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Abstract

Purpose – *The purpose of this paper is to describe conceptions of feasibility of a haptic navigation system for persons with a visual impairment (VI).*

Design/methodology/approach – *Six persons with a VI who were white cane users were tasked with traversing a predetermined route in a corridor environment using the haptic navigation system. To see whether white cane experience translated to using the system, the participants received no prior training. The procedures were video-recorded, and the participants were interviewed about their conceptions of using the system. The interviews were analyzed using content analysis, where inductively generated codes that emerged from the data were clustered together and formulated into categories.*

Findings – *The participants quickly figured out how to use the system, and soon adopted their own usage technique. Despite this, locating objects was difficult. The interviews highlighted the desire to be able to feel at a distance, with several scenarios presented to illustrate current problems. The participants noted that their previous white cane experience helped, but that it nevertheless would take a lot of practice to master using this system. The potential for the device to increase security in unfamiliar environments was mentioned. Practical problems with the prototype were also discussed, notably the lack of auditory feedback.*

Originality/value – *One novel aspect of this field trial is the way it was carried out. Prior training was intentionally not provided, which means that the findings reflect immediate user experiences. The findings confirm the value of being able to perceive things beyond the range of the white cane; at the same time, the participants expressed concerns about that ability. Another key feature is that the prototype should be seen as a navigation aid rather than an obstacle avoidance device, despite the interaction similarities with the white cane. As such, the intent is not to replace the white cane as a primary means of detecting obstacles.*

Keywords *Feasibility, Usability, Haptics, Visual impairment, Field trial, Navigation aid*

Paper type *Research paper*

1. Introduction

Vision provides the ability to identify danger and obstacles at a distance, and also aids in the identification and location of objects in the environment. According to the World Health Organization there are 285 million people with a visual impairment (VI) in the world (World Health Organization, 2012). The International Classification of Diseases (ICD) defines four vision categories: normal vision, moderate VI, severe VI and blindness. Throughout this paper, the term "visual impairment" is used in accordance with the ICD, that is, it implies all categories except normal vision.

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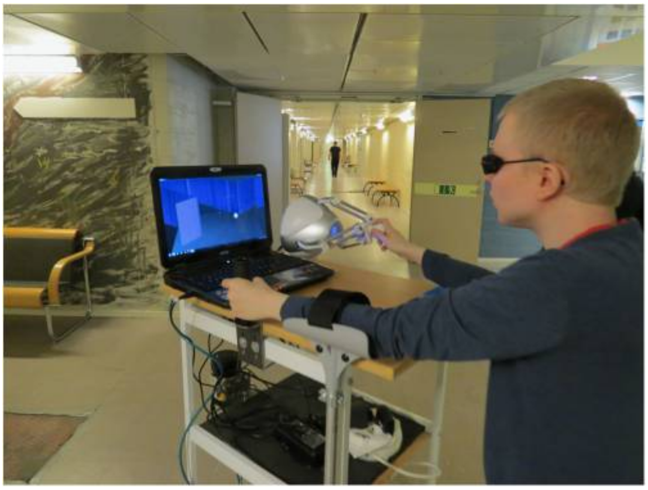
For persons with VI, the primary aid is the white cane, which provides a direct experience of obstacles at close proximity. During the last couple of decades, persons with VI have benefited from the development of technological devices. Many of these have the potential to support a better quality of life for individuals with VI and enhance their ability to participate fully in daily activities and to live independently (Steel and De Witte, 2011).

Technological solutions ranging from accessible GPS devices such as the Trekker Breeze[1] to extensions of the white cane that use ultrasound (e.g. UltraCane[2]) are available, but have not been widely adopted. Most of them involve a great deal of effort and are not intuitive for persons with VI (Hakobyan *et al.*, 2013; Bradley and Dunlop, 2005). Therefore there is a need to focus on both the needs and abilities of persons with VI and on solutions that are usable and that enable the user to make appropriate and timely decisions (Ando, 2008; Ando and Graziani, 2009; Guerrero *et al.*, 2012; Hakobyan *et al.*, 2013). The majority of current solutions use speech interfaces to interact with users with VI, but informing the user of nearby obstacles with sufficient detail is difficult and takes a lot of time (Pitt and Edwards, 1996) compared to the quick and intuitive reaction attained when hitting an obstacle with a white cane.

Due to the problems with speech for spatial information, we chose a haptic interface to communicate nearby obstacles. The present prototype consists of a laser rangefinder, a haptic interface and a laptop (see Plate 1). The laser rangefinder obtains distances to nearby objects. This information is then made into a three-dimensional model, which is transmitted to a Novint Falcon[3] haptic interface for presentation. This way a user can feel obstacles several meters in front of them, much in the same way they would with a white cane. To do this, the user moves the grip of the haptic interface, and because the interface uses force feedback to counteract grip movements, contours of obstacles and walls can be traced. The laptop that runs the software also displays a graphical representation of the model and shows the current probing position (the grip of the haptic interface) as a white sphere. More information about the system itself can be found in an earlier article (Innala Ahlmark *et al.*, 2013). A hand-held version is currently being developed.

Plate 1 The prototype navigation aid mounted on a movable table



Notes: The Novint Falcon haptic interface is used with the right hand to feel where walls and obstacles are located. The white sphere visible on the computer screen is a representation of the position of the grip of the haptic interface. The grip can be moved freely as long as the white sphere does not touch any obstacle, at which point forces are generated to counteract further movement “into” the obstacle

Early field trials in the development of this navigation aid are done in order to explore its potential. The goal is to make the system intuitive for persons who are users of the white cane today. To reach this goal, input for further development from potential users is essential. Thus, the aim of this study is to describe conceptions of the system's feasibility from an end-user perspective.

1.1 Delimitations

The point of this field trial was to get early feedback from potential end-users. Since the prototype might change considerably, we chose to focus on the qualitative aspects rather than performance metrics at this stage. A further aim was to assess how white cane experience translated to using our prototype, as the interaction possesses similarities to that of the cane. Because of this, the participants did not have the opportunity of an extended familiarization phase, and as such we cannot at this stage draw conclusions on the effects of training.

The current prototype has several known limitations. As the laser rangefinder was mounted horizontally, it is not possible to detect drops or small obstacles on the ground. Additionally, no audible feedback from touching an obstacle is generated. These factors pose a major problem if one intends to replace obstacle avoidance devices such as the white cane, but we see a continuation of this device as a navigation aid complementing the cane.

2. Methods

This initial field trial was carried out by six persons with VI. Participants made a one-shot trial during a standardized procedure in two parts: one initial, acquaintance part and one problem solving part. Both of these procedures were video-recorded, and the participants were interviewed about their conceptions of using the prototype. Finally, all gathered data were analyzed qualitatively.

2.1 Participants

The six participants in the study all had at least five years of experience using a white cane, were able to move around without assistance and could communicate their experiences verbally. The persons were recruited with help from the regional ombudsman for persons with VIs in northern Sweden. Ethical approval for this study was given by the Regional Ethical Review Board, Umeå, Sweden (Dnr 2010-139-31).

2.2 Test set-up

The system components were mounted on a table on wheels as depicted in Plate 1. A crutch handle was attached to the left side of the table (from the perspective of the user) so that it was possible to steer it with the left hand and arm. The haptic interface was fastened to the surface of the table and was operated by the right hand, with the arm resting on a foam pad glued to the edge of the table. The laser rangefinder was attached to the front of the table so that it scanned at a height of about 80 cm. Finally, the laptop was placed on top of the table which made it easy to observe – both during the trial and on the recorded videos – the model of the surroundings and what the users were touching. The current position of the grip of the haptic interface was represented by a white sphere clearly visible on the screen.

2.3 Field trial

Before starting the trial, each participant received information about the system and instructions regarding how to use it from one of the researchers. The trials were recorded on video shot obliquely from behind, so that the participants' way of using the prototype were visible on the videos. The first acquaintance part of the field trial was performed in a corridor environment (visible in Plate 1) with obstacles stacked against the walls. The task was to walk a 37 m long and 2.4 m wide corridor, passing through two 1.8 m wide doorways, to turn around at an open space at the end of the corridor and then walk back again. Along the corridor, a few objects (chairs, sofas and a waste bin) were placed along the walls. After accomplishing this, the participants began the second, problem solving part in which they walked through a 1.8 m wide doorway, into a 3.2 m wide corridor, turned right after 1.5 m and passed through a narrow (0.9 m) doorway, thereby entering a classroom (5 m by 5.5 m) cleared of furniture except for a small table half-way along the right wall upon which a soda can was placed. The task was to find the table and the soda can, pick up the can, and then turn around and walk back to the starting point. This was done with few instructions or minor assistance from the researchers. This problem solving part was accomplished on average in ten minutes (range 6-14 minutes).

2.4 Interviews

The interviews with each participant took place directly after the trial. A semi-structured interview guide was used with nine questions regarding the participants' conceptions of the solution's feasibility. The focus of the interviews was on the participants' conceptions of using the device in relation to the use of the white cane, and on what they thought needed to be done to improve the usability of the system. Each interview took approximately 45 minutes and was recorded and transcribed verbatim.

2.5 Data analysis

Video recordings of each participant's trial were observed as for how the participants acquainted themselves with the device, how they used it to navigate, and how they succeeded in clearing obstacles and doorways and finding the soda can. The participants' performance while using the prototype was displayed on the computer screen which was constantly visible on the recorded video. Similarities and differences in observed performance were identified and described qualitatively.

To analyze the interviews, content analysis inspired by Graneheim and Lundman (2004) was used. The text was divided into meaning units, these were then condensed. The condensed meaning units were assigned inductively generated codes that emerged from the data. These codes were then clustered together and sorted into different categories. After that, three different main categories were formulated.

3. Results

During the acquaintance part of the trial, all participants had an initial phase in which they obviously acquainted themselves with the equipment and how to use it in order to feel the area in front of them. In this phase, lasting from one to seven minutes, they all needed verbal cues or physical help in order not to collide with the walls or other obstacles. In this phase they also developed their own pattern of probing the area.

Two participants used a passive pattern, making few and scarce probing attempts with the device. They had difficulties navigating in the corridor and needed frequent verbal cues and physical assistance. One of these participants chose not to perform the problem solving part, and the other was not able to get any effective help from the system.

Three of the participants had an active pattern in which they obviously navigated by actively using the aid after the initial phase. They employed a horizontal *U*-shaped pattern, one with a rather low, and the other two with a rather high frequency. Two used one wall as a reference surface, feeling sideways toward the other wall in regular intervals and more often when approaching a door, while the third constantly moved the grip, alternately feeling the walls on each side. During the problem solving part, these participants navigated well between the walls and managed door openings with the exception that one participant lost the spatial orientation when negotiating one of the doorways.

One participant showed a very active and efficient pattern, moving the grip frequently from side to side, but also forwards and backwards, in a flexible way using different frequencies, directions and amplitudes depending on the situation. This participant was able to identify small obstacles beside the actual course. During the problem solving phase, this participant cleared the walls and most doorways without any problems and needed verbal guidance only in order to find the way toward the narrow doorway after the 90 degree turn. Still, this participant had the same problems as the others with obstacles in the very near vicinity at the sides, and needed verbal assistance when coming close to the table and reaching for the can.

3.1 Findings from the interviews

The content analysis resulted in three categories: to be able to feel at a distance; not without a lot of practice; the need to feel secure in unfamiliar environments. These categories are presented in the text that follows and illustrated with quotations from the interviewed participants.

3.1.1 To be able to feel at a distance. In this category the participants described their conception of how it "felt" to use the system. The walls and corners were obvious to detect; the ability to "in time" feel what was coming up like a door or a corner gave the participants a chance to get a broader perspective of the environment around them. This was according to the participants better than having to actually hit something with the white cane to know it existed:

> To feel an obstacle well ahead of time, so that you know something is coming is an advantage.

With the prototype, range perception was difficult. The participants commented that the range was too large and that it was difficult for them to judge distances. To be able to feel at a greater distance compared to the white cane was met with mixed feelings. One of the risks with the device as a "longer cane" was that it could be easier to lose ones orientation. Another was that it required a lot of concentration that in turn might mean using too much mental resources. One participant described the problem this way: "If it is 20 meters, something has to tell you that, because it is difficult to know how far away something at 20 meters is."

In order to make the device more usable, the participants discussed what distance it should reach; to feel 20 meters ahead was considered too far. According to the participants, 4-5 meters would be a better choice. The need to be able to vary the distance and to receive some sort of auditory feedback was one way to make it more usable.

3.1.2 Not without a lot of practice. The participants' conceptions of the prototype were that it would take a lot of practice to learn. The need to become more familiar with it was important according to the participants. This would increase the feeling of security: "[…] it is not until you get used to it [the device] one might start trusting it more." The participants also discussed that with practice one would not need to concentrate as much as when trying it out for the first time.

The fear of not being able to walk in a straight line and losing focus when not navigating against a wall was discussed as well as how the system would work outdoors. How it would work in an unfamiliar environment was the challenge and something some of the participants wanted to try while others felt that they needed only their white cane.

Using the device had some aspects in common with the white cane. For instance, the participants remarked that they used the same technique as with the cane and that it felt better than they had expected. They also described the test as an interesting and fun experience. Nevertheless, the white cane was easier to move to the sides and the feedback from the prototype was harder to interpret.

3.1.3 The need to feel secure in unfamiliar environments. In this category the participants described some positive and negative aspects of the prototype. It could lead to increased security if practical problems are solved. In order to feel secure with it, one would need to trust its technical features. When able to perceive more distant objects, security could increase by being able to orient oneself when lost. Being aware of obstacles earlier in time could increase the feeling of security. The fact that you could not accidentally hit peoples' legs with the system was another positive aspect.

Another aspect of security the participants described was the ability to locate things in a room upon entering it. This was something that the participants thought could be very useful in new surroundings. In unfamiliar environments, the need to train in each specific location is a must regardless of aid:

> For example to find a place when you enter an unfamiliar environment: when you visit someone or in a waiting room and places like that, to find a chair to sit on.

To be able to read unfamiliar surroundings better could result in greater independence that in turn could result in trying to venture out more and expand ones regularly visited territory. One participant described it this way:

> One can learn more about ones surroundings. One can be more impulsive. Now I can go there by myself. You will be able to go to the pharmacy in your area. If you have to have assistance you will have to apply for it ahead of time and agree on what time, and then you have to arrange your life accordingly. But if I wish to do it right now, that can never be arranged.

The lack of auditory feedback when hitting something was yet another problem the participants conceived. Not being able to feel the tactile surface and lose all the information that auditory feedback gives with the white cane made the prototype less usable:

> With the cane I can feel a pot hole and I can feel where the stairs start.

4. Discussion

This initial field trial showed that most of the participants, despite being introduced to the prototype for the first time, quickly understood how to use it. The participants' conceptions were in general positive; they appreciated the ability to feel at a distance, while perceiving the actual range was difficult. The absence of any auditory cues was also expressed.

The literature lacks of reports on trials of similar systems. Sharma *et al.* (2012) described a trial for an obstacle avoidance system where blindfolded people used a powered wheelchair to navigate an obstacle course. They demonstrated, as do our results, that systems that can provide users with essential navigation information covering distances beyond the reach of a cane might be valuable to support safe mobility.

A remarkable fact is that all participants quickly adopted their own usage technique. This implies an intuitive learning process which could be attributed to the concept of the system, but also to the fact that the participants were experienced cane users. The *U*-shaped pattern that emerged in the participants' use of the system could also be seen as a limited use of it, not utilizing the full potential of scanning the total area in front of them. It must be emphasized that the participants used the prototype for the first time, and it is possible that a prolonged use would have made them aware of this opportunity.

While the participants quickly became familiar with how to use the system, they all had difficulties with range perception. This meant that when performing high-precision maneuvers such as passing through a narrow doorway, positioning themselves at a proper angle was troublesome. Again, the fact that none of the users had prior training with the system is important in this respect; it might be that they simply had not had enough experience to precisely judge the scaling between the small movements of the haptic grip and distances in the physical world. Another important factor to consider is the position of the laser rangefinder and haptic interface relative to the user. In our case, the laser rangefinder was positioned about half a meter directly in front of the user, while the haptic interface was closer, but more to the right of the user. This means that in addition to having to learn the scaling between the physical world and the haptic representation, an additional sideways translation is required in order to properly match the physical world with the virtual model.

Based on the participants' descriptions of using the device and its feasibility it seems like it can provide a combination of a direct experience of an environment as well as a sort of tactile map due to its possibility to feel at a distance. Studies by Espinosa and Ochaita (1998) have shown that being able to combine these two approaches constitutes a useful way to orientate in unfamiliar environments. A longing to explore unfamiliar environments was expressed by the participants in this study, and was something they saw the system could aid in.

Assistive technologies have the potential to enhance quality of life via improved autonomy, safety and by decreasing social isolation (Hakobyan *et al.*, 2013).

This study must be seen as a first field trial and has, as such, a certain number of limitations. A very early prototype was tried, which has effects on the usability for the participants. Nevertheless, we believed that such an early trial would bring us important knowledge for further development. The reason for not offering the participants the opportunity of a longer familiarization with the system was that we wanted to get an impression of how intuitive the system was to learn to use. The fact that this was a very early stage trial also motivated us to choose a qualitative and open approach in describing both user experience and actual performance when using the prototype.

Regarding the trustworthiness of the findings from the interviews, one limitation is the sample size. A larger number of participants might have widened the range of experiences, however, all six of the participants did describe similar conceptions of the system. To strengthen the trustworthiness, the analysis of the transcribed data were discussed among the authors and representative quotations were chosen to increase the credibility of the results (Lincoln and Guba, 1985).

We also would like to emphasize that the participants represented potential users, and were not people with normal vision being blindfolded. This is important as we wanted to get the experiences from people who do not rely on visual information for navigation and who were used to another haptic instrument: the white cane. In this respect, we are aware of the findings of Patla *et al.* (2004), who demonstrated that among individuals with normal vision that was partially or completely restricted, information provided by haptic systems has to match the quantity and immediacy provided by the visual system in order to support a well-controlled motor performance. How haptic information affects motor control in persons not used to rely on visual information needs to be studied specifically.

In conclusion, this early field trial indicated an expected usability of the device from an end-user perspective. We would like to emphasize the participants' appreciation of the ability to feel the environment at ranges beyond white cane range and the swift acquaintance phase, which may be due to the cane-like interaction. The trial also gave important perspectives from the users on issues for further development of the system.

Notes

1. Trekker Breeze: http://store.humanware.com/hus/trekker-breeze-handheld-talking-gps.html/
2. UltraCane: www.ultracane.com/
3. Novint Falcon: www.novint.com/index.php/novintfalcon

References

Ando, B. (2008), "A smart multisensor approach to assist blind people in specific urban navigation tasks", *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, Vol. 16 No. 6, pp. 592-4.

Ando, B. and Graziani, S. (2009), "Multisensor strategies to assist blind people: a clear-path indicator", *IEEE Transactions on Instrumentation and Measurement*, Vol. 58 No. 8, pp. 2488-94.

Bradley, N.A. and Dunlop, M.D. (2005), "An experimental investigation into wayfinding directions for visually impaired people", *Personal Ubiquitous Computing*, Vol. 9 No. 6, pp. 395-403.

Espinosa, M.A. and Ochaita, E. (1998), "Using tactile maps to improve the practical spatial knowledge of adults who are blind", *Journal of Visual Impairment & Blindness*, Vol. 92 No. 5, pp. 338-45.

Graneheim, U.H. and Lundman, B. (2004), "Qualitative content analysis in nursing research: concept, procedures and measures to achieve trustworthiness", *Nurse Education Today*, Vol. 24 No. 2, pp. 105-12.

Guerrero, L.A., Vasquez, F. and Ochoa, S.F. (2012), "An indoor navigation system for the visually impaired", *Sensors*, Vol. 12 No. 6, pp. 8236-58.

Hakobyan, L., Lumsden, J., O'Sullivan, D. and Bartlett, H. (2013), "Mobile assistive technologies for the visually impaired", *Survey of Ophthalmology*, Vol. 58 No. 6, pp. 513-29.

Innala Ahlmark, D., Fredriksson, H. and Hyyppä, K. (2013), "Obstacle avoidance using haptics and a laser rangefinder", *Proceedings of the 2013 IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO)*, pp. 76-81.

Lincoln, Y.S. and Guba, E.G. (1985), *Naturalistic Inquiry*, Sage Publication Inc., London.

Patla, A.E., Davies, T.C. and Niechwie, E. (2004), "Obstacle avoidance during locomotion using haptic information in normally sighted humans", *Experimental Brain Research*, Vol. 155 No. 2, pp. 173-85.

Pitt, I.J. and Edwards, A.D.N. (1996), "Improving the usability of speech-based interfaces for blind users", *Int. ACM Conf. Assistive Technologies*, pp. 124-30.

Sharma, V., Simpson, R.C., LoPresti, E.F. and Schmeler, M. (2012), "Clinical evaluation of semiautonomous smart wheelchair architecture (Drive-Safe System) with visually impaired individuals", *Journal of Rehabilitation Research & Development*, Vol. 49 No. 1, pp. 35-50.

Steel, E.J.A. and De Witte, L.P. (2011), "Advances in European assistive technology service delivery and recommendations for further improvement", *Technology and Disability*, Vol. 23 No. 3, pp. 131-8.

World Health Organization (2012), "Fact sheet, N282", available at: www.who.int/mediacentre/factsheets/fs282/en/ (accessed May 9, 2013).

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