Title

Evaluation of the Electronic Long Cane: Improving Mobility in Urban Environments

Marion Hersh, University of Glasgow, Scotland and Alejandro R. García Ramírez, University of Vale de Itajai, Brazil

Abstract

Mobility and interaction with the environment are important challenges that visually impaired people need to deal with everyday. A wide range of portable and wearable electronic travel aids have been developed to enable them to move around public spaces without a sighted guide. However, few of them have gone beyond the prototype stage and the long cane and guide dog are still the main mobility aids. Despite the importance of evaluation of mobility devices to determine, for instance effective functioning and end-user satisfaction, a standard approach to evaluation has not yet been developed for mobility aids. The paper reports the evaluation of a low cost electronic long cane, developed by the authors and colleagues, in Brazil. It used a two-part methodology involving an experimental investigation of the electronic long cane performance and a questionnaire to explore user satisfaction. The results of the experiments and questionnaire demonstrated both the cane's usefulness and the need for modifications to improve its functioning. The work presented here is also important in terms of the development of methodologies for effective evaluation, including outside Europe, the USA and Japan, since this is the first evaluation of a mobility device developed and carried out in Brazil. In addition it is one of only a small number of evaluations to use real locations and real obstacles. Finally a series of recommendations for carrying out evaluations of mobility devices is presented.

What this paper adds?

A standard approach to evaluating electronic travel for visual impaired people has not yet been developed and the most appropriate approach may depend on the objectives of the evaluation. Existing approaches generally use participants with no previous experience of using the device being evaluated and is carried out indoors with artificial obstacles. The training or device familiarization period usually provided might be insufficient for participants to obtain optimal device performance or an effective comparison to be made of different devices. The approach to evaluating an electronic long cane reported in this paper has three main advantages over previous methods. The participants were experienced users of the electronic long cane who had been using it to support their daily mobility for at least a month. The evaluation was carried out in two different real urban environments with real obstacles. This has the advantages of being close to real life cane use and participants being able to make informed comments and suggestions for improvements as a result of their experience. A questionnaire included questions on user satisfaction with and evaluation of a number of different cane features based on their experiences of cane use over a period. The work is also significant as the first detailed mobility device evaluation carried out in Brazil and in the presentation of a series of recommendations divided into themes for effective evaluation of mobility devices.

Keywords: Assistive Technology, Blindness, Electronic cane, Mobility, User experience.

1. Introduction

Economic development and social welfare issues for blind (and other disabled) people are very important issues, which do not always receive sufficient priority. Nearly 285 million people (about 4%) of the global population of 7.4 billion are visually impaired, with 39 million of them blind. About 90% of visually impaired people live in low income settings (WHO, 2014). The highly advanced state of ICT and other technologies presents exciting opportunities for the development of (low cost) mobility technologies for blind people.

Mobility is very important for participation in modern society, but this is one of the areas where blind and partially sighted people experience significant barriers. Despite the potential of advanced technologies and over a century work in this area, the most commonly used travel aids are still the long cane and the guide dog. Few of the large number of high tech devices developed have gone beyond the prototype stage and only small numbers are in use. The reasons for this include providing little useful additional functionality compared to the long cane and their high price, which is often prohibitive to blind people, particularly in Brazil (Silva & Ramirez, 2013).

The long cane is widely used by visually impaired people, particularly in urban environments. It works by extending the user's tactile reach and intervening between the user and obstacles. It has the further function of acting as a symbolic indicator that the person is blind, though this may discourage use due to the associated stigma (Hersh, 2015). Despite its many advantages, including (relatively) low cost, robustness and ease of maintenance, it also has the disadvantages of requiring a fairly long training period and not detecting obstacles at head and chest height. Such obstacles are not uncommon in towns and cities, largely due to poor design and lack of awareness of accessibility issues. They can lead to accidents and injury. They include wall mounted pay phones, trees with overhanging branches, signs on poles and raised waste bins.

A large number of high tech mobility aids have been developed to resolve this and other issues. They include high tech canes, which obtain additional information from the environment using infrared, ultrasonic and/or laser sensors. They then transmit the information to the user via tactile (vibratory) or auditory (sound) interfaces. High tech canes which are available to users include the Ultracane (Hoyle, 2008) and the Bat-K Sonar (Dakopoulos & Bourbakis, 2010), the Tom Pouce and Télétact (Farcy et. al, 2006), the Laser Cane (Hersh & Johnson, 2008), the iSONIC (Kim et al., 2009) and the Smartcane (Wahab et. al, 2011). Prototypes include an electronic cane with features enhanced by contextual information from the Internet of Things (IoT) and environmental information obtained via haptic feedback (Ramirez et. al., 2017), and an electronic cane with ultrasonic sensors and camera and audio output (Bouhamed et al., 2012). In addition to mobility devices for obstacle avoidance, high tech orientation and navigation aids have been developed e.g. (Hersh, 2009; Pissaloux et al, 2016) for overviews of these devices.

Blind and partially sighted people are involved in the very significant growth in smartphone and touchscreen use in recent years (Grussenmeyer and Folmer, 2017). This gives rise to a need for design for all approaches to enable visually impaired people to use smartphones and touchscreen devices effectively. Some of the relevant design issues have been discussed by (Vatavu, 2017). End-user involvement in design is very important. The results of a survey of visually impaired and other disabled people in Italy and the UK and the extent of their use of mobile apps and interest in using recommender apps with privacy management is presented in (Hersh and Leporini, 2017).

2. Related works: evaluation of electronic travel aids

Despite the fact that work on the development of electronic travel aids started at the end of the nineteenth century (Hersh and Johnson, 2008), it is only in the last thirty years or so that they have been evaluated. One of the earliest devices to be evaluated was the Sonic Pathfinder (Dodds et al., 1984; Heyes et al., 1984) and subsequently evaluation of both mobility and orientation devices has been carried out. The evaluated mobility devices include a robotic sensing device (Molton et al 1999); updated versions of the Laser Cane (Blasch et al, 1989), the GuideCane (Ulrich and Borenstein, 2001); two different electronic mobility canes (Bhatlawande et al., 2014; Kim et al., 2012); night vision glasses or googles (Bowers et al., 2004; Hartong et al., 2004, 2006); other devices designed to improve mobility at night (Friedburg et al., 1999; Morrissette et al, 1983; Rohrschneider et al, 2000; Spandau et al., 2002) and Guido, a multi-function device with obstacle avoidance, map based navigation and physical support functionality. It was briefly commercialised, but is no longer produced (Rentschler et al., 2008; Rodriguez-Losada et al., undated).

The orientation devices evaluated include Talking Signs (Marston et al, 2000), global positioning systems with different types of displays (Marston et al, 2006; Loomis et al, 2005), the use of tactile maps to support wayfinding (Caddeo et al, 2006), talking way-finding systems (Guidice et al, 2007; Kooijman et al, 2000), tactile pathway tiles (Courtney et al, 2000; Ministry, 2000), BrailleNote GPS (Ponchilla et al., 2007), Trekker (Havik et al., 2010), a virtual model traffic environment with sound and haptics (Magnusson et al, 2005) and components of a personal guidance system (Golledge et al, 2004). Some evaluations consider the performance of a single device, whereas others have carried out a comparative evaluation of several devices with related functionality, including night mobility devices (Bowers et al, 2004), general mobility devices (Roentgen et al., 2012ab) and navigation devices (Roentgen et al., 2011).

A standard approach to evaluation has not yet been developed for either mobility or navigation aids. However, evaluation generally involves movement round a course, most commonly indoors with artificial obstacles, though outdoor courses with real obstacles have also been used e.g. (Bowers et al., 2004). In addition, there have been attempts to develop a standard protocol (Havik et al., 2010) and a standard indoor mobility course (Roentgen et al., 2012ab). However, this standard protocol is suggested for evaluation of whether a device is suitable for a particular end user rather than more general evaluation of the device. The evaluation apparently involves two phases, but only the 'intervention phase' is described, involving initial training, device use for a period and three further training sessions with assessment of participant proficiency before each session and at the end of the period. However, the authors do not state how this protocol should be generalised to other devices. In addition, different approaches may be required for mobility and navigation aids and the most appropriate approach may depend on the evaluation objectives. This would give rise to a need for standardised approaches which support adaptation to take account of the evaluation objectives. However, there has been little discussion of evaluation objectives in the literature.

The proposed indoor mobility course (Roentgen, 2012ab) has a high density of artificial obstacles to make it more challenging with minimum spacing of two metres to avoid simultaneous detection of two obstacles. They were placed at above knee (50-100cm), above waist (100 - 150 cm) and shoulder to head height (above 150 cm) and made of polystyrene to avoid injury in the case of collision. They were all white, with higher contrast with the floor and lower contrast with the ceiling and walls and had four different shapes and sizes. It was not assumed people with some vision would wear blindfolds. There were also six real obstacles, of which a photocopier and pictures on an easel are not necessarily always easily available. The use of indoor courses with mainly artificial obstacles has the disadvantages of the obstacles tested not necessarily covering the variety of obstacle textures, shapes and other features found in real environments and lacking the presence of moving and stationary people and noise which can make real world mobility more difficult.

Movement round the mobility course is frequently followed by a questionnaire, administered either orally or in writing. It generally covers the experience of using the device round the course and occasionally suggestions for improvements. Research participants generally lack previous experience of using the device and are provided with a period of training to familiarise themselves with it. In most cases they have a visual impairment which affects their mobility, but tests have also been carried out with blindfolded sighted people.

A related area is the evaluation of the mobility of visually impaired people, generally without the aid of a device. This has included both the use of specially designed courses (Kuyk et al, 1998; Marron et al, 1982), often laboratory or office spaces with specially positioned obstacles, and real trajectories, including residential and other low traffic areas (Dodds et al., 1987; Goodrich et al, 2003; Kuyk et al, 1998) and complex, heavily trafficked shopping centres (Haymes et al, 1996) with naturally occurring obstacles. The variables measured include the percentage preferred walking speed and the distances for visually detecting and identifying an obstacle (Leat and Lalkovie-Kitchin, 2006).

In this area, there have been some attempts to develop a methodology and standardise approaches. For instance, Leat and Lalkovie-Kitchin (2006) made a number of recommendations for trajectories in a real environment including the use of natural obstacles and obstacles that other pedestrians can walk round to avoid them being moved. They suggest positioning deliberately placed obstacles immediately prior to the participant going round the course and advising other people using the area that a study is being carried out. They also suggested use of at least two experimenters and a visually complex trajectory that really tests orientation and mobility skills and provides opportunities for making errors. In addition they proposed recording walking times, hesitations, errors and behavioural modifications, providing a training section of the course to familiarise participants with what is required and giving very precise instructions for each section of the course.

This work presents the evaluation of an electronic long cane, designed in Brazil, with the involvement of experienced blind and low vision users. The evaluation was based on a two-part methodology involving an experimental investigation of the electronic long cane performance and a questionnaire.

3. Material and Methods

3.1 Material: the electronic long cane

The Electronic Long Cane Project started in Brazil, in 2006. It was conceived as a personal aid to assist the mobility of visually impaired individuals in urban spaces (Silva & Ramirez, 2013). The design was based on embedding a haptic interface in the handle of a traditional long cane. Evaluations and design improvements led to an updated model in 2012, with both tactile and audio output (Figure 1).

Figure 1. The electronic long cane developed in Brazil

The cane features an ultrasonic sensor, a micro-motor of the type commonly found in cell phones, a buzzer, a microcontroller and a battery. The ultrasonic sensor is positioned to detect obstacles between chest and head height using reflections from the object. When an obstacle is detected, the user is informed through vibro-tactile and audio feedback, enabling them to take action to avoid a collision. The vibration frequency increases as the user approaches the obstacle. This allows experienced users to estimate the distance to the obstacle. Tactile feedback in the form of vibration was originally chosen to avoid blocking access to audio environmental information which is so important to blind people, particularly for safe mobility. Sound produced by a small buzzer inside the handle was added when the cane was modified to facilitate use by people who experienced difficulties in detecting the vibration. However, the sound can be turned off.

As illustrated in figures 2 and 3, the ability to detect obstacles between chest and head height removes one of the main limitations of the long cane, resulting from its inability to detect obstacles much above ground level (Ramirez et al., 2012).

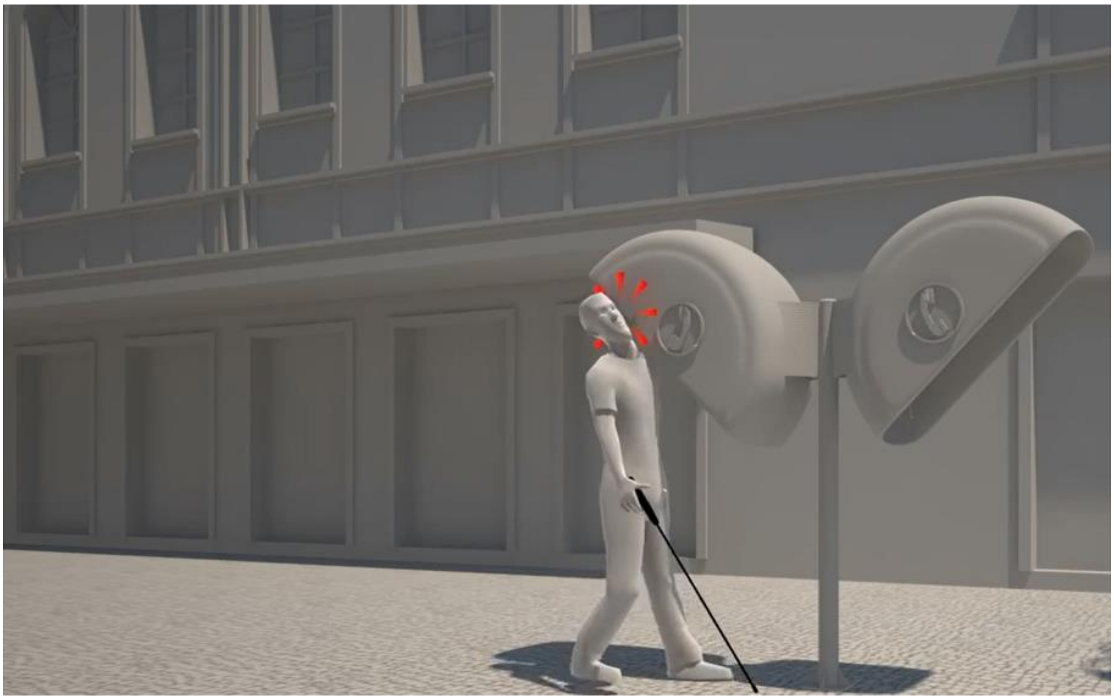

Figure 2. Problems resulting from the long cane's inability to detect high obstacles

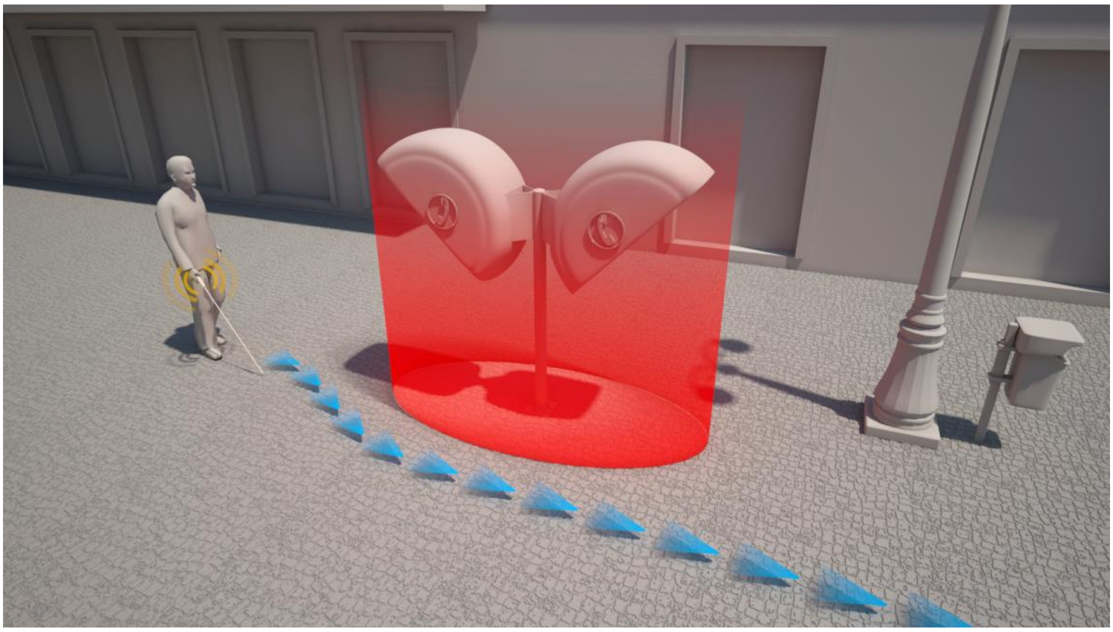

Figure 3. Collision avoidance using the electronic cane

The cane electronics are embedded in the handle of the cane, which is 22 cm long, 3 cm diameter, and weighs 0.170 kg. They comprise an ultrasonic sensor (LV Max

Sonar EZ series, MaxBotix, USA), a micro-motor of the type commonly used in cell phones, a microcontroller (ATtiny13 AVR) and a 9-V rechargeable battery (Ramirez et al., 2012). The battery lasts ten hours and takes less than an hour to recharge. This allows most users to use the cane all day or even for several days and then recharge it at night. A schematic diagram of these components is given in figure 4. The computations required to detect ultrasonic reflections can be carried out in real-time on a small portable device.

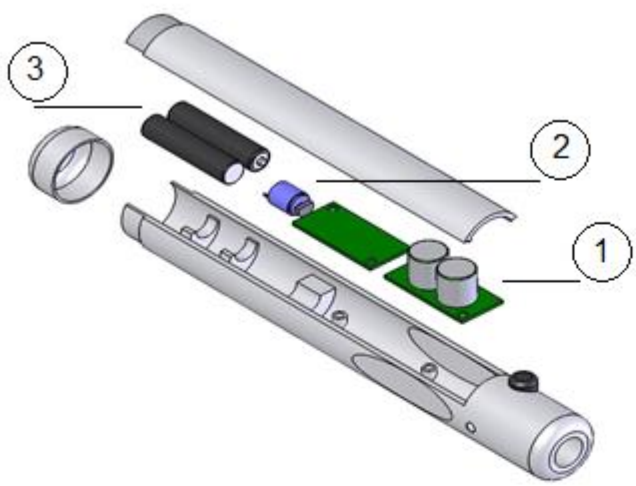

Figure 4. Schematic diagram of the electronic components: (1) ultrasonic sensor, (2) micro-motor and (3) battery.

The wavelength of the ultrasound signal was chosen to be about 4 kHz to give a detection range of 1.8 m and 30°. It could be adjusted downwards for users with a shorter cane. This informs users of high-up obstacles in sufficient time to take evasive action to avoid them, but does not provide information from more distant obstacles, which could possibly cause confusion or make the cane vibrate continuously. The processing time interval for ultrasonic echolocation was set to 100 μs, giving an error of +/- 3.4 cm. While by no means non-zero, this is sufficiently accurate to allow obstacle detection and avoidance.

It is important to note that the design allows users to continue using traditional long cane techniques. Consequently, they can use the long cane to detect obstacles at ground level and explore the environment using the tip of the cane in contact with the ground. This gives tactile feedback about the type of surface the cane is in contact with (Cook & Polgar, 2015).

A preliminary descriptive study of the electronic cane was carried out a few years before the study reported here (Ramirez et al., 2012). It involved 17 users, 12 with previous experience of using a traditional long cane and orientation and mobility (O&M) techniques. Five users lacked experience with the long cane and were unfamiliar with O&M techniques. At this point only one prototype was available for testing and therefore a cane of suitable length could not be chosen each user, as is the case with the current design. One at a time the users tested the electronic cane in the Brazilian Association of Assistance to the Visually Impaired (LARAMARA) and on a walking tour of part of the city of São Paulo. Structured interviews with participants after testing the cane were used to obtain a mixture of qualitative and quantitative data. An O&M trainer and volunteers from Laramara conducted the tests and carried out the interviews.

The results showed 80% overall satisfaction with the device and provided several suggestions for improving it. However, three participants without previous long cane experience were unable to use the electronic cane effectively. This led the authors to conclude that O&M training and previous long cane experience are necessary to use the electronic cane and its additional features effectively.

3.2 Methods: introduction

The evaluation had the following three aims:

1. Investigating the extent to which the cane is able to fulfil its intended function of detecting obstacles between chest and head height and alerting the user to them.
2. Investigating user satisfaction and interest in using the cane.
3. Identifying modifications and improvements to the design to improve performance and user satisfaction.

A two-part methodology, involving an experimental investigation of cane performance and a questionnaire, was used to implement these aims. Ethical approval was obtained from the University of Vale de Itajai in Santa Catarina, Brazil. In line with their requirements, the information sheet about the research and statement of consent were included in a single document. This document also contained the researchers' contact details and an invitation to contact them for additional information and with questions. It was emailed to the participants (who were all blind), rather than a printed information sheet being used, to ensure accessibility.

3.3 Methods: Experimental Investigation

The experimental investigation was carried out in two outdoor urban locations with very different characteristics and involved a number of very varied real obstacles at head and chest height. The authors considered this approach to have severa; advantages relative to the use of artificial obstacles in (artificial) indoor environments. In particular, this provides a user experience and test conditions which are much closer to the conditions and experiences of using the device. This factor and the diversity of obstacles included significantly increases the likelihood of identifying usability problems and determining the modifications required in order to resolve any problems and improve performance. It is rarely possible to include a sufficient variety and diversity of obstacles in an artificial environment to give a very high probability of detecting all possible usability problems. However, this does not necessarily mean that investigations in artificial environments are not an appropriate methodology in some context or unable to detect usability problems.

The experimental investigation involved five experienced users of the electronic cane living in Florianopolis in Santa Catarina, Brazil. They were three blind and two low vision people, three female, two male, aged between 24 and 50 years, who had been using the electronic cane for at least one month, (see table 1). The evaluation took place in two outdoor locations with very different characteristics: the very busy pedestrianised main shopping street in the centre of Florianopolis and the campus of the Federal University of Santa Catarina. Both locations had a number of different obstacles at chest and head height. All five cane users participated in the central location, and only one of them in the university location.

The use of two locations had the advantages of enabling investigation of cane performance with a greater diversity of obstacles and in very different environmental conditions, in particularly noisy and busy, and quiet environments. This enabled investigation of whether environmental conditions affected cane performance. While there would have been advantages in using a larger number of different locations, the choice of two locations provided a good compromise between enabling cane performance in different contexts to be investigated and avoiding excessive demands on participants. The main criteria in choosing the two locations were the presence of a number of different types of obstacles at chest and head height in each location, significant differences in both the overall context of the locations and some of the types of obstacles, the inclusion of obstacles which the cane might find difficult to detect, and inclusion of a location that could stress users.

The choice to involve experienced electronic cane users was motivated by aim 3 (see section 3.2) and the following methodological considerations. The use of participants without any experience would have made it more difficult to determine whether any problems identified were due to their lack of experience and expertise in using the electronic cane or due to the cane itself. This also enabled the cane to be tested in a very demanding environment (a busy shopping centre) without risk to participants. In addition, this allowed participants to be asked about their experiences with and attitudes to the cane. Finally, the use of experienced electronic cane users removed the need for a training and familiarisation period. This increased the time that could be devoted to actual device testing without making excessive time demands of participants or overtiring them. However, it should be noted that the sample included participants with experience varying from one to six months.

Table 1 Profile of participants

Impairment	Gender	Age	Age of onset of impairment	Education	Occupation	Electronic cane experience
Low vision	M	24	Childhood	Graduate	Unemployed	One month
Blind	F	30	Birth	Graduate	Psychologist	One month
Blind	F	50	Childhood	High School	Health care	One month
Blind	F	30	Birth	Graduate	Unemployed	Six months
Low vision	M	41	Youth	High School	Therapist	Four months

One cane user participated at a time. At the start, the participant's preferred walking speed and walking speed when using the electronic cane were measured. This involved the participant walking accompanied by an experienced orientation and mobility (O&M) instructor at their natural speed in an area without obstacles and using the electronic cane in an area with several obstacles, respectively. The number of paces over a period of a minute timed by one of the researchers was counted and recorded by the other.

The O&M instructor positioned the participant at a distance from the chosen chest or head height obstacle and directed them to walk towards it at the preferred speed, without indicating the obstacle distance or location or the type of object. The participant was instructed to stop when either the electronic cane indicated the presence of the obstacle or made contact with it. Two researchers observed the participants and the O&M instructor also followed and observed them to ensure their safety, including by intervening to prevent collisions with the chosen obstacle. When the participants stopped they were asked whether the cane had signalled the obstacle. If this was the case the perpendicular distance from the participant to the obstacle was measured to the nearest centimetre. The participant was repositioned, sometimes at a different angle to the obstacle, for instance to approach it from the side as well as in front, and asked to repeat the process to verify the findings and determine whether the angle of approach made a difference. The angles of approach used and the number of repetitions depended on the type of obstacle and, in particular, whether features of its layout and relationship to other obstacles created a particular collision risk and/or a risk of non-detection. Repetition was also used for repeatability, but the available time of the participant sometimes prevented this. The height of some of the obstacles was also measured.

The process was repeated with a number of different types of obstacles. In a few cases when the cane was unable to properly detect the obstacle the participant was asked to walk more slowly to investigate whether the longer time enabled the cane to detect the obstacle. For each participant and obstacle, one of the researchers noted whether or not the cane made contact with it and whether or not the cane signalled the presence of the obstacle, as well as the distance to the obstacle for the cases when the cane signalled its presence. This approach was used rather than the more commonly used one of participants walking round a course with a number of obstacles, as the researchers considered that it better enabled them to investigate the performance of the cane and identify modifications likely to improve it.

3.4 Methods: Questionnaire

A questionnaire was sent by email to all the 18 users of the electronic long cane, 16 in different cities in Brazil and two abroad. This included the five people who had participated in the experimental evaluation. Sending them the questionnaire by email rather than the answers being recorded verbally by the researchers after the experimental evaluation meant that their questionnaires were not treated differently from those of the other participants. The time involved in the experimental evaluation, the length of the questionnaire and the conditions in the first evaluation location, which was very noisy and busy, also made this more appropriate.

Table 2 Profile of questionnaire respondents

Impairment	Gender	Age	Age of onset of impairment	Education	Occupation	Electronic cane experience
Low vision	M	24	Childhood	Graduate	Unemployed	One month
Blind	F	30	Birth	Graduate	Unemployed	One month
Blind	F	50	Childhood	High School	Health care	One month
Blind	F	30	Birth	Graduate	Psychologist	Six months
Low vision	M	38	Birth	High School	Unemployed	Six months
Blind	F	51	Youth	High School	Retired	Four months
Blind	F	37	Youth	High School	Student	Four months
Blind	F	58	Youth	High School	Housecare	Four months
Blind	M	24	Youth	Post-graduate	Student	Four months
Low vision	M	52	Childhood	Middle school	Retired	Four months
Low vision	F	53	Adult	Post-graduate	Educator	Three years
Blind	M	61	Childhood	Graduate	Technician	One year
Blind	M	50	Childhood	Graduate	Musician	One month
Blind	F	58	Childhood	Middle school	Missionary	One month
Blind	M	27	Childhood	Graduate	Reporter	One month
Blind	F	60	Youth	Post-graduate	Consultant	One month
Low vision	M	36	Youth	Graduate	Psychologist	Four months
Blind	M	41	Youth	High School	Therapist	Four months

As shown in table 2, the participants show good variation over all the demographic variables. They are equally split between male and female and have a good age distribution from 24 to 61 years. 13 are blind and five low vision and there are several participants who have been blind from birth (3), from childhood (7) and from their teens (7), and one as an adult. There is also a distribution of educational experience, including lower secondary school (2), secondary school (6), undergraduate (7) and postgraduate (3) degrees and current status, with the 10 employed having a variety of different occupations, two students, one responsible for the household, two retired and three unemployed. Experience of cane use varied from one month (7) to three years (one) and included 4 months (7), 6 months (2) and 1 year (1). The overwhelming majority (89%) used the electronic cane regularly as their main mobility aid, with 94% using both the electronic and traditional long canes and 6% only the electronic cane.

The questionnaire covered participants' experience of using and attitudes to the electronic cane rather than qualitative aspects of the experimental evaluation. It was divided into two sections. Section A asked for personal information on gender, age, education, employment and the age at which vision impairment started or occurred. Section B consisted of a mixture of open and multiple choice questions on user experience, satisfaction with and suggestions for improving the cane. It was prefaced by a request to provide honest responses even if they were critical, as providing only positive information would make it difficult for the researchers to improve the cane where required. This was intended to avoid bias resulting from participants providing only positive comments to please the researchers. A translation by the first author of section B of the questionnaire is provided in appendix 1.

The first group of four questions in section B were open and covered what cane features participants, liked, did not like and wanted to change. Questions in this group included 'What do you dislike about the electronic cane?' This was followed by four groups of multiple choice and open questions interspersed with open questions asking for clarification or additional comments. The first group of one two-part and one four-part question, each followed by a request for comments, covered participants' opinions on specific features. This included 'Do you consider the sound of the cane: easy to hear; too loud; too quiet', with other questions on the weight of the cane, ease of folding, whether the cane should fold, pleasantness of the audio signal and interest in being able to change it.

The second group of two one-part, one two part and one three-part questions related to preferences and ease of obtaining information, with most groups followed by a request for comments. It included 'Is the electronic cane easy to use as a traditional long cane?', preference for the current integrated design or an additional box, ease of use, interest in information at different heights and distances, and experience of collisions.

The third group of one three-part question followed by a request for comments related to learning to use the electronic cane. It included 'How easy was it to learn to use the electronic cane?', the time required and the best way to learn. The final group of two two-part and two three-part questions, each followed by a request for comments, covered experience and interest in using the electronic cane and other mobility devices. This included 'In your everyday travel when do you use the electronic cane?', interest in purchasing it at an appropriate price, how much they would be willing to pay and experience of using other technological canes or other mobility aids. The final question provided a further opportunity for comments and suggestions.

The researchers chose to design their own questionnaire rather than using an existing one to enable them to investigate specific aspects of the cane, in line with the three aims stated at the start of the section. It was decided not to include additional questions on qualitative aspects of the practical evaluation for the five participants involved to avoid making further demands on them. The researchers decided not to pilot the questionnaire, as there were only 18 potential respondents.

Statistical significance of the questionnaire results was tested at the 0.05 level using the Fisher exact test with software developed by Langsrud (undated). Analysis of the qualitative comments was based on a simple coding strategy to identify and group together common themes. In addition, the number of comments in several theme areas was counted to give an indication of the relative importance of the comment.

4. Experimental Tests and Results

The results of the tests are summarised in tables 3-5. Table 3 shows that all five cane users walked more slowly with the cane in the presence of obstacles, at between 80 and 87% of preferred walking speed. This is accounted for by the brief halts required when obstacles were detected, three or four in the space of a minute for all five users. The number of users was insufficient to enable investigation of any relationship between their preferred walking speeds or length of experience of electronic cane use and the percentage reduction.

Table 3 Walking pace

Feature	P1	P2	P3	P4	P5
Preferred walking speed (paces/minutes)	92	103	90	99	110
Walking speed with cane in obstacles (paces/min)	80	86	72	84	94
Percentage of preferred walking speed with cane	87	83	80	85	85
Number of stops in one minute walk with cane	4	4	4	3	3

Tables A1a-b and A2 in Appendix 2 provide an overview of the number of users, their experience, the type of location and the types of obstacles in these studies. Tables 4a-d provide summaries of the main results for the centre of Florianopolis and Tables 5a and b for the University of Santa Catarina. To improve readability obstacles for which data for only one trial is available have been omitted from tables 4 and 5, but is provided in the appendix.

The organisation of data in tables 4a and b is based on participants and in tables 4c and 4d on obstacles Table 4a provides information on the percentage of successful obstacle detection by the cane for each participant for different obstacles and table 4b the percentage of times the cane made contact with each obstacle.

Table 4a Evaluation in centre of Florianopolis: Individual values for the cane signalling an obstacle

Participant (%)	Bin	Phone box	Bushes	Pole	Narrow pole	Bin & pole	Letter box	Wheeled stall	Stall/ cart	Aver-age	No trials
Participant 1	100	100	100	0		0				75	13
Participant 2	100	100	100	50			75			86	22
Participant 3	80	75	50	50	0				50	60	26
Participant 4	50	75	100	100	25	100		100	50	65	34
Participant 5	100	100	100	50	50		100	100	100	71	17

Table 4a shows that the cane was moderately to very successful at signalling obstacles other than the narrow pole, but that there significant differences in the experiences of the different users with average scores varying from 60% for participant 3 to 86% for participant 2.

Table 4b Evaluation in centre of Florianopolis: Individual values for cane contacts

	Bin	Phone box	Bushes	Pole	Narrow pole	Bin & pole	Letterbox	Wheeled stall	Stall /cart	Average
Participant 1 (%)	0	0	0	100		100				31
Participant 2 (%)	38	0	0	75			75			23
Participant 3 (%)	20	25	50	50	100				50	46
Participant 4 (%)	50	25	0	33	75	0		0	50	32
Participant 5 (%)	0	0	0	50	50		100	100	0	29

From table 4b participants were again moderately to very successful in avoiding cane contacts with obstacles, other than for the narrow pole. However, there was again considerable variation in the contact rates from 23% for participant 2 to 46% for participant 3. In addition, participant 2 had the highest preferred walking speed and participant 3 the lowest. Overall participant 2 had the 'best' performance and participant 3 the 'worst'. While great care should be taken in generalisations from a small number of participants, there do not seem to be any obvious relationships between length of experience of cane use or extent of visual impairment and success in avoiding cane contacts or the cane signalling obstacles. However, even from this small number of participants, it is clear that there are individual factors which affect successful use of the electronic cane and which may include overall mobility skills. Therefore further investigation with a larger number of participants is required to determine both what training or other input users need, as well as what design improvements are required to optimise cane use for all users.

Table 4c Evaluation in centre of Florianopolis: Individual values of average distance for different obstacles

Participant/ cm	Bin	Phone box	Bushes	Pole	Narrow pole	Bin & pole	Letter box	Wheeled stall	Stall/ cart	Average
Participant 1	27	34	43							35
Participant 2	61	60	88	44						64
Participant 3	58	73	119	111					160	105
Participant 4	65	44	25	172	56	20		92		68
Participant 5	46	51	72	46	75				125	70

From table 4c there is again great variation in the average distances at which obstacles were detected with both the type of obstacle and participant. Other than the fact that participant 1 was having to approach obstacles more closely**,** there do not seem to be any particular patterns in the data.

Table 4d Evaluation in centre of Florianopolis: average values of % cane contacts

	Bin	Phone box	Bushes	Pole	Narrow pole	Bin & pole	Letter box	Wheeled stall	Stall/ cart
% cane contacts	28	15	15	44	67	50	80	50	38
% signals obstacle	78	85	85	69	33	50	80	100	63
Av. distance (cm)	56	51	69	100	68	20	n/a	92	143

Tables 4d and A1 show that the cane performed very well in detecting the phone box and bushes over a reasonable number of trials by all participants (85% of 20 and 13 trials respectively) and reasonably well in detecting the waste bin on a post over a large number of attempts (78% of 32 trials), but in the latter case cane contact was only avoided in 72% of cases. Performance was less good for the stall/cart (63% of 8 trials) and the pole (69% of 16 trials) with cane contact only avoided in 56% of cases for the pole. Object detection was poor for the narrow pole (33% of 9 trials). Adding the number of cane contacts and obstacle detections in tables 4a and 4b or 4d gives a result over 100 in some cases. This indicates that, in a small number of cases the cane signalled the presence of an object (waste bin on post, pole and letter box), but the participant did not react in time to prevent the cane contacting the object. From tables 4a and 4b only participant 2 experienced this problem. However, despite this, they had the overall best performance.

Table 5a shows the number of cane contacts and times the cane signalled the object for the obstacles for which more than one trial was carried out.

Table 5a Evaluation at Federal University of Santa Catarina: average values of % cane contacts for selected objects

	Group of trees	Column	Overhang	Overhang	Cycle rack	Tree	Barrier	Sign on pole	Sign on pole
Height			150	170		167	120	167	180
% cane contacts	0	50	50	50	33	0	0	100	100
% signals obstacle	100	50	50	50	67	100	100	0	0
Av. distance (cm)	125	90	145	65	63	56	38		

Table 5b presents average data both overall and for objects at different heights and narrow objects. Overall performance was reasonably good with the cane detecting the object in 60% of 42 trials and making contact in 38% of them, with contact not occurring though the cane did not signal the object in one case. It was slightly better for objects between 1.4 and 1.8 metres with the cane detecting 63% of objects and making contact with 37% of them. It was very poor at only 50% detection for objects between 1 and 1.4 m (8 trials) and below 1 m (4 trials), though in the later case the cane only made contact in 25% of cases.

Table 5b Evaluation at Federal University of Santa Catarina: Average Values

	Overall	Objects over 1.8m	Objects from 1.4 to 1.8m	Objects from 1 to 1.4m	Objects below 1m	Long narrow objects
Number	42	1	27	8	4	2
% cane contacts	38	0	37	50	75	50
% signals obstacle	60	100	63	50	25	50

Performance was excellent for the air conditioner condenser, individual and groups of trees, a bunch of leaves at a height, small truck and large lorry, the motor bike with baggage and the slightly higher barrier (100% detection in 16 trials). Particular problems were experienced with the motor bike without baggage, cleaning cart, lower barrier and signs on a pole at 1.67 and 1.82 m (no detection in 8 trials) It should also be noted that a motor bike without baggage was not detected, but a slightly higher motor bike with baggage was and that a higher barrier was detected, but a slightly lower one was not. Poor performance with only 50% detection occurred for the column and overhanging buildings at various heights (14 trials).

Participant 4 participated in evaluations at both locations. Comparison of the average numbers of cane contacts and obstacle signals in the two locations (tables 4a, 4b and 5) shows that the values are comparable, but slightly better for the busy, noisy location for signalling (65% compared to 60%) and for the quiet location for avoiding cane contacts (34% compared to 38%). It is difficult to draw any conclusions from this due to insufficient data and the fact that there may have been more challenging obstacles in the quiet location.

4.1 Questionnaire

All 18 participants responded to the first three questions on what they liked and did not like and suggested modifications to the electronic cane. Half of them liked the fact that the electronic cane is able to detect obstacles at a height/above the waist and a further 22% its related ability to warn the user of obstacles and avoid danger/increase security. Other features that users liked included its texture, the roller tip and the combination of a sound signal and vibration. 11% of participants stated that there was nothing they disliked about the cane. However, a number of negative features were also mentioned. Those stated by more than one respondent were the inability to use the cane in the rain, problems in distinguishing obstacles in busy areas with a lot of movement, a too loud or attention catching sound and the slow response time of the sensor, which could result in it indicating an obstacle at the same time as the user discovered it. Problems raised by only one person included difficulties in folding the cane, a handle which was too large and too smooth and required excessive force to move, and the cane sliding down when leant against a wall.

Nearly four fifths of participants proposed changes or modifications to the sensor. They included improving sensor responsiveness and speed and its abilities to detect narrow obstacles such as posts and obstacles at leg height/below the waist, distinguish between different types of obstacles and eliminate error. Other suggested changes to the sensor included making it water resistant and changing its range and location. Changes to the physical structure of the cane included a design based on components that could be attached to any cane, a thinner handle, elastic rather than cord, more flexible internal elastic, reduced dimensions, lighter weight, easier to fold and a more compact folded cane. Suggested changes to the user interface included different signals to indicate people and objects, a more discrete, different or louder sound and the ability to modify the melody of the sound and vibration. Finally, there were suggestions of additional functions, such as GPS, and canes of different colours so they could be colour coordinated with the user's clothes.
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Participant satisfaction with various cane features is presented in Tables 6-12. Since data has been rounded to the nearest integer, the figures may not add up to 100%. From table 6 just over three fifths (62%) were satisfied with the cane's weight and ease of folding and just under three quarters (72%) thought it should be foldable. Participants commented that being able to fold the cane easily increased its practicality, as it allowed the cane to be put in a bag, for instance when the participant was accompanied. While most participants were satisfied with the ease of folding, negative comments included the need for greater flexibility and that the handle's thickness made folding more difficult.

Table 6 Cane physical properties

Weight of Cane		Ease of Folding			The Cane should fold		
Heavy	Satisfactory	Yes	No	Unsure	Yes	No	Unsure
39%	61%	61%	39%	0%	72%	28%	0%

Just over and just under three quarters of participants respectively were happy with the volume of the cane sound (78%) and its tone (72%) (table 7). However, 11% commented that they would have preferred only vibration and no sound and 12% that they wanted something quieter and/or more discrete and 6% that they had had a sound damper attached which improved it. 17% commented that the sound was agreeable, 6% that the beep was typical of this type of application, and 6% that they only wanted to be able to increase the volume. Nearly three times as many respondents (17%) considered the cane too loud compared to too quiet (6%). Just under three quarters (72%) wanted the option to change the volume, but only slightly over half (56%) the option to change the tone (table 7). 22% commented on the need to adjust the volume to take account of ambient noise levels and 6% on the need for hard of hearing people to be able to adjust the volume to meet their needs. 12% wanted different sounds like on a mobile phone or to distinguish different types of objects and 6% to adjust the sound according to the user's preferences.

Table 7 Cane audio properties

Volume of Cane			Tone of Cane		Want option to change volume			Want option to change tone		
Easy to hear	Too loud	Too quiet	Unpleasant	Ok	Yes	No	Unsure	Yes	No	Unsure
78%	17%	6%	28%	72%	72%	28%	0%	56%	44%	0%

Just under three quarters (72%) of respondents preferred the existing design with the electronics integrated into the case to the electronics in a small box (28%) and no respondents suggested another design (table 8). Comments in support of this included maintaining the characteristics and aesthetic of the traditional long cane and avoiding the need for additional components. Comments in support of a small box included the fact that it could be transferred to another cane if the original cane was damaged and could protect the electronic components against rain. Over four fifths (83%) found the electronic cane easy to use as a traditional cane and nearly 90% (89%) found the additional functions easy to use (table 8). 28% commented that the electronic cane could be used like a traditional long cane with the advantage of detecting obstacles at a height and 6% that both canes required orientation and mobility techniques. 6% had not used a long cane to any significant extent previously.

Table 8 Design

Electronics			Easy to use as traditional cane			Ease of use of additional functions		
Integrated in cane	Small box	Other	Yes	No	Unsure	Yes	No	Unsure
72%	28%	0%	83%	17%	0%	89%	6%	6%

All respondents (100%) were interested in information about obstacles at head height chest height and two metres distance. However, well under a third (28%) were interested in information about objects at a greater distance, with two thirds not interested and 6% unsure (Table 9).

Table 9 Information about objects required by users

Head Height			Chest Height			2 Metres Away			More than 2 metres away		
Yes	No	Unsure	Yes	No	Unsure	Yes	No	Unsure	Yes	No	Unsure
100%	0%	0%	100%	0%	0%	100%	0%	0%	28	67%	5%

Over four fifths (83%) found it easy to obtain information on high up obstacles using the electronic cane and nearly all respondents (94%) found this information useful (table 10). 11% of respondents commented that the functioning of the cane depended on their speed and it did not work when they walked fast and 6% that in noisy environments they needed to use the vibration, whereas in quieter ones the sound was very helpful. 6% commented that they had not used the electronic cane for long, were still becoming accustomed to it and did not yet find it easy to use. They also walked with care and more slowly than when using the traditional cane. 6% commented they found it difficult to identify when there was an obstacle.

Table 10 Ease of use and usefulness

Easy to get info on high objects			Useful for info on high objects		
Yes	No	Unsure	Yes	No	Unsure
83%	6%	11%	94%	0	6%

Comments about the usefulness of information about high obstacles included to avoid banging their heads, accidents and injuries, most of which occurred due to collisions with high obstacles, to increase feelings of security and avoid users becoming afraid to go out. Figure 5 shows a hazardous situation due to a vehicle parked unexpectedly in the area the participant is crossing.

Figure 5 – A hazardous situation.

All respondents found the electronic cane either very easy (28%) or easy to learn to use (72%) (table 11). The length of time considered necessary for learning to use the electronic cane varied from a day to two months. A third of participants considered one to a few days sufficient, 11% one or two months and 17% a week. 11% considered that a similar amount of time was required as for the traditional long cane. The preferred way of learning (61%) was a course followed by demonstration and practice (39%) (table 11). 17% stressed the importance of training in orientation and mobility.

Other comments included the need for training by a professional, whatever approach was used, and the importance of training, patience and practice, as for any other learning, with more training and concentration required to use the cane in busy environments. Participants also noted the difference in training needs based on existing proficiency in traditional long cane use.

Table 11 Learning to use the electronic cane

Ease of learning to use					Best way to learn		
V. easy	Easy	Moderate	Hard	V. Hard	Demonstration + practice	Course	Other
28%	72%	0%	0%	0%	39%	61%	0%

Three fifths of the respondents were interested in buying the cane either as it was (39%) or with suggested changes (22%) and only 6% had no interest in purchasing it. However, nearly half (44%) did not know or were uncertain what price they would be willing to pay for it. For the remainder prices varied from RS100 to RS 500-1000 (table 12), with one participant commenting 'up to 25% of a normal cane, about RS 200'.

Table 12 Interest in purchase

Interested in buying				Price willing to pay (RS)*							
Yes	Yes with suggested changes	Maybe	No	100	100-200	200	300	300-400	500	500-1000	Do not know
39%	22%	33%	6%	6%	6%	6%	11%	6%	17%	6%	44%

* 1 RS ≈ €0.28

The overwhelming majority of respondents had no experience of other electronic travel aids, though one was on the waiting list for a guide dog. The one respondent who had used a guide dog previously was unable to 'adapt to the guide dog'. Another respondent used a number of different applications, including google maps and a points of interest app.

Under additional comments participants noted the importance of a 'means of secure locomotion, as cities are deficient in this respect', that the device was close to being 'an efficient mobility device for visually impaired people', though it would be necessary to improve sensor responsiveness, as the majority of visually impaired people did not walk slowly enough to use it effectively. Additional suggestions for improving the cane included using a more robust material for the lower part to reduce the possibility of damage in the case of accidents and elastic on the reverse side of the cord to facilitate keeping it closed, a roller tip and a thinner handle.

Half the participants were male and half were female. The only statistically significant difference between their experiences and preferences at the 0.05 level was on ease of folding the cane. 89% of women compared to only 33% of men considered it easy to fold, whereas 11% of women and 67% of men did not (p=0.0498). Half the participants had been to university (either graduate or postgraduate) and half had not (either completed secondary school or lower secondary school). The only statistically significant difference between the two groups was in their satisfaction with the tone of the cane. All of the non-graduates, but only 44% of the graduates found it satisfactory (p=0.029). Two thirds of participants were blind and one third were low vision. The only statistically significant difference between these two groups was in interest in being able to change the tone. 75% of blind participants, but only 17% of low vision participants wanted to be able to do this (p=0.0498). The difference in interest in information on objects at greater than two metres, with 42% of blind people interested in this information and 17% of low vision people possibly wanting it, was approaching statistical significance (p=0.087) and would probably have been significant for a larger sample.

39% of users had one month of experience and 61% 4-6 months. None of the differences between these two groups were statistically significant. The closest to significance was interest in objects at greater than two metres: 57% of less experienced and only 9% of more experienced participants were interested in this information (p=0.076). This would have probably become significant for a larger sample. 44% of participants were aged 24-41 and 56% aged 50-61. None of the differences between these groups were statistically significant or even approaching significance.

5. Discussion

The electronic cane was designed to extend the functionality of the traditional long cane, which detects obstacles on the ground and just above it. Since the detection height depends on the height at which the user holds the cane handle and its angle, so does the height at which obstacles can be detected. For adults between 1.5 and 2.0 metres holding the cane at a angle of 45° this would give detection heights of between 1.80 and 2.20 metres. Such obstacles can be a significant hazard to blind people, as indicated by the fact that the overwhelming majority of questionnaire respondents (89%) had experienced collisions with objects at chest or head height and a third of respondents had experienced frequent collisions. Figure 6 shows one of the participants approaching a phone box, which is one of the most cited causes of collisions.

Figure 6 – User approaches a phone box

The tests also included some objects at lower level, but the main focus was on higher objects. The tests indicated generally good performance in terms of obstacle detection by the cane and avoidance of cane contact for higher obstacles and poorer performance for lower obstacles. However, even in the case of higher obstacles, performance was not perfect and detection of certain types of obstacles was poor. Excellent performance was obtained for individual and groups of trees, including those of slightly lower height, a small and large truck/lorry and a motor bike with baggage. Very good performance was obtained for a phone box and bushes and reasonably good performance for a waste bin on a pole.

However two signs on a pole at head height could not be detected. Signs of this type could easily prove dangerous. One of the recommendations arising out of previous research by the authors was that signs should always have two poles or supports to enable them to be detected by the long cane (Hersh, 2016). Problems were also experienced in detecting overhanging buildings at between chest and head height with part of the building jutting out without any masonry under it. These are a potential hazard since they cannot be detected by the long cane. The reason for the problems in detecting certain types of objects may have been related to their shape, size and/or angle and further investigation will be required. In addition it may be necessary to add to or adjust the positions of the sensors to enable them to detect smaller objects or those at an angle.

As expected, detection was poor for long thin obstacles, such as poles and columns, indicating that objects need to be a certain dimension before being (easily) detected. However, this is unlikely to prove a problem, since in the interests of stability they and other similar obstacles generally either have the same circumference throughout or are slightly larger at the base. This means that they will be detected by the long cane before the user makes contact with them. Again, as expected, detection was poor for low objects, such as tables, bicycles, cycle racks, coolers and carts, since the electronic cane is not designed to detect them. However, slightly unexpectedly, the cane did manage to detect them on some occasions. This does not require further investigation, since the traditional long cane is able to detect this type of object before collisions occur.

Participants' preferred walking speed reduced by 13 to 20% when using the electronic cane in areas with large numbers of obstacles. This was due to the need to pause briefly to mentally process and respond to the signal. Further work will be required to investigate design and training improvements to reduce this reduction in speed. However, it may not be possible to eliminate it totally due to the need for some mental processing. It would also be interesting to compare the reduction in speed to that when using other aids.

5.1 Users' experiences

The results of the questionnaire in section 4 showed that respondents were generally satisfied with the cane's properties, usefulness, ease of use and ease of learning to use it. In particular, there were high satisfaction rates for ease of obtaining information about high objects (83%) and the usefulness of this information (94%). These facts and the fact that the main thing users liked about the cane was the detection of obstacles at a height indicate that the cane functioned as intended and that users appreciated this function. While all users indicated interest in information about objects at head and chest height, there was limited interest in information about objects further than two metres away (28%). However, some of this lack of interest may have resulted from lack of familiarity with devices which provide this information. Users also found both the traditional cane (83%) and additional functions (89%) easy to use.

Although all users found the cane either very easy or easy to learn, the preferred method of learning was a formal course rather than the process they had used of practice after being shown how to use it. Several participants mentioned the importance of orientation and mobility training and the need for electronic cane training by professionals. This raises the issues of the relative advantages and disadvantages of learning to use the electronic cane as the first mobility aid and first learning to use the traditional long cane, and the need for training for orientation and mobility instructors in teaching electronic cane use.

While there was a strong preference (72%) for the existing design, familiarity may have been a contributory factor, since few participants had had experience of other electronic mobility aids. About three quarters of respondents both found the cane volume easy to hear and wanted to be able to change it. Users were generally happy (72%) with the type of sound and only just over half (56%) wanted to be able to modify it. Participants' comments indicate that their greater interest in adjusting the volume may have been due to recognition that the appropriate volume is dependent on ambient sound levels with a need for much high volumes in areas with higher ambient sound levels. However, as long as the tone was audible, users were less concerned about what it sounded like, though some participants suggested providing different sounds to indicate different types of obstacles. In view of this very small minority preference and the additional complexity that would result from an option to adjust the tone, it is probably not worth developing the cane to provide it. However, the fact that a significant minority (28%) found the sound of the cane unpleasant indicates that it would be useful to carry out experiments with different sounds to determine whether a sound can be found which is both more pleasant to listen to and which can be easily distinguished in a variety of ambient sound conditions.

Nearly three quarters of respondents wanted to be able to fold the cane, so this feature should continue as part of the design. The majority (61%) were happy with the cane weight and ease of folding. However, a significant minority (39%) was not satisfied with these factors and there were several comments about reducing the weight and making the cane easier to fold, indicating that design improvements to achieve this should be investigated, while paying attention to cost and other features of the design. In addition, it may be useful to investigate whether there are particular user characteristics which lead to difficulties in folding the cane. From the above discussion an option to adjust the volume of the cane sound should be added and it would be worth investigating whether there is another type of sound users would prefer, as well as the feasibility of reducing the weight and increasing ease of folding.

Finally, respondents showed a significant interest in purchasing the cane, either with (22%) or without (39%) changes and only 6% definitely not wanting to do this. While this is very encouraging and gives added support to the value of developing the cane further, the difference between expressing interest in purchasing a device and actually doing so should be recognised. However, they indicated that they would be willing to pay considerably less for it than a traditional long cane. This may be due to what they could afford and considering the traditional long cane overpriced.

The results indicate the desirability of improving the responsiveness of the sensor with regards to speed and ability to distinguish narrow objects. It would also be useful to modify its position and possibly also add an additional sensor to both improve the detection rate and enable the detection of objects below the waist. It would also be useful to make the cane more waterproof to allow use in the rain. Other modifications that could usefully be investigated include improvements to the folding mechanism and a slight reduction in weight and thickness. However, the cost implications of any changes will need to be considered in order to keep the costs of cane production low while maintaining high quality and functionality. In addition, it is essential that end-users are involved to ensure that the final design does best meet their needs.

6. Conclusions

A detailed evaluation of the electronic long cane has been carried out. This involved end-user tests and a questionnaire. Five end-users with between one and six months experience of using the cane tested it with a variety of different real obstacles in a busy city centre location and one end-user tested it with real obstacles on a university campus. The questionnaire obtained quantitative and qualitative date on user experiences and attitudes to the functioning and various features of the electronic cane, as well as suggestions for improvements. It was completed by 18 end-users with between one month and three years experience of electronic cane use. The main limitation of the study is the small number of participants involved in the tests. However, a larger number of participants completed the questionnaire. This enable statistical significance to be obtained for several of the differences between different groups of participants.

The results indicate that the electronic cane is able to successfully fulfil its intended function of informing users of the presence of obstacles at a height and that this function is of interest to users. The results obtained from the tests of cane performance and the questionnaire were consistent and complemented each other. However, using the electronic cane in an area with a large number of obstacles reduced walking speed by between 13 and 20% and not all users were happy with this. Users had a reasonable degree of satisfaction with cane properties such as its weight, ease of folding and sound, but also suggested a number of modifications. Those worth investigating include improvements to both the sensor and the cane’s physical properties. Sensor improvements include increasing its response speed and detection ability, modifying its location and adding an additional sensor. Improvements to the physical properties include an option for adjusting the sound volume, slightly reduced weight and thickness, improved folding ability and changes to the internal elastic and external cord. However, care will need to be taken to ensure that the modifications do not significantly increase the cost and end-users should be involved at all stages. The extent of user satisfaction and performance of the current prototype and the expressed interest in purchasing the cane, particularly if modifications are made, indicate the value of further developing the electronic cane. The results obtained in this study are compatible with, but considerable more detailed and in depth than the results obtained from a previous descriptive study of an earlier version of the prototype (Silva & Ramirez, 2013).

Unlike most work to date on evaluating electronic travel aids, this evaluation of the electronic cane involved experienced users, real obstacles and outside locations. In addition, performance was tested by repeatedly approaching different obstacles rather than traversing a set course. The results indicate that this approach performed well in allowing both investigation of the cane's performance and areas where modifications and improvements were desirable. The results also indicate the additional information that can be obtained from the use of a questionnaire and that the results of the questionnaire and experimental tests were consistent. However, there could be value in a comparative evaluation using different approaches to investigate their relative advantages and disadvantages and different potential applications. The authors would be interested in applying this approach to the evaluation of the revised prototype of the electronic cane.

As a result of their experiences of testing electronic travel aids and study of the literature the researchers would like to make the recommendations presented below. However, these recommendations do not cover ethical issues related to evaluation and researchers should familiarise themselves with the relevant literature, issues and ethical approval procedures.

General

1. Researchers should pay attention to usability principles, such as awareness of aims and appropriate choices of locations for evaluations.
2. Evaluation should generally involve the collection of both qualitative and quantitative data e.g. quantitative data on participants' mobility performance with the device and qualitative data on participants' attitudes to the device.
3. The use of a two stage process, involving experimental testing and a questionnaire, has a number of advantages, including enabling the collection of both quantitative and qualitative data.
4. Useful equipment includes a tape measure for measuring participants' positions relative to obstacles and a digital recorder for recording participant observations and feedback.

Location for experimental testing

5. There are advantages in the use of real outdoor environments with real obstacles, as discussed in section 3.1.
6. In the case of the evaluation of mobility devices the location should include a variety of different types of obstacles. The types of obstacles chosen should depend on the cane function e.g. only obstacles at a height if the cane is intended to detect high obstacles.
7. Where feasible, the use of several different locations with different characteristics is recommended, to enable evaluation of device performance in different conditions. This could include quiet and noisy locations and/or locations with different types of obstacles.

8. Where feasible, locations which are not familiar to the participants should be chosen. This will avoid the possibility of them using prior location knowledge rather than information obtained from the device being tested.

Procedures for practical evaluation

9. Practical evaluation should involve testing by one user at a time to enable proper observation and safety monitoring.
10. At least three people should carry out the evaluation, two to perform and record observations and one (preferably a trained orientation and mobility professional) to ensure participant safety. Participant safety should be a paramount concern to the extent of cancelling testing with the particular user or the total evaluation if safety cannot be ensured.
11. Where participants do not have sufficient previous experience of device use sufficient time should be allowed for training and familiarisation. This is necessary for participant safety and effective device use during the evaluation. However, particularly in the case of more complex devices, the time demands for participants to learn to use the device sufficiently well may be excessive for an evaluation. This would make the use of experienced participants preferable.

Participants

12. The minimum number of participants for effective evaluation may depend on the stage of device development and the particular features and functions being evaluated. For instance, effective evaluation may be feasible with smaller numbers in the early stages. Larger samples are required when the aims include investigation of the correlation of performance with demographic, environmental and other factors, as this increases the likelihood of statistical significance. We would note that the literature is by no means conclusive and rarely considers the additional difficulties involved in recruiting disabled participants. From our own experiences with similar samples, about 30 participants is generally sufficient to evaluate statistical significance of the results, which does not necessarily mean that statistical significance cannot be obtained with fewer participants. Nielson (1993) considered that four participants could generally find 65% of usability problems. However, the 35% of undetected problems could be important and Nielsen did not specifically consider the potential interactions of usability and accessibility issues for disabled people. In addition, the difficulties in recruiting disabled participants, particularly if there are further constraints e.g. experience of using a particular device, should be noted. End-user testing is essential, even if it sometimes has to be carried out with a less than ideal number of participants.
13. As discussed in section 3.1, there are advantages in using end-users with some experience of device use, including not requiring a device training and familiarisation stage and being able to use their previous experience.
14. While taking account of other constraints, including participant availability, factors, such as age, gender, ethnic origin/cultural background, type/extent and age of onset of impairments, the presence of multiple impairments, education and employment, should be considered in recruiting participants. This will facilitate the detection of a wider range of usability problems and enable the investigation of the preferences of different groups of users.

Measurements

15. The specific measurements required will depend on the type of device being evaluated and the aims of the evaluation.
16. Potentially useful measurements include the following: percentage preferred walking speed with the device; number of contacts or collisions, possibly with the device and with the user's normal mobility aid; the number of times the obstacle was detected by the device; the distance at which the obstacle is detected; the

height of the obstacle; and the width of the obstacle. Percentage preferred walking speed and number of contacts or collisions are frequently measured in device evaluation. Recording of the detection of the obstacles by the device and the distance at which this happens allows investigation of device functioning and user ability to respond to the device. Measuring the device dimensions allows analysis of what types of obstacles the device is able to detect.

17. Where feasible with regard to participants' time availability, measurements should be repeated to check consistency and accuracy.
18. There are advantages in treating each obstacle separately e.g. positioning the participant a certain distance (and angle) from the obstacle and then allowing them to approach it rather than passing obstacles as part of a designated course. This allows detailed investigation of the device's ability to detect that particular obstacle. This can be very useful when the obstacle presents particular difficulties. Specifically, it can allow investigation of approaches at different angles and speeds. It also allows repetition for confirmation and makes it easier to check the distance at which the obstacle was detected.
19. It is useful to prepare tables in advance with the measurements to be made at the top, a column of boxes to write the names of the obstacles down the side, and sufficiently large boxes to write the measurements in the body of the table. This can both save time and improve the accuracy of data recording.

Questionnaire

20. Topics which it may be useful to investigate include the following: subjective experiences of the evaluation; what users like, do not like and would want to change about the device; specific features of the device e.g. design alternatives, what users like and do not like about these features; experiences of using the device and other devices with related functionality; the types of information users are interested in/would like the device to obtain for them; interest in owning/purchasing the device and, if relevant, what users would be willing to pay.

In summary the study reported here has advanced the state of the art in a number of important ways. It has demonstrated the success of an approach to evaluation based on the use of experienced device users with real obstacles in two different outdoor locations. This has the advantages of being close to real life cane use and participants being able to make informed comments and suggestions for improvements as a result of their experiences. This approach also enables investigators to determine the extent to which participants are using the device and how useful they find it. However, the authors would be interested in carrying out a subsequent comparative evaluation using this and more traditional approaches. The study is also important as the first detailed electronic cane evaluation carried out in Brazil. The approach has been applied to the evaluation of a particular cane to demonstrate both its usefulness and the need of modifications to improve its functioning. It also showed the value of the cane to users and that it had become an important mobility aid for them. Finally the study has led to a set of recommendations divided into a number of themes for evaluating electronic travel aids.

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Appendix 1

Section B (translated from the Portuguese original by the first author)

Please answer honestly. We would like to know what you do not like about the electronic cane, as well as what you do like. If you tell us only positive things we will not know what changes we need to make to improve we cane. We also want to know if you do not like the cane.

1. What do you like about the electronic cane?

2. What do you dislike about the electronic cane?

3. Please describe the changes and improvements you think we should make.

4. What do you think of the cane's weight?

5a. How easy is it to fold the cane?
b. Do you think the cane should fold?
c. Please comment on your replies to parts a and b.

6a. Do you consider the sound of cane to be?
Easy to hear
Too loud
Too quiet

b. Do you consider the sound of cane to be?
Too high
Too low
About right

c. Do you want to be able to change the volume?

d. Do you want to be able to change the tone?

e. Please comment on your replies to parts a, b, c and d.

7a. What would you prefer?

The current design with the electronic components for the additional functions integrated into the cane
A small box attached to the cane forthe electronic components for the additional functions
Other

b. Please explain

8a. Is the electronic cane easy to use as a traditional long cane?

b. Do you get all the information from the electronic cane that you get from the long cane?

c. Please comment on your answers to parts a and b.

9a. Do you consider the following information important for mobility?
About objects at head height
About objects at chest height
About objects at a distance of two meters
About objects at a distance of five meters
About objects at a greater distance

b. Please comment on your answers

10a. Have you ever had any collisions at chest or head height?
b. If yes, how often?
c. With what objects?

11a. How easy is it to obtain information about high objects from the electronic cane?

b. How useful is information about high objects?

c. If you think the electronic cane should have additional functions, please describe them.

d. Please comment on your answers to parts a, b and c.

12a. How easy was it to learn to use the electronic cane?

b. How much time do you think is required to learn to use the electronic cane safely and effectively?

c. What do you think would be the best way for a person with good long cane skills to learn to use the electronic cane?
Practice on your own after being shown how to use it
Do a formal training course. Please give details.
Other, give details.

d. Please comment on your answers to parts a, b and c.

13a. In your everyday travel when do you use the electronic cane?

b. In your everyday travel when do you use the standard long cane?

c. Please comment on your replies to parts a and b.

14a. If the price were reasonable would you be interested in buying an electronic cane?
Yes
Yes, if the changes I have suggested are made
Maybe
No

b. What price could you pay for an electronic cane?

c. Please comment on your replies to parts a and b.

15a. Have you used or tried another technological cane?
b. If so, which one?
c. What do you prefer about the electronic cane?
d. What do you prefer about the other technological cane?

16a. Have you used or tried any other travel aid e.g. guide dog, a device mounted on glasses?
b. If so, which one?
c. What do you prefer aboput the electronic cane?
d. What do you prefer about the other travel device?

17. Please provide additional comments and suggestions about the electronic cane.

Appendix 2

Table A1a Evaluation in centre of Florianopolis: individual participants

	Obstacle	Waste bin on post	Waste bin on ground	Phone box	Bushes	Pole	Narrow pole	Waste bin + pole	Letter box	Table	Cooler	Stall on wheels	Stall/cart
Participant 1	Trials	4	0	3	2	3	0	1	0	0	0	0	0
	% Ct	0		0	0	100		100					
	% Sig	100		100	100	0		0					
	Dist cm	38,16, 26, 27		30,34, 37	25, 60								
	Av dist cm	27		34	43								
Participant 2	Trials	5	1	1	2	4	0	0	4	0	0	0	0
	% Ct	0	0	0	0	50			75				
	% Sig	100	100	100	100	50			25				
	Dist cm	25, 50, 60, 100, 70	100	60	46, 130	27, 60			n/a				
	Av dist cm	61	100	60	88	44							
Participant 3	Tries	5	0	4	4	4	1	0	0	4	1		4
	% Ct	20		25	50	50	100			50	0		50
	% Sig	80		75	50	50	0			50	100		50
	Dist cm	73, 53, 52, 53		31, 86, 103	116, 122	130, 92				90, 25	n/a		90, 230
	Av	58		73	119	111				58			160

	dist cm												
Participant 4	Trials	12	0	8	3	3	4	1	0	0	0	1	2
	% Ct	50		12	0	33	75	0				0	50
	% Sig	50		88	100	67	25	100				100	50
	Dist cm	47, 100, 36, 33, 97, 74		47, 60, 50, 29, 39, 30, 56	24, 25,26	240, 103	56	20				92	
	Av dist cm	65		44	25	172	56	20				92	
Participant 5	Trials	3	0	2	2	2	4	0	1	0	0	1	2
	% Ct	0		0	0	50	50		100			100	0
	% Sig	100		100	100	50	50		0			0	100
	Dist cm	53, 42, 44		46, 56,	57, 86	46	86, 63						130, 120
	Av dist cm	46		51	72	46	75						125

Ct = The electronic cane made contact with the obstacle. Sig = The cane feedback to indicate obstacle. Dist = distance (cm)

Table A1a provides data for each participant and each object on the number of trials, percentage of contacts of the cane with an object, percentage of times the cane signalled the object and the individual and average distances from the object. For each object, table A1b presents the percentage of cane contacts and cane signals and the average distance at which the object was detected, as well as the total number of trials over all participants and the number of participants testing the cane with the particular obstacle.

Table A1b Evaluation in centre of Florianopolis: average values

Obstacle	No. tries	No. Participants	% Collisions	% Signals	Av Distance cm	No signals, collison
Waste bin on post	32	5	12	78	56	3, 9%
Waste bin on ground	1	1	0	100	100	0
Phone box	20	5	15	85	51	0
Bushes	13	5	15	85	69	0
Pole	16	5	31	69	100	2, 13%
Narrow pole	9	3	67	33	68	0
Waste bin + pole	2	2	50	50	20	0
Letter box	5	2	80	20	n/a	1, 20%
Table	4	1	50	50	58	0
Cooler	1	1	0	100	n/a	0
Stall on wheels	2	2	50	50	92	1, 50%
Stall/cart	8	3	37	63	143	0

Table A2 is for the evaluation at the second location, the Federal University of Santa Catarina. It shows the number of trials, number of cane contacts and number of times the cane signalled the object and the distance for each object, as well as the total number of trials, percentage of cane contacts and percentage of times the cane signalled the object overall, for objects at different heights and for narrow objects.

Table A2 Evaluation at Federal University of Santa Catarina

Obstacle	Height (cm)	Tries	Contact	Signal	Distances (cm)
Air conditioner condenser		1	0	1	170
Bicycle		1	0	0	
Group of trees		2	0	2	140, 110
Column		2	1	1	90
Overhanging building	150	4	2	2	120, 170
Overhanging building	170	6	3	3	50, 80, 50
Overhanging building	124	2	1	1	110
Cycle rack		3	1	2	100, 40
Motor bike with baggage	140	3	0	3	85, 75, 107
Motor bike	120	1	1	0	
Leaves		1	0	1	110
Tree	167	3	0	3	15, 97
Tree	117	1	0	1	110
Shaped tree		1	0	1	100
Small truck		1	0	1	127
Cleaning cart	113	1	1	0	
Barrier	107	1	1	0	
Barrier	120	2	0	2	46, 30
Sign on pole	167	3	3	0	
Sign on pole	180	2	2	0	
Large lorry		1	0	1	120
Overall		42	40 %	60%	
Objects above 1.8 m		1	0	100%	
Objects between 1.4 & 1.8 m		27	37%	63%	
Objects between 1 and 1.4m		8	50%	50%	
Objects below 1 m		4	75%	25%	
Narrow long objects		2	50%	50%	