A Detachable Electronic Device for Use With a Long White Cane to Assist With Mobility

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Vision-impaired individuals often use a long white cane to assist them with gathering information about their surroundings. However, these aids are generally not used to detect obstacles above knee height. The purpose of this study is to determine whether a low-cost, custom-built electronic device clipped onto a traditional cane can provide adequate vibratory warning to the user of obstacles above knee height. Sixteen normally sighted blindfolded individuals participated in two mobility courses which they navigated using a normal white cane and a white cane with the electronic device attached. Of the 16 participants, 10 hit fewer obstacles, and 12 covered less ground with the cane when the electronic device was attached. Ten participants found navigating with the electronic device easier than just the white cane alone. However, the time taken on the mobility courses, the number of collisions with obstacles, and the area covered by participants using the electronic device were not significantly different ($p > 0.05$). A larger sample size is required to determine if the trends found have real significance.

It is anticipated that additional information provided by this electronic device about the surroundings would allow users to move more confidently within their environment.

**Keywords:** assistive technology, blind navigation, blindness, electronic aids to daily living, mobility

**Introduction**

The World Health Organization estimates that 285 million people worldwide are visually impaired, with 39 million individuals who are blind and 246 million individuals who have low vision (World Health Organization, 2014). This loss of vision restricts individuals’ mobility particularly in outdoor environments (Lamoureux, Hassell, & Keefee, 2004) by decreasing their walking speed and increasing the number of obstacles that they contact (Turano et al., 2004). Many blind individuals use a long white cane to assist them with their mobility. Typically, individuals use a sweeping motion in front of their body to detect ground surfaces and obstacles positioned at the height of the cane tip such as steps, road-side curbs, or fences (Bongers, Schellingerhout, van Grinsven, & Smitsman, 2002). A downfall of the white cane is that obstacle detection is limited by the length of the cane, and it provides minimal feedback about obstacles that are off the ground, such as tree branches or overhanging signs which may be located at arm or head height.

While blind individuals often struggle with orientation as well as mobility, this study focuses on mobility. Mobility is the detection and avoidance of obstacles or path changes in height and material. Orientation is the analysis of position and direction in relation to the environment. Because effective navigation involves both mobility and orientation, the path travelled by the user is useful to analyze as well as how well obstacles are avoided (Giudice & Legge, 2008).

Secondary mobility aids have been developed to enhance the functionality of a white cane. Many of these aids are electronics-based and are either positioned directly onto the cane (Balakrishnan et al., 2008; Kim, Park, Lee, & Ha, 2009; Kim & Cho, 2013), handheld or worn by the user (Bahadir, Koncar, & Kalaoglu, 2012; Bousbia-Salah, Bettayeb, & Larbi, 2011; Kammoun et al., 2012; Palleja, Tresanchez, Teixido, & Palacin, 2010; Pradeep, Medioni, & Weiland, 2010; Praticco, Cera, & Petroni, 2013). These devices are intended to give additional feedback to the user about their surroundings. The feedback generated is conveyed to the user in a variety of forms including tactile (Balakrishnan et al., 2008; Kim & Cho, 2013; Palleja et al., 2010; Pradeep et al., 2010; Praticco et al., 2013), audio (Dunai, Fajarnes, Praderas, Garcia, & Lengua, 2010; Ercoli, Marchioni, & Scalise, 2013; Ifukube, Sasaki, & Peng, 1991), or a combination of both (Kim et al., 2009).

Tactile feedback is considered to be relatively simple and does not interfere with other audio cues that blind individuals use to gain further information about their surroundings. However, the vibrations of an electronic travel aid (ETA) that is positioned on a white cane must not interfere with tactile feedback from the ground, as this is the major function of this mobility aid. Ground surface feedback travelling up the length of the white cane has been found to resonate at frequencies of between

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30–100Hz (Morioka & Maeda, 1998). The vibration of the electronic device can be set to differ in frequency to avoid interfering with this feedback. Signal-processing algorithms have also previously been developed to address the issue by filtering the device feedback from other tactile feedback obtained in their environment (Kim et al., 2009). An alternative approach is to convey this tactile information in a device that is worn by the user. Several groups have adopted this approach with different devices, including clothing items such as belts (Prattico et al., 2013), vests (Bousbia-Salah et al., 2011; Pradeep et al., 2010) and T-shirts (Bahadir et al., 2012). These systems are often more complex than devices attached to a white cane, as they contain multiple locations on the body to generate feedback that needs to be learnt and deciphered by the user. The number of feedback channels mainly ranges between 2 (Bousbia-Salah et al., 2011), 4 (Pradeep et al., 2010; Prattico et al., 2013), and 8 (Bahadir et al., 2012). Currently, the optimal number of feedback channels is unknown, and further investigation surrounding this issue is required.

An alternative feedback system is centered on audio cues. These auditory cues can be similar in approach to tactile feedback in that a single buzzer changes frequency and intensity based on an object’s location (Ercoli et al., 2013). Additionally, the advantage of auditory feedback is that it can provide an avenue for conveying more sophisticated descriptions about obstacles including information about movement (Dunai et al., 2010), color (Kim et al., 2009), or advice of optimal navigation routes when combined with global positioning tracking systems (Kammoun et al., 2012). These types of devices aim to address the main criticism of many of the electronic aids in that most devices are only able to give information about the presence of an obstacle rather than the shape or form of that object (Easton, 1992). Auditory feedback may also have additional health benefits for blind individuals, as different types of audio feedback have been shown to improve posture in blind individuals so that the incidence of falls is reduced (Magalhaes & Kohn, 2011). However, several drawbacks exist for this type of feedback, as these devices may limit individuals from receiving other auditory cues in the environment that are normally relied upon for mobility. Additionally, if the electronic device conveys auditory information in a method other than through headphones, then this might be difficult for individuals to detect in noisy environments, or individuals might be self-conscious of this feedback from the device, particularly in quieter environments.

Kim et al. (2009) used a dual approach by combining tactile and auditory feedback to convey information about obstacles. Tactile feedback conveyed the location of an object and auditory feedback conveyed the color and brightness of an object. Devices which have both tactile and auditory feedback may benefit users and provide flexibility to choose which feedback option to select for a given environment.

Despite the number of ETAs available, user acceptance is low. ETAs are rejected for a variety of reasons: Feedback from the sensor often compromises the natural feedback of the cane or the user’s own senses, many ETAs feed unwanted ambient echoes to the user from walls and ceilings, and the costs of current ETAs range from hundreds to thousands of dollars, which is prohibitively expensive for most blind people to buy on their own budget. The complexity of some of the available ETAs and the limited training available also reduce the uptake of ETAs (Calder, 2009; Giudice & Legge, 2008; Hersh & Johnson, 2008; Kim & Cho, 2013).

This study uses a low-cost, custom-built electronic device that has been developed to attach onto a traditional white cane and provide tactile feedback to the user about objects positioned above knee height. The aim of this study was to examine users on a mobility course to evaluate the performance of the electronic device. The expectation was that this device would be simple to learn to use, would provide adequate feedback of objects without feeding back unwanted ambient echoes, and would not compromise the natural tactile feedback of the cane on the ground.

Materials and Methods

Sixteen normally sighted individuals were blindfolded and participated in two mobility courses which they navigated using a normal white cane and a white cane with the electronic device attached. The hypothesis was that the tactile feedback provided by the sensor would change how participants navigated the area by providing warning of obstacles.

Electronic Device

Because commercial ETAs are often complex and prohibitively expensive for most blind users, as well as the sensory feedback often compromising the natural feedback of the cane, this device has been designed for simplicity and low cost. The device consists of an ultrasonic sensor (MB1200, MaxBotix Inc, Minnesota, USA) that continuously searches for obstacles and, upon detection, provides tactile feedback to the user in the form of a vibration from a vibrating motor (Pico Vibe 307-100, Precision Microdrives Ltd, London, UK), positioned under the palm of the hand. Because ground surface feedback travelling up the length of the white cane resonates at frequencies between 30–100Hz (Morioka & Maeda, 1998; Wong & Zelek, 2006), the vibrating motor had a vibration frequency of 230Hz to make it distinguishably higher than ground feedback. This choice was to ensure that the frequency of the motor did not compromise the cane’s natural feedback.

The MB1200 sensor was chosen because it is low-cost ($40 when bought individually), with a range of 0.2 m to 7.65 m (8 in to 300 in). It is light weight (6.1 g/0.22 oz) and has low power requirements, which is beneficial for a battery operated system. The MB1200 sensor has a resolution of 0.01 m (0.4 in) and a cone-shaped beam pattern, with the same detection pattern vertically as horizontally. The sensor allows for various calibrated beam widths. The device has two scanning ranges to enable faster movement in open spaces but fewer ambient echoes in tighter spaces. For this study, the shorter scanning range was used. This scanning range was from the sensor’s minimum scanning distance of 0.2 m (0.7 ft) to 1 m (3.3 ft) because a larger scanning distance would provide excessive echoes from walls and ceilings, which would detract from the device’s usefulness in object detection. A smaller range would cause the cane to hit a floor-based object before the sensor picked up its presence. At 1 m (3.3 ft) distance, the beamwidth was approximately 1.2 m (3.9 ft).
The sensor was located at the handle of the cane, so a typical cane grip would enable the vertical detection to cover knee to head height. A pulsed vibration occurred when an obstacle was detected within 0.6–1 m (2–3.3 ft) and a constant vibration occurred when an obstacle was detected within 0.2–0.6 m (0.7–2 ft). A flowchart of the decision-making process for detecting obstacles and controlling the vibration feedback is shown in Figure 1.

A custom-built printed circuit board incorporating a microcontroller (PIC18F46J11, Microchip Technology Inc, Arizona, USA) controlled the sensor and motor, and the device was powered by a 9V battery. A case was designed and manufactured to fit onto the handle of a standard long white cane. The lightweight device, shown in Figure 2, weighs 110 g and could be further reduced to 82 g if a 123A non-rechargeable battery replaced the 9V battery.

**Mobility Course**

The course was a straight pathway that was located outdoors in an undercover area. It measured 21.2 m (70 ft) in length and 2 m (6.6 ft) in width. Five obstacles of varying sizes and heights were positioned on the course at 4.2 m (13.8 ft) intervals. The obstacles are listed in Table 1 and were chosen to simulate table tops, signs, posts, or over-hanging tree branches. The test environment simulated the type of environment a vision impaired person is often required to navigate. Of particular interest was the simulated tree branch, because the white cane alone was unable to detect it using a typical swing style. Many simple ETAs provide constant ambient feedback from the walls in a corridor, so the test environment provided information on whether the device would be useful in an indoor setting. Two different courses were arranged for these trials, and each participant trialed both courses to avoid adaptation and learning of the courses. The order in which the courses were used was alternated between each subsequent participant. The location of each of the obstacles on the course is shown in Figure 3.

**Participants and Mobility Sessions**

All experiments were approved and undertaken in accordance with the Flinders University Social and Behavioural Research Ethics Committee. Sixteen normally sighted participants who had normal gait and mobility abilities were used for this study. All participants were required to wear a blindfold while on the mobility courses to simulate blindness.

The mobility sessions required participants to take part in a mobility course using two different methods. One method required the participant to use a standard white cane for navigation through the mobility course, and the other method required the participant to use a standard white cane with the addition of the electronic device. The order that the two methods were undertaken was alternated such that half of the participants...
started with one method and half with the other. Additionally, half of the participants used the first method on the first mobility course, and the other half used this method on the alternate mobility course. Participants were not able to see the mobility course prior to the experiment.

Each participant was given a practice session prior to each method so that they were able to become familiar with the respective mobility aid that they would be using. The practice session involved the participant being shown how to hold the cane, and they were able to navigate in a designated area that was separate from the course for an unlimited amount of time until they were comfortable with commencing the course. There was no criterion-learning measure to ensure participants reached a nominal level of competence before completing the mobility task. However, researchers observed the progress made by participants.

Table 1. Details of the obstacles used on the mobility course.

<table>
<thead>
<tr>
<th>Obstacle</th>
<th>Description</th>
<th>Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair</td>
<td>Standard office chair with fabric seating and wire frame.</td>
<td>Positioned normally on the ground.</td>
</tr>
<tr>
<td>Foam 1</td>
<td>1 m in length and 0.15 m in diameter.</td>
<td>Vertically positioned with one end resting on the ground.</td>
</tr>
<tr>
<td>Foam 2</td>
<td>1 m in length and 0.15 m in diameter.</td>
<td>Horizontally positioned off the ground at 1.3 m and protruding onto the course by 1 m.</td>
</tr>
<tr>
<td>Small box</td>
<td>0.45 m in height, 0.45 m in width, and 0.45 m in depth.</td>
<td>Positioned at ground level.</td>
</tr>
<tr>
<td>Box stand</td>
<td>Stack of cardboard boxes. 1.2 m in height, 0.3 m in width, and 0.2 m in depth.</td>
<td>Positioned at ground level.</td>
</tr>
<tr>
<td>Trolley</td>
<td>0.9 m in height, 1 m in width, and 0.55 m in depth.</td>
<td>Positioned normally on the ground.</td>
</tr>
</tbody>
</table>

Fig. 2. The electronic travel aid.

Fig. 3. Placement of obstacles on the mobility courses. (A) Schematic representation of the location of the five obstacles positioned on course 1 as seen from a top-down view. (B) Actual image of course 1 as seen from the starting position. (C) Schematic representation of the location of the five obstacles positioned on course 2 as seen from a top-down view. Dimensions as depicted in A. (D) Actual image of course 2 as seen from the starting position.
during their practice session and only suggested beginning the course once the participant appeared comfortable using the cane with the grip demonstrated by the researchers. The rotation of the methods and course order for each participant also aided to counter the effects of participants learning the cane technique during the study.

Following the completion of both methods, participants were required to complete a questionnaire about their experience with the mobility aids.

Data Measurement and Analysis

The recorded parameters enabled a comparison of how participants navigated the course with the device versus without the device in order to test the hypothesis that the tactile feedback provided by the sensor would change how participants navigated the area. These parameters included the total time taken for each participant to complete the course, the number of times an obstacle was touched with the white cane, and the number of times a participant touched an obstacle with their body. The way in which participants navigated around each obstacle was observed while they were on the courses. A video was taken of each participant for off-line analysis. The amount of ground covered by the cane during a session was obtained from this off-line analysis by dividing the mobility course into a 7 × 17 grid (0.3 m x 1.2 m [1 ft x 4 ft] grid), and each time a participant was located in a section of this grid, the location was recorded. The total area covered on the mobility course was the addition of all of these positions.

Subjective data was collected via an anonymous questionnaire filled out immediately after participants finished the two obstacle courses. This allowed users to rate the difficulty out of 10 of navigating through the courses with and without the device attached to the cane and how useful they found the device. Participants also commented on whether they felt they were faster or slower when using the device and whether they felt they had touched more obstacles with or without the device attached. This gave some indication of whether a user felt more comfortable in the environment when the device was attached. Participants were also given an opportunity to provide feedback on the device and the experience.

Statistical Analysis

One-way analysis of variance (ANOVA) was used to examine the time taken on the course, the number of times obstacles were hit, and the area covered by the participants when they were using the different mobility aids. For ANOVA, when the assumption of homogeneity was violated, the data underwent a square root transformation. Results are reported as mean ± standard deviation, and a result was considered significant for p < 0.05. The software program SigmaPlot (Systat Software Inc, San Jose, California, USA) was used for all analyses.

Results

Time Taken to Complete the Mobility Courses

A one-way ANOVA found no statistically significant results for the total time taken by participants on the mobility course (F[1,30] = 0.480; p = 0.494). Additionally, the time taken for participants to complete their first or second trial (F[1,30] = 1.230; p = 0.276) or whether they were navigating course 1 or course 2 (F[1,30] = 0.042; p = 0.839) showed no statistically significant results.

Navigating Around Obstacles on the Mobility Courses

Ten out of 16 participants hit fewer obstacles on the mobility courses when using the electronic device, with a decrease of 26.4 ± 16.5% in the number of obstacles hit in a trial. However, this was not found to be statistically significant (ANOVA: F[1,30] = 1.02; p = 0.320).

Six of the 16 participants came in proximity of the foam pole that was positioned horizontally at chest height while using the cane without the electronic device, and these 6 participants all hit the pole with their bodies. Seven of the 16 participants came in range of this foam pole while using the electronic device, and 5 of the 7 participants detected it with the electronic device as noted by participants stopping on the course.

Four of the 5 obstacles on the obstacle course were tall enough to be sensed by the electronic device. In 25% of cases, participants paused as they came into sensor range of one of these obstacles.

Ground Covered With the Electronic Device Attached

Figure 4 shows examples of the paths travelled by three participants in their trials with both of the mobility aids. The average area covered by all participants with both test conditions is shown in Figure 5. Twelve out of 16 participants covered less ground with the cane when the electronic device was attached. This reduction was found to be 8.01 ± 2.0%, but the ANOVA showed no statistical significance (F[1,30] = 1.85; p = 0.184).

Subjective Results

Results showed that 10 participants found it easier to navigate the course with the electronic device attached, 4 participants found it harder, and 2 participants did not notice a difference in how easy the course was to navigate. Similarly, 11 participants found the device useful, 3 did not find it useful, and 2 were undecided.

Seven participants felt that they had navigated the course slower with the device attached, 6 felt they were faster, and 3 felt no difference. Interestingly, even though only 10 participants hit fewer objects when using the device, 14 participants felt that they had hit fewer, and no participants felt that they had hit more objects with the device attached.

Participants commented that they did not feel any difference in the weight of the cane with the device compared to the cane without the device. They also claimed they felt more confident when using the device and did not need to be as careful. However, some participants found it hard to differentiate between the device’s vibrations and the vibrations of the rough surface. The ability to hear the vibration of the motor as well as feel it helped to compensate for this. Two participants felt nervous not knowing the exact direction of the object when the vibrations started at a 1 m (3.3 ft) distance.
Fig. 4. The area covered by three different participants on the mobility course. The course was divided into 119 equal sections arranged in a 7 x 17 grid. The sections where a participant travelled are depicted by gray squares. Obstacle locations are represented by black squares, and white squares represent sections where neither an obstacle nor the participant was located. Trials with the white cane are shown on the left panels of the figure, and trials with the white cane and electronic device are shown on the right panels of the figure. (A) Participant 1 covered a total of 71 m² using the white cane and 52 m² using the electronic device. (B) Participant 2 covered a total of 85 m² using the white cane and 68 m² using the electronic device. (C) Participant 3 covered a total of 80 m² using the white cane and 63 m² using the electronic device.
Fig. 5. The area covered by all participants on the mobility course. Participants covered less area when they used the electronic device with the white cane compared with just the white cane. Asterisk indicates p < 0.05.

Discussion

Performance Measures of an Electronic Secondary Mobility Aid

Results show that this low-cost electronic device that clips onto a traditional cane provides vibratory feedback to warn the user of obstacles above knee height. The study assessed the performance of the electronic device with mobility trials using two common measures of mobility: Speed and obstacle contact. It was found that the time taken for users to complete the mobility course using either a white cane or the white cane with the electronic device was not significantly different. This is consistent with the findings from a previous study that trialed a similar electronic device with 20 individuals who were blind (Kim & Cho, 2013). Their prototype also attached to a white cane but used multiple ultrasonic sensors to provide the vibrotactile feedback at a 2 m (6.6 ft) range.

Kim and Cho (2013) also investigated the collision rate of obstacles using the different navigation aids and found that users had decreased collision rates when they were using their electronic device. This was not found in the present study, possibly due to the differences in trial order of the mobility aids. Kim and Cho (2013) had all participants use the white cane in their first trial and the electronic device in the second trial when participants would have been more familiar with the obstacles on the course, and this may have contributed to the lower collision rates reported. The present study eliminated this effect by alternating this order for each participant and by changing the location of the obstacles in the two mobility trials that each participant was required to undertake.

Another factor that may influence these performance measures are the learning effects from either practice in a certain situation or broad experience with a particular mobility aid. Both Kim and Cho (2013) and the present study only investigated the electronic aid on one occasion. However, a study has shown that practice can influence performance, as it was reported that the time taken for participants to complete a mobility course using an electronic aid decreased with each subsequent trial due to familiarity with the device (Bousbia-Salah et al., 2011). On the other hand, prior experience may not have such an influence on performance. Kim and Cho (2013) used a combination of experienced white cane users and non-white cane users for their trials and found that the only difference that was shown between these groups was that experienced users completed the mobility course quicker. There were no effects on the participant’s obstacle avoidance between the two user groups. This highlights that previous experience with a mobility aid did not have a large impact on the assessment of the functionality of the electronic device.

While no statistical significance can be claimed from the findings, this may be due to small sample size. A larger study would be required to determine whether the observed trends have any significance. More practice, testing with visually impaired participants, or testing with larger numbers of overhanging objects that are hard to detect with a cane alone may lead to more detectable findings.

Twelve out of 16 participants covered less ground with the cane when the electronic device was attached. This suggests that the cane’s natural function was not fully utilized when using the electronic device. This result may show a preference for feedback provided by the electronic device over the cane’s functionality in the peripheral region. As 10 out of 16 participants hit fewer obstacles on the mobility courses when using the electronic device, the results suggest that users received useful feedback from the device without fully utilizing the cane’s natural function.

Because auditory feedback may have additional health benefits for blind individuals such as improving posture to reduce the incidence of falls, the optimal approach is perhaps to use a combination of both tactile and auditory feedback to convey information about obstacles (Magalhaes & Kohn, 2011). In the current study, some individuals reported that it was useful being able to hear the vibration of the motor and thus still gain information from the electronic device by means of audio cues without holding the motor on the handle. This demonstrates that devices which have both tactile and auditory feedback may benefit users, especially if they have the flexibility to choose which feedback option to select for a given environment.

Subjective responses were mostly positive, with participants finding navigation easier, feeling more confident, and perceiving fewer obstacle collisions when using the electronic device. This correlates with a review of mobility devices by Roentgen, Gelderblom, Soede, and deWitte (2009) who found that the majority of studies incorporating user feedback on electronic mobility aids showed that users perceived their travel to be safer, with increased comfort and less stress when using the devices.

Triangulation using multiple sensors, as described in Gearhart, Herold, Self, Birdsong, and Slivovsky (2009), could allow users to receive more detailed information on the direction
of the detected object, which some users felt would be useful. However, this would increase the cost of the device and would take longer to learn, defeating the primary aims of this ETA.

Conclusion

Overall, the low-cost electronic device was able to convey information to the user about their surroundings to assist with effective navigation through a mobility course. As hypothesized, the tactile feedback provided by the sensor changed how participants navigated the area. The majority of participants hit fewer obstacles and covered less distance with the cane when the electronic device was attached, often pausing before the cane made contact with an object on the course. Many participants found navigating with the electronic device easier than with the white cane alone. A further study could analyze whether visually impaired participants show similar responses to the device. It is anticipated that with daily use, the combination of the long white cane with the electronic device would offer blind individuals an additional mobility aid so that they are able to move more confidently in their surroundings.

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