
Vision-deprived Virtual Navigation Patterns Using Depth Cues & the Effect of Extended Sensory Range

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Abstract

How does the lack of vision affect one's path through real & virtual environments? How do these routes change when different assistive tools, such as the traditional White-Cane or new devices such as the EyeCane, are used? These questions have significant repercussions as independent Mobility poses one of the main challenges facing the blind. Here, we use a series of virtual environments and non-visual interfaces to comparatively explore the differences in intuitive navigation: when using the virtual-EyeCane, when using a virtual White-Cane, when navigating without using a device at all and finally when navigating visually. We show that using the virtual-EyeCane as a non-visual interface to virtual environments increases their accessibility, that characteristics of navigating with it are different from those of White-Cane users and from those of navigation without an assistive device, and that users of the virtual-EyeCane complete more levels successfully, taking a shorter path and with less collisions than users of the white cane or no device. Finally, we demonstrate that navigation with the virtual-EyeCane takes on patterns relatively similar to those of navigating visually.

Author Keywords

Universal access; blind; Virtual reality; navigation;

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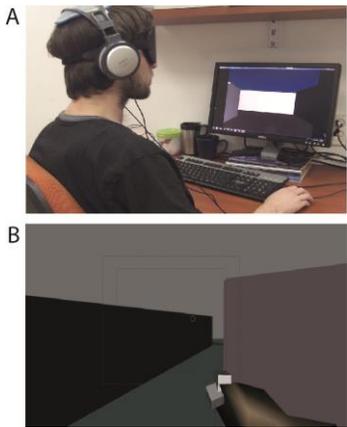


Figure 1. The experimental setup. (A) Demonstrates the equipment used. (B) 1st person view of the virtual avatar using the virtual-EyeCane.

ACM Classification Keywords

H.1.2 User/Machine Systems; H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.2 User Interfaces: Auditory (non-speech) feedback;

Introduction

How does the lack of vision affect the route one takes through real and virtual environments? How do these routes change when different assistive tools are used? And finally, can we use this information to predict paths in new environments?

The challenges involved in independent mobility in unfamiliar environments pose some of the greatest barriers facing the blind and visually impaired [1, 3, 10]. This is true even when using traditional aids such as the White-Cane, leading to a need for both new devices and new mobility strategies.

Unlike visual navigation, navigating without vision is mainly limited to using information from the immediate surroundings. When using a White-Cane the user's reach is extended but is still severely limited (~1.2m). Dedicated Mobility programs have been designed to help the blind navigate using this limited information, and they have been shown to indeed increase mobility skills [4].

One of the main tools for researching these mobility patterns has been the use of virtual environments for simulating and tracking the users' movement [6]. Such virtual environments require non-visual interfaces, usually based on the White-Cane. The development of these interfaces is a worthy goal in and of itself – if such a non-visual interface proves simple and generic

to implement and use, then it would **improve the accessibility of virtual worlds in general to blind and visually impaired users**. These environments are becoming an increasingly important part of our everyday lives, and while many recent projects have increased aspects of their accessibility [9, 11, 12] they are still far from accessible.

While there are many differences between navigating virtually and in the real world, virtual environments offer us access to the general characteristics of navigation, more control over parameters and more varied and complex environments. Additionally, as it is well established that spatial information can be transferred between virtual and real-world environments both for the general population [2, 13] and for the blind [5], these same environments also hold a great rehabilitation potential.

Previous research focused on mobility skills and accessibility without a device and with the White-Cane, but how are they affected by an increase in the device's range? Would such an increase be ignored by the users, or would it make their path more similar to that of a sighted person? Would the use of a device with an increased range require a different rehabilitation paradigm, and if so could this have been one of the factors limiting the adoption of such devices by the blind community? Can we learn enough from these patterns to predict paths in new environments?

To explore these questions we used a virtual version of the EyeCane, an electronic travel aid for the blind recently developed in our lab which offers the user distance information (<5m) of a single pixel using simple auditory cues (See methods).

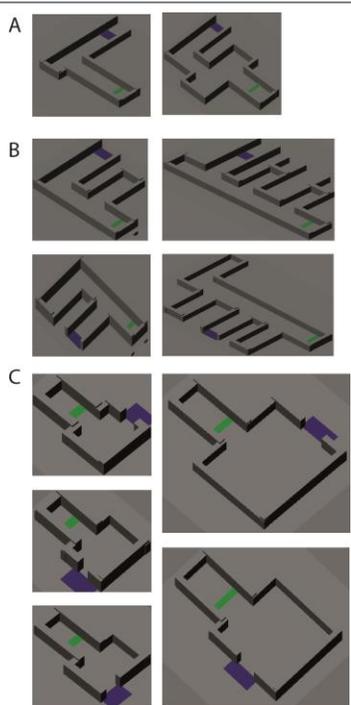


Figure 2. 3rd person view of the virtual environments (A) Training (B) Corridors (C) Rooms. Users navigated from the green starting line to the blue endplate.

Here, we comparatively explore with blindfolded sighted participants the differences in initial intuitive navigation in virtual environments when using different non-visual interfaces: when using the virtual-EyeCane, when using a virtual version of the White-Cane, when navigating without using a device at all and when navigating visually. This exploration takes place in a series of virtual levels including corridors and rooms.

Methods

The EyeCane & virtual-EyeCane

The EyeCane, recently developed in our lab, augments the White-Cane with additional range (up to 5m, collected using narrow-beamed IR), by transforming distance information from a single pixel into auditory cues such that the closer the object the higher the frequency of cues. We have previously shown that it can be used for tasks such as distance estimation, indoor navigation and obstacle avoidance. We then created a virtual version of this device and shown that it can be used for virtual indoor navigation [8], as well as other tasks such as virtual shape recognition [7]. See figure1 for illustration of its use.

Experimental design:

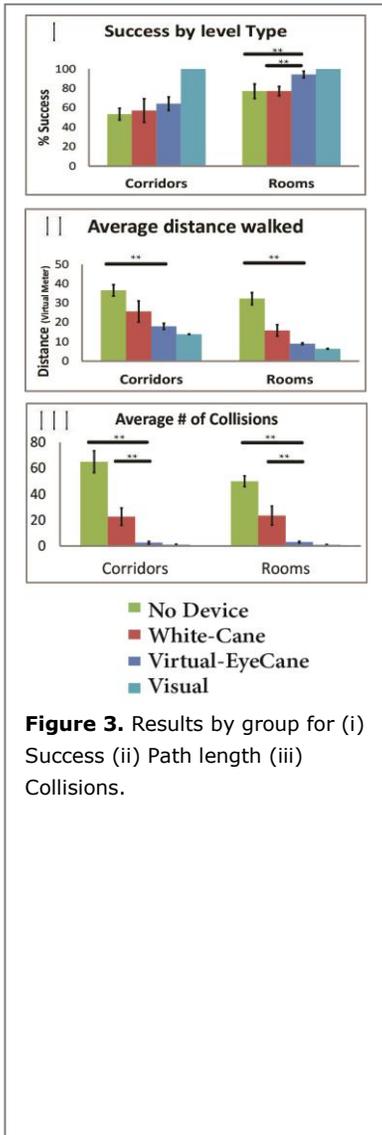
The experiment consisted of 11 different virtual environments (see figure 2), of which the first 2 were training corridors, 4 were splitting corridors (task 1, **Corridors**) and 5 were rooms (task 2, **Rooms**). All participants performed these levels in the same order. In the corridor trials of task 1, participants were given a specific instruction to the goal before starting each trial (for example: “turn left at the 3rd corridor”) and they had to get there by following the instruction. In the Room trials of task 2, participants had to find the exit from the room and navigate out of it.

We automatically measured three parameters for each experiment. **Success** was determined by successfully completing the level within the predefined time frame of 3.5 minutes, **Distance** was measured by the length of the path the participants took in the virtual environments, and **Collisions** were measured by the number of collisions of the participant’s avatar with the walls. It is important to note that we considered any contact the avatar had with the walls as a collision, as these contacts are obtrusive and form one of the main problems the blind have when navigating indoors in the real world (for example, running their hand along a desk and knocking over a cup of coffee or running their hand into a sharp object). Additionally, we recorded participant’s full path through the virtual environment.

The participants were divided into 4 groups, each using a different device. Group 1, VEC, used the virtual-EyeCane. Group 2, WC, used a virtual representation of the traditional White-Cane. Group 3, NoDev, did not use any device and relied solely upon the sound of collisions of the avatar with the virtual walls. Group 4, Visual, performed the task visually. The participants of groups 1-3 were blindfolded throughout the experiment.

Participants

28 sighted participants for both tasks (16 male, aged 27.9 ± 6.7 , 25 right-handed), divided into 4 groups of 7 each. The experiment was approved by the Hebrew University’s ethics committee, and all participants signed informed consent forms.



Results

Corridors task:

Success: Group 1, VEC, succeeded in $64.2 \pm 6.8\%$ of the levels. Group 2, WC, succeeded in $57.1 \pm 12\%$ of the levels. Group 3, NoDev, succeeded in $53.5 \pm 6\%$ of the levels. Group 4, Visual, had a full success rate of 100% (see figure 3i). The results for the VEC group were better than the results of the WC & NoDev groups, but not in a significant fashion.

Distance: Group 1, VEC, averaged a path length of $17.9 \pm 1.5\text{m}$. Group 2, WC, averaged a path length of $25.6 \pm 5.4\text{m}$. Group 3, NoDev, averaged a path length of $36.5 \pm 2.9\text{m}$. Group 4, Visual, averaged a path length of $13.9 \pm 0.1\text{m}$ (see figure 3ii). The results for the VEC group were better than the results of the WC but not in a significant fashion and significantly better than those of the NoDev ($p < 2.3 \times 10^{-4}$) group.

Collisions: Group 1, VEC, averaged 2.5 ± 1 collisions. Group 2, WC, averaged 22.6 ± 6.5 collisions. Group 3, NoDev, averaged 65 ± 8.4 collisions. Group 4, Visual, averaged 1 ± 0.3 collisions (see figure 3ii). The results of the VEC group were significantly better than those of the WC ($p < 1.7 \times 10^{-2}$) & NoDev ($p < 1.9 \times 10^{-5}$) groups.

Common strategies observed in these levels:

Group 1, VEC, tended to walk in straight lines forward with frequent stops for scanning. This group spent a lot of their time scanning when locating a junction, but usually did not enter them until the correct one. Most collisions occurred when attempting to turn into the final corridors. Participants of group 2, WC, tended to first head for one of the walls, and then walk very close to them, with frequent scans. As in Group 1 members of this group spent a lot of their time scanning at

junctions to be sure where the junction started and ended, and usually did not enter these corridors. The participants in group 3 tended to walk near the wall, frequently colliding with it, which they reported was aimed at making sure it was there and locating doors in it. Participants in this group often accidentally entered the turnoff corridors, and tended to have a much weaker perception of their general surroundings. Participants of group 4 tended to walk in lines that were less straight than those of other groups, and typically proceeded directly to the final corridor and turned there without delays along the way (Figure 4).

Rooms task:

Success: Group 1, VEC, succeeded in $94.2 \pm 3.4\%$ of the levels. Group 2, WC, succeeded in $77.1 \pm 4.8\%$ of the levels. Group 3, NoDev, succeeded in $77.1 \pm 7.4\%$ of the levels. Group 4, Visual, had a full success rate of 100% (see figure 3i). The results for the VEC group were significantly better than the results of the WC ($p < 9.9 \times 10^{-3}$) & NoDev ($p < 3.8 \times 10^{-2}$) groups.

Distance: Group 1, VEC, averaged a path length of $9 \pm 0.4\text{m}$. Group 2, WC, averaged a path length of $15.8 \pm 2.9\text{m}$. Group 3, NoDev, averaged a path length of $32.3 \pm 3.1\text{m}$. Group 4, Visual, averaged a path length of $6.3 \pm 0.1\text{m}$ (see figure 3ii). The results for the VEC group were better than the results of the WC but not in a significant fashion ($p = 0.05$) and significantly better than those of the NoDev ($p < 1.7 \times 10^{-5}$) group.

Collisions: Group 1, VEC, averaged 2.9 ± 0.5 collisions. Group 2, WC, averaged 23.4 ± 7.3 collisions. Group 3, NoDev, averaged 49.9 ± 4.1 collisions. Group 4, Visual, averaged 0.8 ± 0.1 collisions (see figure 3iii). The results

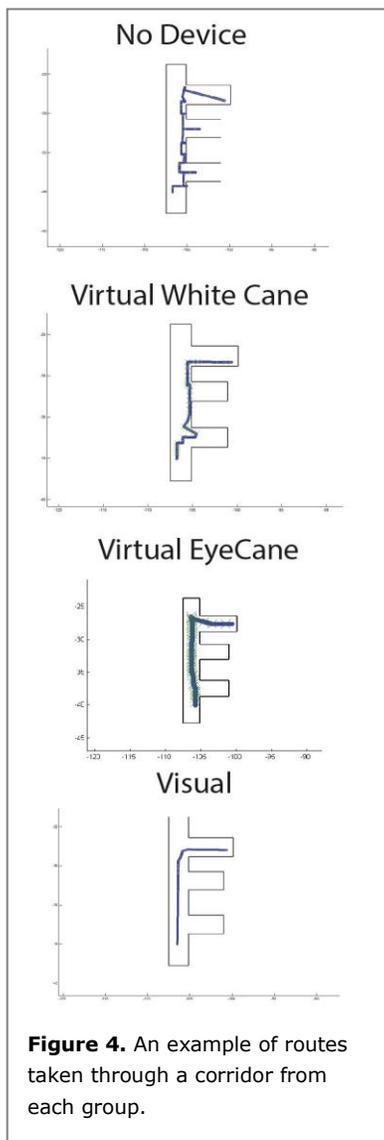


Figure 4. An example of routes taken through a corridor from each group.

for the VEC group were significantly better than those of the WC ($p < 2.4e-2$) & NoDev ($p < 2.3e-7$) groups.

Common strategies observed in these levels:

Group 1, VEC, tended to walk in a straight line forward with frequent stops for scanning, until locating a door, and then turning towards it. Participants of group 2, WC, tended to first head for one of the walls, and then walk very close to it, with frequent scans. The participants in group 3 tended to walk near the wall, frequently colliding with, which they reported was done to make sure it was there and locate doors in it. Participants of group 4 tended to walk into the room and then head directly to the exit (Figure 5).

Discussion

The initial results shown here suggest that the EyeCane is indeed successful as a non-visual interface in increasing the accessibility of virtual environments. Additionally, they suggest that the characteristics of navigating with the EyeCane are different from those of white cane users and of navigation without an assistive device, and that users of the virtual-EyeCane complete more levels successfully, taking a shorter path and with less collisions than users of the white cane or no device. Finally, they demonstrate that navigation with the virtual-EyeCane takes on patterns relatively similar to those of navigating visually.

In progress...

These interim results are a first step towards answering the questions we raised in the introduction, but there is still a long way to go. This includes (1) running this experiment on a **larger number of participants**, and with more complex virtual environments. (2) **blind participants**, to explore questions such as whether the

differences in patterns of navigation between sighted and blind without a device or using traditional aids, reflect an inherent internal difference, or simply a lack of data availability beyond the reach of the blind? (3) As moving through an environment is usually linked to a purpose, more **complex & realistic scenarios** and goals are required for evaluating movement patterns (4) Finally, our main goal is to computationally extract from these navigation patterns information which will enable us to predict the likely paths of a non-visual navigator through an unfamiliar environment, in order to optimize mobility training and as an architectural accessibility analysis tool.

Implications for the CHI community

The interim-results offer another incremental step in increasing the accessibility of virtual environments, and a general addition to the non-visual interface toolbox. The difference in navigation patterns reported here has implications for the use of other non-visual accessibility tools as well, as it shows that skills learned in traditional mobility programs using the White-Cane might lead to sub-optimal use, and that there is a need to create different training for these navigational aids. Finally, if we indeed succeed in extracting from these patterns predictions for potential non-visual paths through environments using different aids, including the traditional white-cane, it will potentially prove a powerful tool for increasing accessibility both virtually and in real world architecture.

Recommendations for incorporation into practice

Our results suggest the virtual-EyeCane might prove useful as an additional accessibility interface for navigation in virtual environments. As the use of the virtual EyeCane does not require any special hardware,

