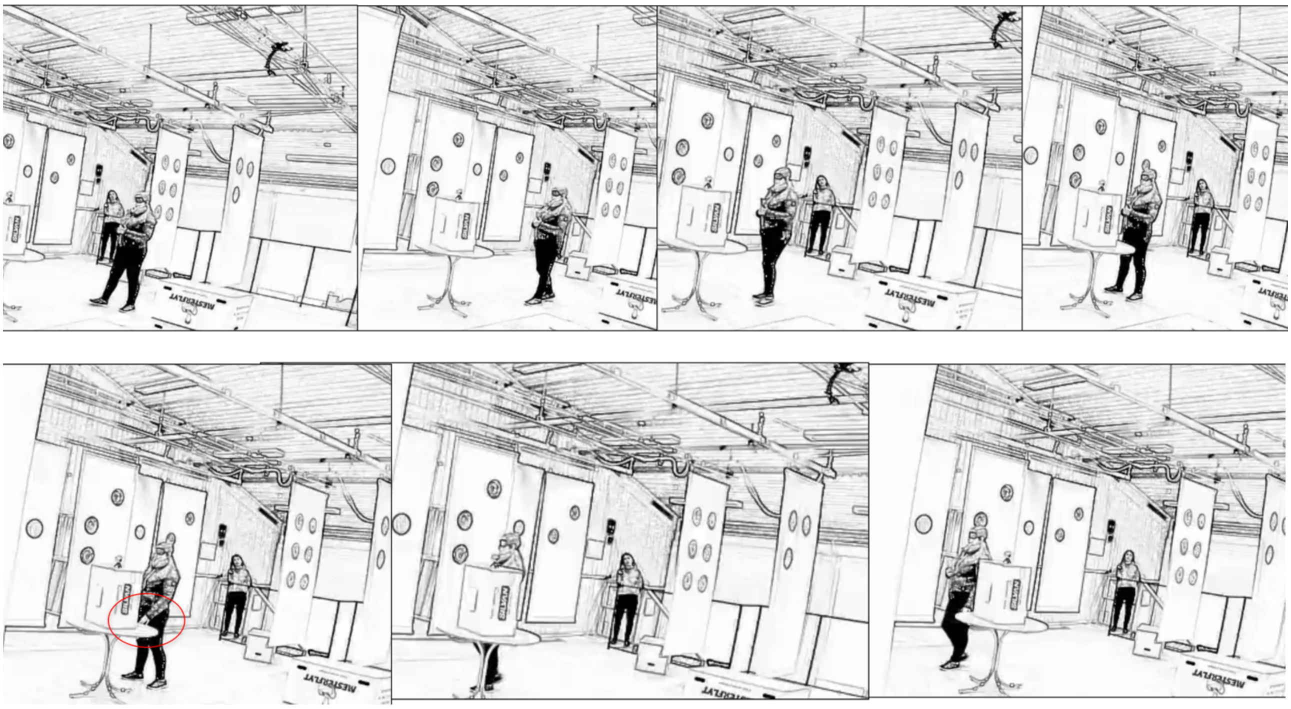

Figure 10: the blind person walks towards an obstacle (a table in the middle). The Tango detects it and provides auditory feedback; the blind person touches the object and moves around it.

Although we had a clear understanding of the ability of the technology from these first semi-experimental tests, they also quickly revealed many unresolved issues related to 1) the optimal distance to an obstacle, 2) how to segregate an obstacle from its surrounding (e.g. the floor, the wall), 3) the appropriate field of view and 4) the type and amount of auditory feedback.

One of the most important findings was that the technology must be trustworthy (Figure 11). If the technology fails to provide the correct information in all trials, or somehow stops working, the user loses confidence in the system. This is a methodological problem in a testing environment – but totally unacceptable in natural occurring environments when e.g. the blind has to cross a road. These issues were discussed at length with the software developers, which has led to the latest version, which was used in the quantitative study (described below).

Figure 11: A blind person approaches an obstacle using Tango but bumps into it because the Tango software suddenly stopped working.

6. Quantitative data with SensoryFusion

In this section, we report on the data obtained with the SensoryFusion software in a group of blind individuals and sex- and age-matched sighted controls. Our goal was to test the application on the Lenovo smartphone that would allow blind people to navigate in an environment by detecting and avoiding obstacles. We will start by placing the current work within the context of our previous experience in the field of sensory substitution devices for navigational purposes in blindness.

6.1. The Tongue Display Unit

At BRAINlab, we have extensively investigated the phenomenon of sensory substitution, which refers to the use of another sensory modality to perform a task that normally is primarily subserved by the lost sense. Braille reading is probably the best known sensory substitution device, replacing vision by touch for a task that is normally performed by (the lost sense of) vision. We initially started our work on sensory substitution by a device that replaces vision by touch. We used the Tongue Display Unit (TDU) that was developed by prof. Paul Bach-Y-Rita at the University of Wisconsin. The TDU consists of a grid of 144 electrodes that are placed on a grid that is apposed on the tongue, and connected to system that converts a visual stimulus, grabbed by a camera, into electrotactile pulses (Figure 12). With training, blind subjects, but also blindfolded sighted controls learn to decode the stimulus and to perform simple visual tasks (Chebat et al., 2017).

A **B** **C**

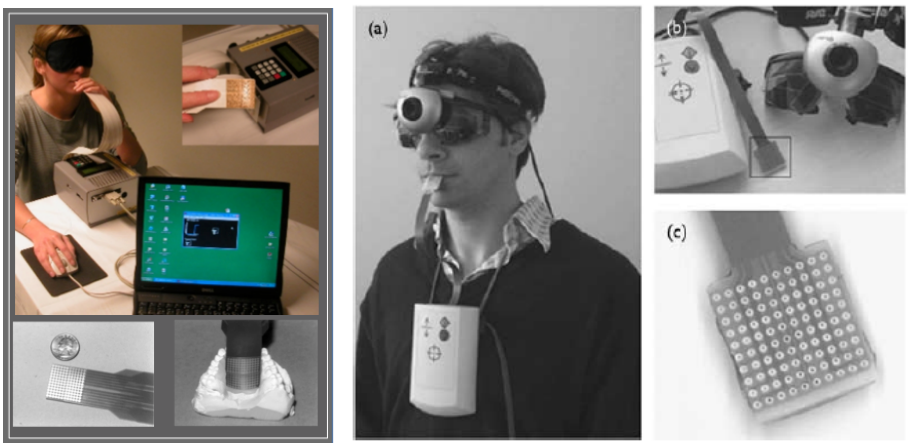

Figure 12: Subjects with the TDU in table-top (A) and portable (B) version. The components are in the lower section of A and in C.

In subsequent experiments, we tested participants for their ability in discriminating visual motion and shapes and showed that their performance, in both tasks, was excellent. Using brain imaging, we were able to show that blind participants activate their visual cortex when they perform visual discrimination tasks using the TDU (Ptito et al., 2005). We also demonstrated the usability of the TDU to perform simple object detection and avoidance tasks (Chebat et al., 2011). Using functional magnetic resonance imaging (fMRI) in combination with the TDU, we showed that congenitally blind subjects activated both their visual cortex and parahippocampus, brain areas that are heavily involved in spatial navigation in normal sighted individuals (Kupers et al., 2010). These data indicate that the blind brain undergoes, through plasticity, a complete anatomical reorganization that leads to the use of the visual system (which still is still present in blind subjects) for transmitting non-visual information (Kupers et al., 2011). We have showed that the visual cortex of the blind, although reduced in volume, maintains projections with other parts of the brain and can be activated by a number of other senses (audition, touch and smell) (see details in a recent review by Kupers and Ptito, 2014).

Although the results with the TDU were promising for helping the blind, the device also suffers from several shortcomings, such as the relatively low resolution of the grid, the large wire connecting the grid that protrudes from the mouth, the bulkiness of the camera and an insufficient software capability. This prompted us to look for a more user-friendly device that is built upon a normal smartphone and does not require any bulky additional hardware components. The Tango platform turned out to be a very promising technology. Below, we describe the device and the SensoryFusion software that was developed for it, and we also report on the behavioural data that we have acquired. These data were also presented at the Synoptik Foundation symposium that was held on September 22, 2017 at the Rigshopitalet.

6.2. The SensoryFusion System

6.2.1. The components of the SensoryFusion system.

The system comprises of a Tango-operated smartphone equipped with SensoryFusion software and a pair of wireless bone conducting headphones. To keep the smartphone in place on the forehead, i.e. directed to the visual environment, we have built a special customized head holder (Figure 13). The smartphone contains three rear cameras, a regular RGB, a low-resolution wide angle and infrared depth sensors. The system is illustrated in figure 13.

A. Components of the system B. Subject fitted with the device

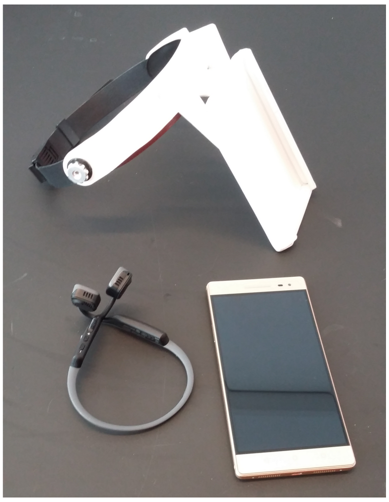

Figure 13 : A. The sensoryFusion device. B. Subject wearing the device.

The Tango smartphone uses three core principles for spatial localisation: motion tracking, area learning and depth perception. All these three components are crucial for navigation (see appendix for a more technical description). The latest version of the application (version 2.4) that we used for our quantitative data (presented below) was the result of of close interchange between the developers and the end-users.

6.2.2. Experimental design

An artificial walkway, measuring 21 m long and 2,4 m wide, in which we placed 6 obstacles, cardboard boxes measuring 40x40x180 cm, spaced equally over the length of the walkway. Participants were instructed to walk as quickly as possible to the other end of the walkway, thereby detecting or avoiding (depending on condition) the maximum number of obstacles.

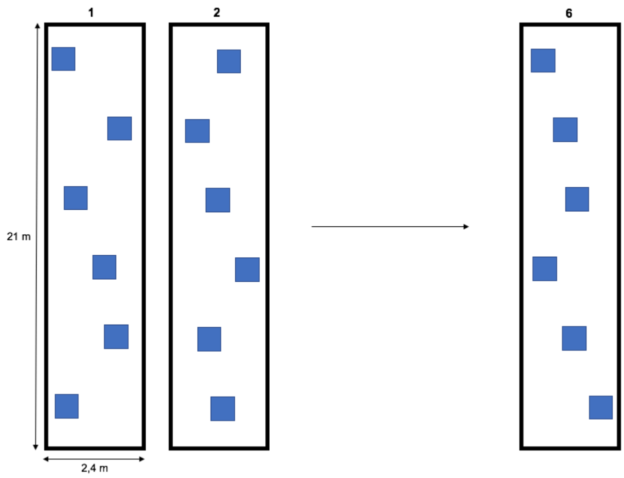

Figure 14: Experimental walkway with 3 configurations of obstacle placements

Participants

We included a total of 13 congenitally blind (7M, 6F; age: 43±13 y) and 15 blindfolded sighted controls (8M, 7 F; age: 33±12 y).

Experimental procedures

There were three phases in our experimental paradigm: a familiarization phase, a training phase, and the actual testing of detection and avoidance of obstacles.

i- Familiarization and training periods

During the familiarization phase, participants were explained the purpose of the study, the Tango operating system and the SensoryFusion software. We also tested their ability to point to a sound source, using a hand-held laser. This was done because in the detection task, participants had to use a hand-held laser to point to the obstacle, once detected. Thereafter, we started the training phase. Participants were explained the object detection and avoidance tasks using a single object. They were instructed how to interpret the auditory feedback, how to distinguish between an obstacle placed close to a wall and an obstacle placed in the middle of the walkway, and how to distinguish between an obstacle and a wall. We also taught them how to make judgments about distances using the device. Before starting the real testing period, we made sure that all participants mastered these basic tasks. The time it took to train varied from one participant to the other, but never succeeded 30 minutes.

ii- Testing period

During the testing phase, participants had to walk as quickly as possible from one end to the other in the walkway, making the fewest amount of errors possible. In the detection task, participants had to locate the position of the objects. Once a participant detected an obstacle, he/she was asked to point to it with the laser and walk towards it until it was within hand reach. Next, the participant had to detect the next obstacle until he/she had reached the last one at the end of the walkway. This sequence was repeated six times. Following each run, the position of the obstacles was changed. In the avoidance task, participants were asked to walk as quickly as possible to the other end of the walkway, thereby avoiding to hit any of the obstacles or bumping into the wall. The order of the two conditions was randomized across participants and was spread out over two different testing days.

All video sessions were recorded on camera for offline scoring. As outcome measures, we calculated the number of obstacles detected / avoided, number of false alarms (i.e. mistake the wall for an obstacle), time to perform each run, and judgment of the distance of the object (within hand reach, too far or collide). Following the second session, participants were invited to fill in a number of questionnaires and underwent a semi-structured interview.

6.2.3. Results

<u>Detection task</u>

Figure 15 shows that both groups of subjects successfully detected the obstacles in the corridor with a similar performance. As can be seen in Figure 16, the number of objects detected did not change with the number of trials. Finally, the estimation of the distance to the obstacle was correct in the vast majority of the trials (Figure 17) for both the blind and the sighted. Obstacles that were placed in the center of the hallway were more easily detected than objects that were placed closer to the walls (data not shown).

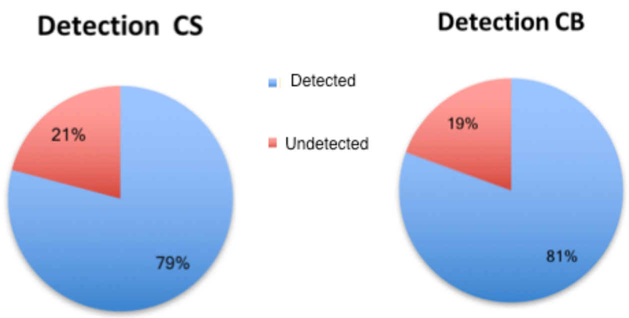

Figure 15: Percentage of detected and undetected obstacles (detection task).

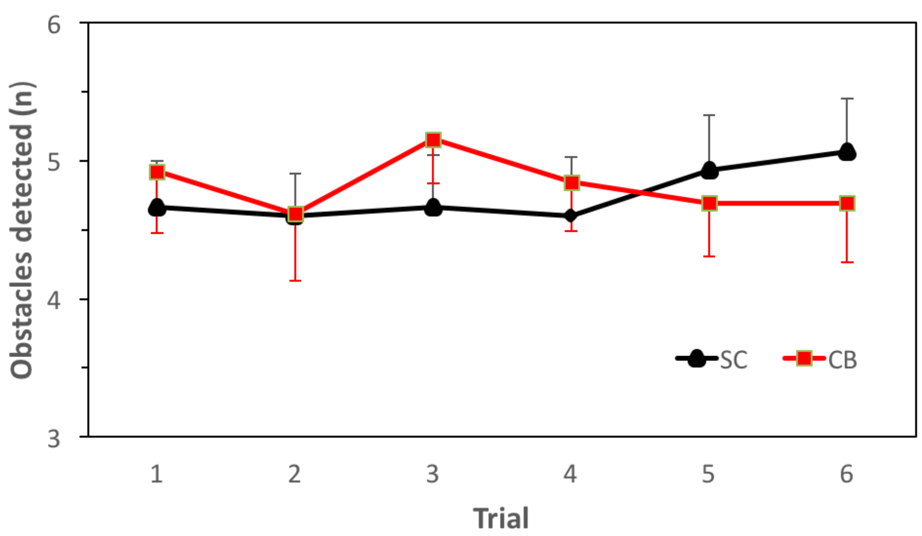

*Figure 16: Performance in the detection task over the six trials***.**

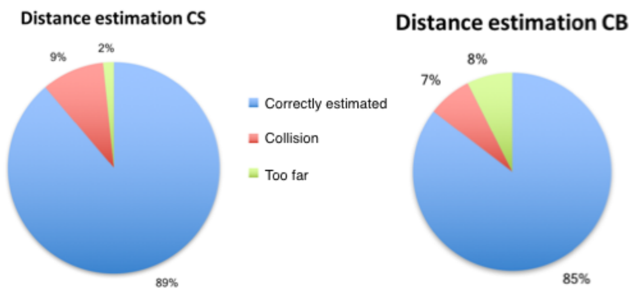

Figure 17: Distance estimations (detection task).

Avoidance task

Figure 18 shows the results of the avoidance task. As can be seen, both groups performed equally well in the number of obstacles avoided. As for the detection task, the number of obstacles avoided did not vary across trials for both groups (data not shown).

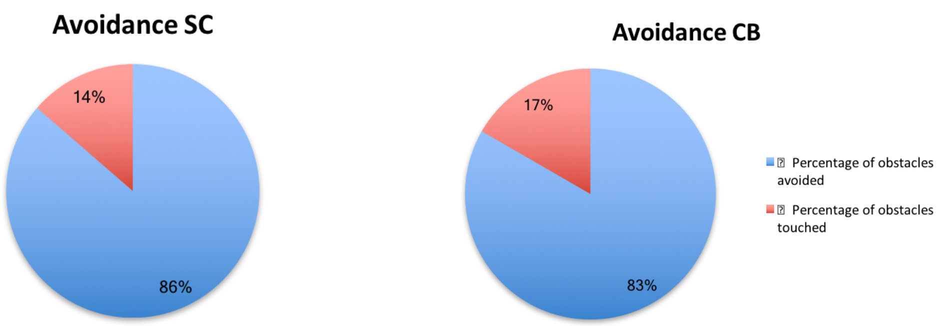

Figure 18: Average percentage of obstacles avoided in both groups

Although there was no group difference in the number of objects detected, blind participants were significantly faster than their sighted counterparts in finishing the avoidance task (Figure 19).

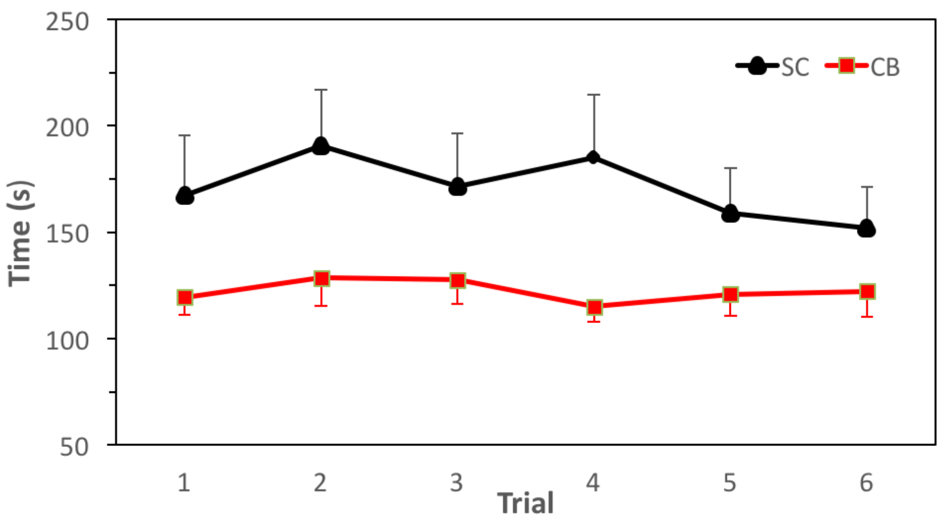

Figure 19: Time needed to finish the avoidance task.

Qualitative feedback from blind participants

From the interviews following the behavioural testing sessions, it appeared that the blind participants saw a great potential in the device. All of them liked the fact that the system doesn't need any additional hardware besides a smartphone, and that everything is contained in a smartphone, a system that they all carry with them permanently. The majority told that they would use the device on a regular basis in daily life, either as a stand-alone device or in combination with the white cane or a guide dog, if a solution could be found for holding the camera in a position from the one used in the experiments. They particularly were fond of the fact that SensoryFusion allowed them to detect obstacles outside their immediate egocentric space, and objects placed above waist level. They also had some criticism on the system, complaining for instance that the software that was tested was not stable enough (there was indeed an issue that the system tended to crash when it came too close to an obstacle, or when facing a featureless white wall) and that the system tended to respond too slow. The latter could be due to the fact that the processor on our Tango device was not very powerful.

6.2.4. Conclusions on the experimental study

A number of conclusions can be drawn from our experience with the Tango platform in combination with SensoryFusion software. First of all, participants performed very well in both tasks, even with a minimum amount of training. This is in sharp contrast with our experience with other sensory substitution devices such as the TDU or the vOICe, which take many hours or days of practice before the user can make sense of the electro-tactile or auditorily encoded visual information. This quick learning is very hopeful with respect to the propensity of the system to perform well in more complex navigational tasks. We are convinced that SensoryFusion offers an exciting and completely novel avenue for sensory substitution. Indeed, to the best of our knowledge, SensoryFusion is one of the first "smart" sensory substitution devices, based on state-of-the-art area learning routines, depth perception, and motion tracking.

For the first time in our many years of work in the field of sensory substitution, we have the impression that we are finally dealing with a product whose utility is not limited to laboratory conditions, but that has all the potential to become a real breakthrough for navigational purposes for blind individuals, although its potential in real-life situations and in more complex navigation tasks still needs to be demonstrated.

Proper functioning of the software is dependent on flagship hardware due to the high computational demands of the software. Indeed, the phone's camera collects up to 50.000 points per scan, and 5 scans are performed per second, resulting in 250.000 data points per second that are used to reconstruct the scanned section of the environment. These heavy processing demands put limits on battery life and speed of the system, issues that can be solved by rewriting of some of the underlying base code. Future updates of the software could also easily integrate artificial intelligence that allows for object recognition.

7. General Conclusion

In this report we have reported on a research project based on video ethnographic data collection and analysis of blind people's naturally occurring problems when navigating. We developed and tested the "SensoryFusion" app that uses core principles of the Tango platform to provide the user auditory feedback about the 3D space around. Blind subjects performed very well in an experimenal navigational task using the Tango device, with only a minimum amount of training. Two major improvements of SensoryFusion compared to the white cane are that it allows the user to detect obstacles that are placed above waist level and are outside the immediate egocentric space. In the future, we would like to add several new features to the software that go beyond simple obstacle detection and that form the cornerstones of wayfinding and object recognition. This will be done by combining Tango's core features for motion tracking and depth perception with maps of the area and buildings and associated metadata of the world point, available via a cloud service, and artificial intelligence identification.

Appendix: Conceptual and technical description of SensoryFusion

By Danny Bernal, Signal Garden

The SensoryFusion prototype application allows users to navigate around obstacles in an unmapped environment by providing spatial awareness through the use of passive auditory feedback. The application will not tell the user *where* to go. Instead it informs the user where they should *not* go via manipulation of sound properties such as position and pitch. The researches have been instructed to tell the participants that “the sound is lava” in order to convey the instruction of *avoidance*.

Real-time three-dimensional mapping and spatial awareness is accomplished via a combination of software techniques and technologies leveraging the device’s onboard sensors. The application produces geometry for an augmented reality environment that directly matches the real world environment. Passive spatial auditory feedback is then generated for the user based on detected geometry. The application uses real-time AR technologies and advanced signal and data processing pipelines to map out and understand the physical shape of the environment around a user. Feedback is conveyed through the spatial placement of auditory cues within the Augmented reality environment. Manipulation of the audio properties such as pitch provide a secondary alert system for proximity.

The technology and techniques in SensoryFusion could also be applied to various other domains including autonomous robotic navigation to solve real time contextual pathfinding and obstacle avoidance on a low power device. This shows some of the potential of the technology.

The Sensory Fusion is designed to run on the Lenovo Phab2Pro. This device was chosen because it is a low-power, commercially available, off-the-shelf smartphone that is AR capable and is equipped with a Google Tango-enabled sensor package (accelerometers, gyrometer, cameras, etc.), which includes a time of flight depth sensor. Other compatible devices may become available in the near future, which makes this technology very applicable as blind people can easily buy it and use it as part of their everyday lives.

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