Obstacle Identification and Avoidance Using the 'EyeCane'

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Abstract. One of the main challenges facing the blind and visually impaired is independent mobility without being obtrusive to their environment. We developed a tactile low-cost finger-size sensory substitution device, the EyeCane, to aid the Blind in obstacle identification and avoidance in an unobtrusive manner. A simplified version of the EyeCane was tested on 6 sighted blindfolded participants who were naïve to the device. After a short (2-3 minutes) training period they were asked to identify and avoid knee-to-waist-high (Side) and sidewalk-height (Floor) obstacles using the EyeCane. Avoidance included walking around or stepping over the obstacles. We show that in the fifth trial, participants correctly identified 87±13.6% (mean ± SD) and correctly avoided 63±15% of the side obstacles compared to 14% in the control condition (p<4E-10 and p<1.1E-05 respectively). For Floor obstacles, participants correctly identified 79±18.8% and correctly avoided 41±%37.6 compared to the control's10% (p<0.002 and p<0.06 respectively).

Keywords: sensory substitution · obstacle avoidance · mobility · Blind · assistive technology

1 Introduction

Mobility is crucial in numerous everyday situations. As vision is a leading factor in facilitating this ability the Blind and visually impaired are disadvantaged in this respect.

The most common means adopted by the Blind to overcome this problem is the white-cane, which significantly increases the mobility skills of this population. However this device is not used by many of the Blind, and especially not by the visually impaired [1,2,3]. One of the main reasons for this is the inherent obtrusiveness of the white-cane which by definition will often come into contact with people or fragile objects in the users' vicinity, especially in cluttered environments.

One approach for avoiding this inherent obtrusiveness would be a mobility aid which replaced the physical cane with a sensor beam. Several devices have been developed in an attempt to implement this approach (for some examples see [4,5], for review see [6,7]) but so far have not been adopted by the Blind community. While the reasons for this are not fully clear, common reasons cited include availability, cost, weight, reliability, complexity and length of required training and problems with the information received about the environments such as over estimating the location and size of obstacles [7].

We developed the EyeCane (see also [8]) in an attempt to deal with these issues. The EyeCane transforms information about the distance from objects through haptic cues, such that the closer the user is to an object the stronger the vibration. The EyeCane is light-weighted, finger-sized and low-cost. It has a very quick learning curve (can be used successfully after several minutes), and uses a narrow-beam approach to provide the user with accurate information about his environment.

In this study we begin testing the functionality of the EyeCane in identification and avoidance of different types of obstacles in an unobtrusive manner while navigating a cluttered environment.

2 Methods

2.1 Equipment

We developed the "EyeCane" which translates point-distance information into tactile cues. The device provides the user with distance information for detecting nearby ground level obstacles (0 - 1m).

The distance is detected via a narrow infra-red (IR) beam (<5°) in the direction at which the device is pointed. This sensor (GP2Y0A02YK0F) was tested on different surfaces and in various lighting conditions. It was found that the sensor works also with transparent obstacles, such as glass, with decreased accuracy [9]. The signal modifies the baseline voltage in the electrical circuit, translating the distance from the detected object into a DC voltage signal. This DC-voltage signal is translated in real-time (>50Hz) into vibration amplitudes and frequencies enabling instantaneous feedback to the user such that the closer an object is to the user the stronger and higher the frequency of vibration (fig 1).

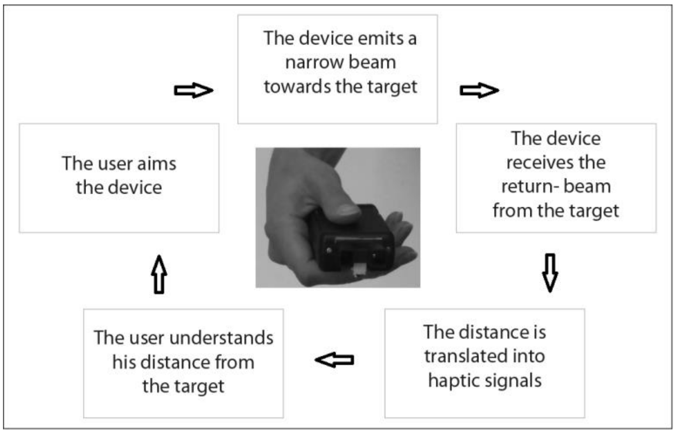

Fig. 1. Device function diagram

2.2 Participants

A total of 6 blindfolded sighted individuals participated (4 female, age 24± 2.13 years (mean ± SD)) in this experiment. All participants were naïve to the device.

2.3 Ethics

The experiment was approved by the ethical committee of the Hebrew university. All participants signed their informed consent.

2.4 Stimuli

The experiment included 14 obstacles in different heights. For 10 of the obstacles, cardboard boxes of knee-to-waist-high (5- 1m high, 2- 0.8 and 3- 0.45m) where used. The additional 4 obstacles where cut out of cardboard in the height of 0.2m, similar to that of a sidewalk.

2.5 Procedure

This experiment included three parts; training and two tests. In both tests the participants needed to detect obstacles and to avoid them. The tests varied in the avoidance method they required of the participants; walking around the obstacle, or stepping over it. In both tests, the participants did not know the number of obstacles, but were told which avoidance method would be required.

In both tests the participants were asked to state when they detected an obstacle and only then try to avoid it. Additionally, they were requested to focus on completing the test as accurately (noticing as many obstacles as they could without touching them or any walls) as possible. Location of obstacles varied between trials and participants.

Each test included 5 trials with the device and as a control, an additional trial without it. This paradigm was chosen over that of direct comparison to a white-cane, as a control, because by definition, identification with the white-cane is achieved through its collision with the obstacles so that the user can then avoid them, and indeed due to the size of obstacles and corridor such contact with both obstacles and walls would be unavoidable. This defines early unobtrusive identification and full avoidance with the white-cane as 0%**,** rendering such a control irrelevant**.**

Training. Participants received a basic explanation about how the device works and how to use it. They then walked towards and away from a wall, while pointing the device at it, to get a feeling of how the different distances are translated into vibration frequencies. They also identified the location of objects that were brought nearer to them in their vicinity while they remained stationary. Training duration was 2-3 minutes.

Test 1. The participants needed to walk down a straight corridor while walking around 10 knee-to-waist-high obstacles on their right and left (fig 2.a). This corridor has large windows, thus lighting it up with sunlight.

Test 2. Participants were required to walk down the same straight corridor while stepping over 4 obstacles in the height of the sidewalk (fig 2.b).

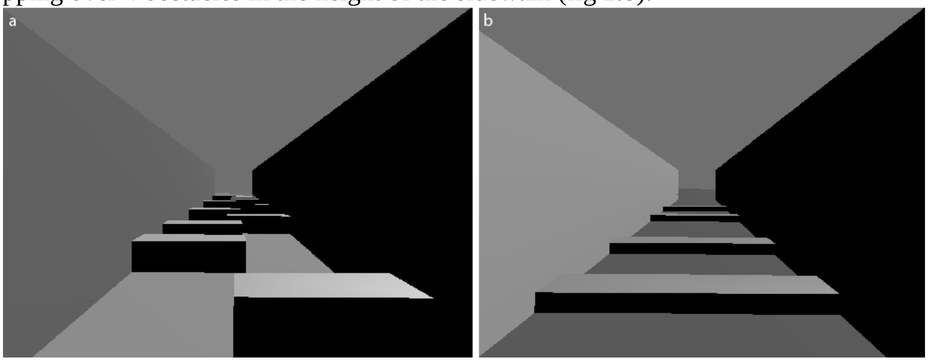

Fig. 2. Virtual recreation of the experimental setup for illustration: a. Corridor with knee-to-waist-high obstacles. b. Corridor with obstacles in the height of the sidewalk

2.6 Scoring

The avoidance score, for both tests and controls, was defined by the number of obstacles the participant did not collide with. Identification was considered successful if the participants both discerned the presence of an obstacle before attempting to avoid collision and also whenever they actually avoided it.

In the control trial, only collision or avoidance played a meaningful part in the assessment of participants' success, as they have no way of detecting the obstacles without collision. Due to technical reasons, one participant did not participate in a control trial.

3 Results

All participants were able to successfully navigate to the end of the corridor in all of the trials in both tests.

Scores are given in the format of "mean%±SD% (worst-best/total)". For each test we added details about the actual range of obstacles that the participants avoided or identified. e.g., the notation (3-8/10) indicates that the participant with lowest success identified/avoided 3 obstacles, and the participant with the highest success identified/avoided 8 obstacles out of 10.

3.1 *Test 1*.

In the control experiment participants reached an average success rate of 14% (0-3/10).

Participants performed in a highly significant level above control already from the first trial (two-tailed T-test, Identification: $p<3.1E-07$, Avoidance: $p<2.7E-05$) with an average correct identification of 68±21.3% (3-9/10) and avoidance of 53±19.6% (2-7/10). This improved even further in their final trial when they identified 87±13.6% (7-10/10) and avoided 63±15% (4-8/10) of the obstacles in a highly significant manner (two-tailed T-test, Identification: $p<4E-10$, Avoidance: $p<1.1E-05$) (figure 3.a).

When comparing the obstacle identification results of the participants' 1st and 5th trials, a highly significant improvement was found (two-tailed paired T-test, $p<1.2E-2$) from 68±21.3% (3-9/10) to 87±13.6% (7-10/10). Looking at the scores for proper obstacle avoidance a non-statistically-significant improvement of 10% was found (two-tailed paired T-test, $p=0.23$) from 53±19.6% (2-7/10) to 63±15% (4-8/10) (figure 3.a).

3.2 *Test 2*.

In the control experiment participants reached an average success rate of only 10% (0-1/4).

Already at their first attempt subject's ability to correctly identify obstacles (29±36.7% (0-3/4)) was higher with the device than without it (two-tailed T-test, $p=0.03$), but at their last trial (79±18.8% (2-4/4)) they improved to a significantly higher level (two-tailed T-test, $p<0.002$) than that of control (figure 3.b). Avoiding the obstacles proved far more difficult to all participants. In the first trial, participants avoided only 8±20.4% (0-2/4) of the obstacles. By the fifth trial, this improved to 41±37.6% (1-4/4), but still was not significantly higher than that achieved by the control ($p=0.05$) due to large variability between participants.

When comparing the obstacle identification results of the participants’ 1st and 5th trials, a highly significant improvement was found (two-tailed paired T-test, $p<0.007$). Looking at the scores for proper obstacle avoidance a similar, though smaller and not statistically significant, improvement (two-tailed paired T-test, p<0.07) was found (figure 3.b).

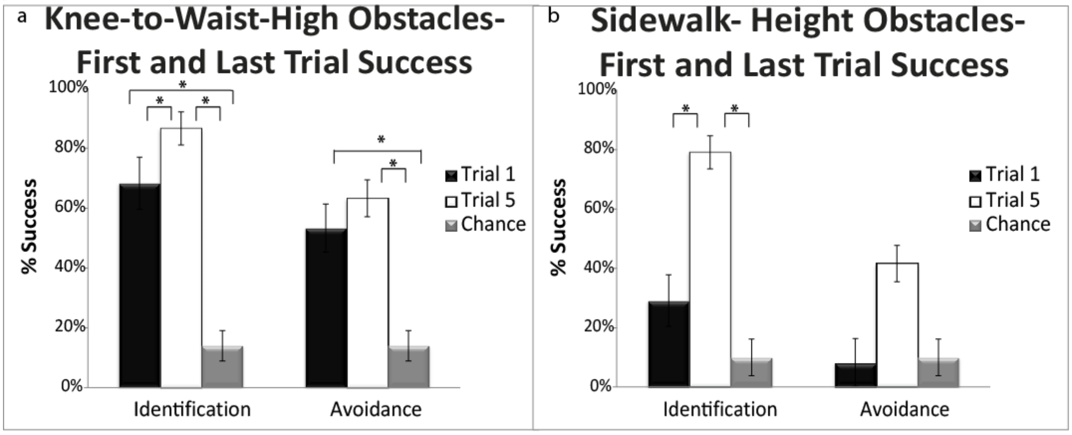

Fig. 3. Results. a: participants success in the first and last trial of test 1 compared to control. b: participants success in the first and second trial of test 2 compared to control.

4 Discussion

We presented the "EyeCane" and showed that it can be used successfully for detecting and avoiding obstacles in an unobtrusive manner and with very short training. For the first test, where obstacles were knee-to-waist-high, participants succeeded in noticing and avoiding them after less than five minutes of practice. In the second test, in which obstacles where lower, participants needed more experience (e.g. the earlier trials in the test were not as good as subsequent ones) to achieve better scores than control in detection. Also, avoidance of obstacles was harder in the second task because, in addition to finding the obstacle, participants also needed to perceive its distance from their foot in order to be able to step over it. This required the users to not only observe the location of an obstacle but to learn to sense its actual distance. The major advantage of the EyeCane over the commonly-used white-cane is in its feature of unobtrusiveness. This benefit comes at the "cost" of a decreased sense of security reached when using a device that is stable, independent of battery power and provides information about the different contours of the walking surfaces such as the white-cane[10,11]. Thus, for many users the EyeCane might mainly be useful in specific scenarios such as cluttered environments while using the traditional white-cane in others according to the tool that fits his or her needs in different circumstances.

The EyeCane uses a focused-beam. This approach differs conceptually from most previous assistive devices which use wide-beam sensors, for example, the Sonic Pathfinder [4] and the UltraCane [5]. Wide beams are easy to use passively, but come at the cost of a reduced accuracy which leads mainly to many false positives (i.e. identifying a door as an obstacle due to detection of its sides). Our approach adopts an active sensing "spotlight" method for obstacle detection and forces the user to constantly scan his environment, but in return allows him to locate obstacles with greater accuracy and gain more information about them. This choice was made following many accumulating results in recent years emphasizing the importance of active sensing for perceiving one's environment and the objects within it [12,13,14]. As part of this approach the EyeCane was also optimized for speedy accuracy (refresh rate of >50Hz) and decreased size and weight to facilitate easy scanning [15].

Chebat and colleges confronted obstacle avoidance with the use of a sensory substitution device called the Tongue Display Unit (TDU)[16] and found that the Blind's performance exceeded that of sighted participants. This finding leads us to believe that blind participants will succeed in this task using the EyeCane, a hypothesis which will be tested in the next stage of this research. Our results here are in compliance with their findings that step-over obstacles were harder to avoid.

An alternative explanation for the increase in success rates as trials advances is due to the fixed size of the step-over obstacles and the motor learning of the proper step to take. Based on our empirical observation of the experiment we do not believe this to be the case, and feel that the difficulty was centered in perceiving its location and not its size. Furthermore, we believe that with additional training success in this avoidance task will continue to improve and exceed control in a significant manner, both in this specific task and also with varying sizes of floor obstacles.

5 Conclusions

The EyeCane device was found to be helpful in identifying and avoiding obstacles in a discrete and unobtrusive manner after a very short training. This device has the potential to aid the Blind in numerous everyday circumstances and thereby become a useful tool in the assistive devices toolbox available for them.

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