Virtual 3D shape and orientation discrimination using point distance information

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ABSTRACT

Distance information is critical to our understanding of our surrounding environment, especially in virtual reality settings. Unfortunately, as we gage distance mainly visually, the blind are prevented from properly utilizing this parameter to formulate 3D cognitive maps and cognitive imagery of their surroundings. We show qualitatively that with no training it is possible for blind and blindfolded subjects to easily learn a simple transformation between virtual distance and sound, based on the concept of a virtual guide cane (paralleling in a virtual environment the "EyeCane", developed in our lab), enabling the discrimination of virtual 3D orientation and shapes using a standard mouse and audio-system.

1. INTRODUCTION

Understanding the distance between ourselves and the objects surrounding us is fundamental to our perception of our environment. It helps us locate objects, estimate their sizes, recognize them and the spatial relation between them, manipulate them and navigate to and between them. Our perception of these distances relies heavily on visual information (as can attest anyone who ever tried to find something in a dark room).

This reliance on visual information is exacerbated in virtual environments, which are becoming an increasingly larger part of our lives in fields ranging from education through navigation to games. While computer screens are flat 2D surfaces, the information conveyed within them often includes depth information, known as 2.5D. This feeling of depth is accomplished using a series of graphical visual cues, such as shading, which our visual system interprets as depth. As this information is visual, it is completely inaccessible to the blind, and usually very difficult for the visually impaired to interact with as well.

Enabling the blind to quickly and easily assess distance to virtual objects is especially important as virtual environments hold great potential for the blind, such as allowing them to safely pre-learn novel real environments before visiting them, when currently they are restricted to routes trained explicitly on a one-on-one basis with an instructor, limiting independence in every-day lives.

While many attempts have been made to create dedicated virtual environments for the blind, these environments suffer from two major problems. First, they rely on either a 3rd person map-like view from above (Feintuch 2006), or on simulating the white-cane within the environment (Lahav 2009), instead of allowing a more realistic egocentric 1st person or close-3rd person experience as most virtual environments offer and which is also easier for the blind to learn, since they use more egocentric-based spatial strategies than map-like ones. Second, they require heavily preprocessing for tagging various in-world objects with the meaningful descriptors these environments require, which renders most virtual worlds irrelevant.

Here we attempt to use a virtual version of a new technique from the real-world, a virtual cane known as the "EyeCane" (Maidenbaum 2011), in order to avoid these problems. The "EyeCane" measures the real-world distance between the device and the object it is pointed at using infra-red emissions and produces a corresponding auditory signal. As point distance information can be calculated from any 3D Mesh, using a virtual parallel of such a method is easy to implement in any virtual environment, which is a significant step in making nearly all virtual environments more accessible. Additionally, success under these conditions would show that it can potentially be achieved in the real world as well, showing the potential for real-world narrow-beamed virtual canes for enabling such recognition.

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As a first step we tested the ability of our subjects to use this approach to recognize simple virtual shapes within a virtual environment. Previous successful work using other methods focused on the ability of the blind to correctly discriminate between 2D shapes (Amedi 2007, Chen 2011), a task which we chose to repeat and begin from as a foundation for the next steps. We then tested this concept in two additional levels by having the subjects discriminate between the 3D orientation of rectangles and between various 3D shapes. This experiment was conducted with no training at all, to show the simplicity of the concept.

2. METHODS

2.1 The tasks

The experiment consisted of three tasks:

1. *2D shape recognition***.** Subjects were requested to identify and discriminate between 2D virtual shapes. Specifically, whether the virtual shape was a circle, square or triangle.
2. *3D rectangle orientation.* Subjects were requested to identify the orientation of the virtual rectangle and decide if the top end of the shape was oriented into the screen, parallel with the screen or out of the screen. An example of such 3D rectangles can be seen in fig 1b.
3. *3D shape recognition*. Subjects were requested to identify if the virtual shape was a sphere, a bowl, a half-cylinder or a pyramid. An example comparing the sphere and bowl is shown in in fig 1c.

Tasks 1 and 2 were given in a random order, but always preceded task 3. No training was given for any of the tasks, and thus subjects had to recognize the shapes throughout the trials and not simply discriminate between them. A yes/no feedback to their responses was given between trials.

Subjects were instructed to disregard time and scanning-path length and focus on correct identification. They were encouraged before the tasks to try and think of strategies to recognize the various shapes.

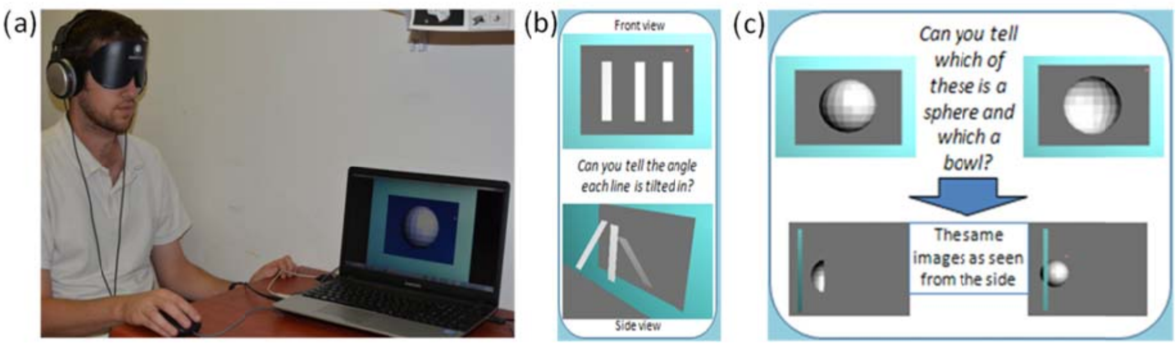

Figure 1. *(a) A blindfolded sighted user with the system. (b). Illustrates the 3D rectangle orientation task. In the upper panel are 3 rectangles, whose 3D orientation is undeterminable to the user visually. The lower panel illustrates the relative simplicity of this task when performed visually from a different angle. In the experiment only one rectangle was presented at a time. (c). Illustrates the 3D object recognition task. In the upper part are a concave bowl, and a convex ball. As in (a) the lower part illustrates the relative simplicity if performed visually from a different angle. While in (b) one could attempt to use slight visual cues such as shading to discern between them, the correct answer indicated by shading depends on the location of the light source. In the experiment only one shape was presented at a time.*

2.2 The software

We created dedicated virtual environments using Blender 2.49, and Blender-Python modules using python 2.6.2. Within these environments we used a Ray-Casting algorithm (which calculates the distance to the object the virtual device is pointed at, much like the sensors in the real world "EyeCane" (Maidenbaum 2011)) and links it to a sound-file recorded from the "EyeCane"'s auditory output (the closer the object the higher the frequency of beeps). While in this case there is no difference to the user (who is either blind or blindfolded), the environments have a graphical output.

The environments are controlled using a standard keyboard and mouse. The software automatically tracks any activity within the virtual environments and stores it in a log file which includes information such as timing and the exact location of the device. The subject's answers were recorded by the experimenter.

2.3 *Experimental procedures and authorization*

In all parts of the experiment subjects were seated comfortably in front of a computer and used a standard Mouse as the virtual cane. The virtual representation of the user was locked to place, and only the virtual cane could move in the XZ plane.

The experiment was approved by the Hebrew university ethics committee in accordance with the 1964 Helsinki Declaration, and all subjects signed informed consent forms.

2.4 *Subjects*

We tested 23 blindfolded sighted subjects (11 male, average age 25.1(22-32)) and 3 congenitally blind subjects (all female, average age 28(23-36), blindness due to peripheral injury). All subjects were healthy apart from their visual impairment.

3. RESULTS

3.1 *Blindfolded sighted subjects*

On all three tasks, subjects' performance (shown in fig 2) was significantly above chance (33% in tasks 1-2, 25% in task 3). In the 2D shape discrimination task the success rate was 61.1%±12.9%(SD) (p<5E-9, standard t-test). In the 3D orientation tasks subjects success level was 97.9%±5.7% (p<2E-27). In the final task of 3D shape recognition subjects success rate was 81.1%±17.8% (p<3E-13).

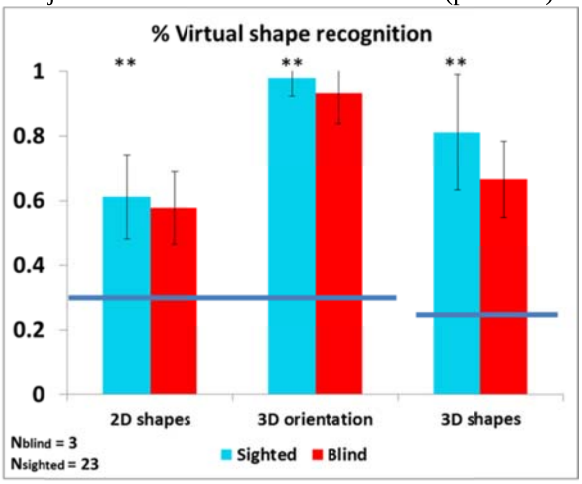

Figure 2. *% of correct answers in the 3 tasks for the blindfolded sighted (N=23) and for the blind subjects (N=3). error bars denote standard deviation. ** denote significance above chance level.*

3.2 *In the blind*

Initial results (shown in fig 2) from a small sample of 3 blind subjects, show that they were able to perform these tasks significantly above chance. In the 2D shape task they were able to discern the correct shape with a 57.7%±11.3%, which is significantly higher than the chance level of 33%. In the 3D orientation task subject correctly recognized the orientation with a 93.3%±9.4% success rate, with even higher significance above the chance level of 33%. In the 3D shape task their success rate of 66.7%±9.4% was still above the chance level of 25% but not as high as in the 3D orientation task.

The results of the blind subjects conform to those of the blindfolded in the first 2 tasks, but their performance is lower in the 3rd task.

4. DISCUSSION

Several studies have successfully shown that it is possible to recognize 2D virtual shapes using auditory information in various methods without vision (Amedi 2007, Chen 2011). Our work takes another step upon this path, and does so as part of a wider vision, of full interaction with virtual environments using the same concept - a virtual version of a virtual guide cane. Such interaction would help make virtual environments, whose importance is constantly increasing, more accessible to the blind and visually impaired population.

It should be noted that we are not the first to attempt to convey 3D virtual objects. Some previous attempts were made using tactile actuators to understand 3D virtual shapes. However, most such attempts required dedicated pre-processing, and unlike the widely accessible audio system used here, tactile actuators currently require a unique, and usually expensive, platform and are relatively low in resolution.

It is interesting to note that while the blind subjects described the tasks as very difficult, and described at first difficulty in conceptually understanding them, they too were able to successfully complete the 2D shape and 3D orientation tasks with a success level similar to that of the blindfolded sighted, and the 3D object task in a manner significantly above chance, even if less so than the blindfolded subjects. We anticipate that following brief training their performance will improve to levels comparable with the sighted here as well.

The extremely high success level in task 2, even with no training shows that this task is in fact far easier than expected, and that the basic ability to build a 3D mental image of a shape can be accomplished even in the absence of any vision, and even in the congenitally blind.

While further analysis is required to quantitatively assess this data, we observed that during the tasks several subjects developed scanning strategies, beyond simply semi-randomly scanning the virtual shape. One such strategy was to scan the whole virtual scene in a coherent manner (such as traveling back and forth along the whole scene in parallel lines) and another was to try to mentally envision the shapes and look for specific differences between them (such as looking for sharp corners using a 90°motion to differentiate the pyramid from the round shapes). Preliminary exploration of this data reveals that both strategies were more efficient than random scanning, while the second strategy was more efficient than the first

5. CONCLUSIONS

In conclusion, we have presented here a simple-to-implement system which the blind, visually impaired, and in some cases even the sighted, can use to understand 3D information by exploration. We have shown that this information alone is enough for the subject to recognize simple shapes and 3D orientations even without any training, indicating that this algorithm may serve as a useful tool for making virtual environments more accessible to the blind.

These results also lead us to view optimistically the potential use of the "EyeCane" in the real world for not only locating obstacles but also for a low-resolution understanding of main components of whole environments and their surrounding spatial layout.

Additionally, as these tasks and others using this technique can be performed safely while within an fMRI scanner we can utilize it to explore the creation of the novel sensory-motor loop in the groups of subjects to better understand the neural correlates of spatial representation and learning.

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