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A blind person's cognitive mapping of new spaces using a haptic virtual environment

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Mental mapping of spaces is essential for the development of efficient orientation and mobility skills. Most of the information required for mental mapping is gathered through the visual channel. Blind people lack this crucial information, facing in consequence difficulties in mapping as well as navigating spaces. The work reported here is based on the assumption that the supply of appropriate spatial information through compensatory sensorial channels may contribute to blind people's spatial performance. The main goals of this study were: (a) the development of a haptic virtual environment enabling blind people to learn about real life spaces; (b) the study of blind people's cognitive mapping of these spaces; and (c) the study of the contribution of this mapping to blind people's spatial skills and performance in the real environment. The focus of this paper is on a case study of G, a 25-year-old late blind. The results were encouraging: G mastered the ability to navigate the virtual environment in a short time; after navigating, he generated a verbal description and a physical model of it which unveiled a fairly precise map of a space he did not know before; and finally G showed impressive navigating performance in the real space.

Introduction

The ability to navigate spaces independently, safely and efficiently is a combined product of motor, sensory and cognitive skills. Normal exercise of this ability directly affects the individual's quality of life. Mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel (Lynch, 1960). Blind people lack this information and, in consequence, they face great difficulties in (a) generating efficient mental maps of spaces, and therefore (b) navigating efficiently within these spaces. A result of this deficit in navigational capability is that many blind people become passive, depending on others for continuous aid (Foulke, 1971). More than 30% of the blind do not ambulate independently outdoors (Clark-Carter, Heyes & Howarth, 1986).

Researchers have adopted different theoretical perspectives to address the cognitive aspects of blind people's orientation and navigation performance (Kitchin, Blades & Golledge, 1997). For example: *deficiency* theory states that the lack of perceptual (e.g. visual) experience is a critical obstacle for the development of appropriate spatial understanding; the *inefficiency* theory relates to the inferior nature of blinds' spatial understanding based on non-visual information; and the *difference* theory looks for intervening variables that possibly affect blind persons' spatial performance other than those directly related to the visual impairment. However, by any perspective there is an agreement that blind individuals face serious difficulties in spatial cognitive mapping and performance. The work reported here is based on the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may contribute to the mental mapping of spaces and, consequently, to blind people's spatial performance. By this assumption we do not intend to claim that a full equivalent of the qualities of lost visual information can be supplied by alternative channels. Our main claim is that the integration of alternative perceptual data, using a tool that enables alternative exploration and mapping strategies (for example, whole-object exploration, non-linear scanning of the space), may substantially support the cognitive processing of spatial information.

Research on blind people's mobility in known and unknown spaces (e.g. Golledge, Klatzky & Loomis, 1996; Ungar, Blades & Spencer, 1996) indicates that support for the acquisition of spatial mapping and orientation skills should be supplied at two main levels: perceptual and conceptual. At the perceptual level, the deficiency in the visual channel should be compensated with information perceived via other senses. Touch and hearing become powerful information suppliers about known as well as unknown environments. In addition, haptic information appears to be essential for appropriate spatial performance. Haptics is defined in the Webster dictionary (Webster, 1983) as: 'of, or relating to, the sense of touch.' Fritz, Way and Barner (1996) define haptics as follows: 'tactile refers to the sense of touch, while the broader haptics encompasses touch as well as kinesthetic information, or a sense of position, motion and force.' For the blind, haptic information is commonly supplied by: the cane – for low-resolution scanning of the immediate surroundings; palms and fingers – for fine recognition of objects' form, texture and location; and the feet, regarding surface information. The auditory channel supplies complementary information about events, the presence of other people (or machines or animals) in the environment, or estimates of distances within a space (Hill, Rieser, Hill, Halpin & Halpin, 1993).

As for the conceptual level, the focus is on supporting the development of appropriate strategies for an efficient mapping of the space and the generation of navigation paths. Research indicates that people use two main scanning strategies: route and map strategies. Route strategies are based on linear (and therefore sequential) recognition of spatial features, while map strategies, considered to be more efficient than the former, are holistic in nature, comprising multiple perspectives of the target space (Fletcher, 1980; Kitchin & Jacobson, 1997). Research shows that blind people use mainly route strategies while recognising and navigating new spaces (Fletcher, 1980).

Advanced computer technology offers new possibilities for supporting visually impaired people's acquisition of orientation and mobility skills, by compensating for the deficiencies of the impaired channel. Research on the implementation of haptic technologies within virtual navigation environments reports on its potential for supporting rehabilitation training with sighted people (Giess, Evers & Meinzer, 1998; Gorman, Lieser, Murray, Haluck & Krummel, 1998), as well as with blind people (Jansson, Fanger, Konig & Billberger, 1998; Colwell, Petrie & Kornbrot, 1998).

The work reported in this paper follows from the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may contribute to the mental mapping of spaces and, consequently, improve blind people's spatial performance. The main goals of this study are:

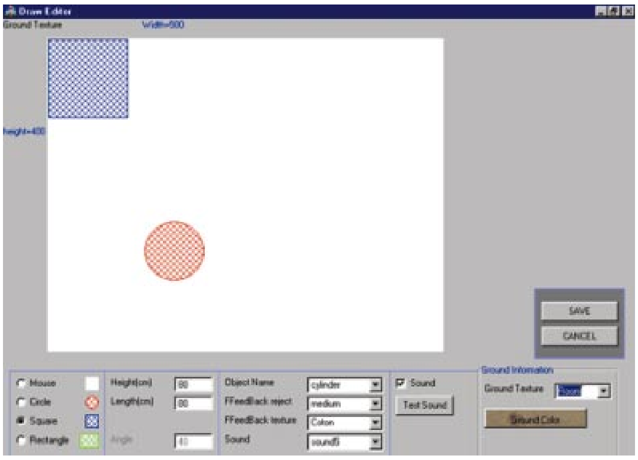
1. The development of a multisensory virtual environment enabling blind people to learn about real-life spaces which they are about to navigate (for example, school, workplace, public buildings).
2. A systematic study of a blind person's acquisition of spatial navigation skills by means of a virtual environment.
3. A systematic study of the contribution of this mapping to the blind person's spatial skills and performance in a real environment.

The following sections present a brief description of the virtual learning environment, as well as preliminary results of a case study of a blind person's learning process with the environment.

The haptic virtual environment

As part of the research project reported here, we developed a multisensory virtual environment simulating real-life spaces. This virtual environment comprises two modes of operation: developer/teacher mode, and learning mode.

Figure 1: Haptic environment builder



Object Name: cylinder
FFeedBack reject: medium
FFeedBack texture: Coton

The core component of the developer/teacher mode is the virtual environment editor, which includes three tools: (a) 3D-environment builder; (b) force feedback effects (FFE) editor; and (c) audio feedback editor (see Figure 1). By using the 3D-environment editor the developer can define the physical characteristics of the space, for example size and form of the room, or type and size of objects (such as doors, windows, furniture pieces). Using the FFE editor the developer is able to attach haptic effects to all objects in the environment. Examples of FFEs are vibrations produced by ground textures (such as stone, parquet, grass), and attraction/rejection fields surrounding objects. The audio editor allows the attachment of sounds and auditory feedback to the objects, for example, 'You're facing a window', or realistic sounds (such as steps).

The learning mode, or the environment within which the users work, includes operating features for both student and teacher. The students navigate the environment using the force feedback joystick (FFJ). While 'walking' they interact with the simulated space components, for example they look for the form, dimensions and relative location of objects, or identify the structural configuration of the room (location of walls, doors, windows, etc.). As part of these interactions the users get haptic feedback through the FFJ, equivalent to the information they usually get by their foot while walking in real spaces. In addition, the users get three types of auditory feedback: (a) for the space's structural components, the user gets audio feedback (i.e. the window's sound representation is 'birds chirping') or its name (e.g., 'first door'); (b) for the objects located within the space their names are reported (e.g., 'first box', 'second cube'); and (c) a 'guiding agent' helps the user in walking around the objects by reporting the proximity of corners or required turns (e.g., 'turn left'). This audio feedback is contextualised for any particular simulated environment and it is intended to provide appropriate references whenever the users get lost in the virtual space. Figure 2 shows the user interface screen. The red circles indicate the hot spots which trigger the guiding agent's intervention.

Several additional features are offered to the teachers during and after the learning session. Monitoring frames, for example,

Figure 2: The user interface

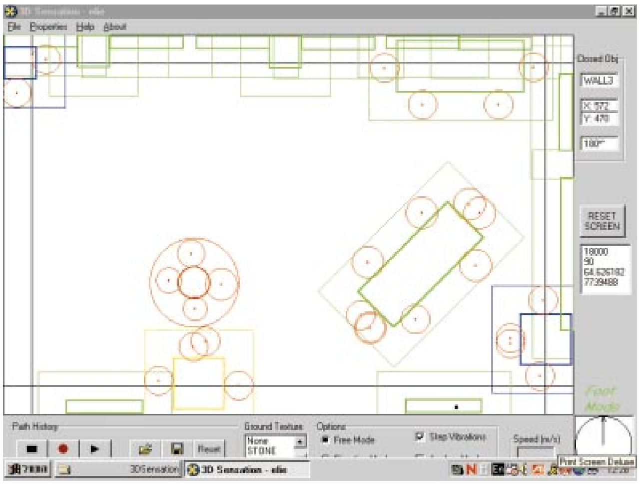
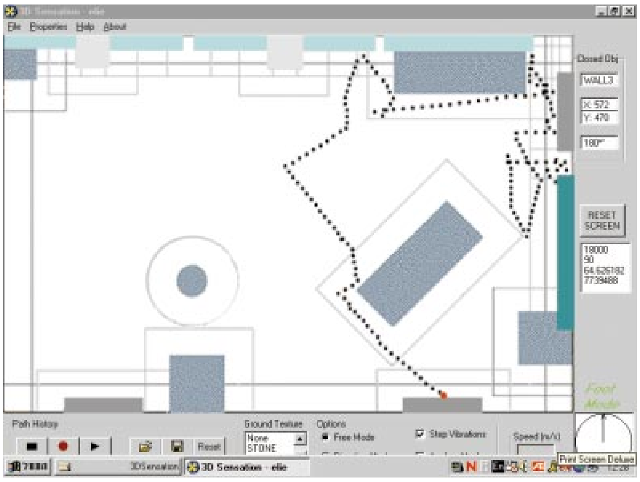


Figure 3: Recorded log and monitoring data



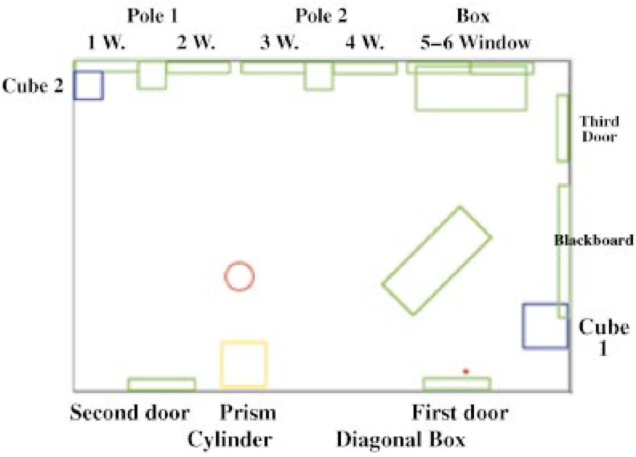
present updated information on the user's navigation performance, for example position or objects already reached. Another feature allows the recording of the user's navigation path and its further replay to analyse and evaluate the user's performance. Figure 3 shows the replay of the recorded log and monitoring data of a user's navigation path within the room's space and around some objects.

The case study: a blind subject's performance within the multisensory virtual environment and in the real environment

The preliminary evaluation of the virtual environment was conducted in the form of a case study of a blind person's working with the force feedback-based tool. The case study's goals were to collect information on five main aspects:

1. The user's response to FFJ, and the type of FFEs that strongly affected his navigation performance.
2. The user's ability to identify structural features of the environment and the objects in it.
3. The user's ability to navigate the *virtual* environment.
4. The user's ability to construct a cognitive map of the simulated room.
5. The user's ability to navigate the *real* environment.

Figure 4: The environment



Method

The participant

The subject of this case study, G, is a 25-year-old late blind student. G became a total blind (without any visual fields) at the age of 20 as a result of an accident. For outdoor mobility G is assisted by a guide dog. G has been a computer user for more than three years, using voice output. He was a totally naive subject recruited for the evaluation phase of this study.

The research environment

The unknown real space to be explored was virtually represented in the computer environment (see Figure 4). The real space was a room of 54 square metres with three doors, six windows and two columns. There were seven objects in the room, five of them attached to the walls and two placed in the inner space.

Procedure

The study consisted of three stages: (1) familiarisation with the virtual environment conponents; (2) navigation in the virtual environment; and (3) navigation in the real environment.

In the preliminary stage of familiarisation with the virtual environment G received a short explanation about its features and how to operate the FFJ. The series of tasks that were administered at this stage included: (a) free navigation; (b) directed navigation; (c) tasks focusing on emerging difficulties; and (d) a task aimed to evaluate auditory feedback referring to orientation, turns and proximity to objects. The experimenter did not instruct G on the use of any particular strategy for navigating the virtual environment. Data about G's performance was collected by direct observation, an open interview, and video recording. This preliminary stage lasted about three hours (two meetings).

The navigation in the virtual environment stage included three tasks: (a) exploration and recognition of the virtual environment (see Figure 4); (b) a target-object task (e.g., walk from the starting point to the blackboard); (c) a perspective-taking task (e.g., walk from the cube in the corner of the room to the rightmost door – the usual starting point). Following the exploration task the subject was asked to give a verbal description of the environment and to construct a scale physical model of it (selecting appropriate components from a large set of alternative objects and models of rooms). Several data-collection instruments served this stage: a log mechanism built into the computer system which stored G's movements within the environment; video recording; recording of G's verbal descriptions; the physical model built by G. The second stage lasted about three hours.

The third stage, navigation in the real environment (the actual space which was simulated in the virtual environment), also included two tasks: (a) a target-object task (e.g., reach the rectangular box and identify the object placed on it); (b) a perspective-taking task (e.g., walk from the rightmost door to the cylinder). Data on G's performance were collected by video recording and direct observation. This stage lasted about half an hour.

Results

Familiarisation with the virtual environment components

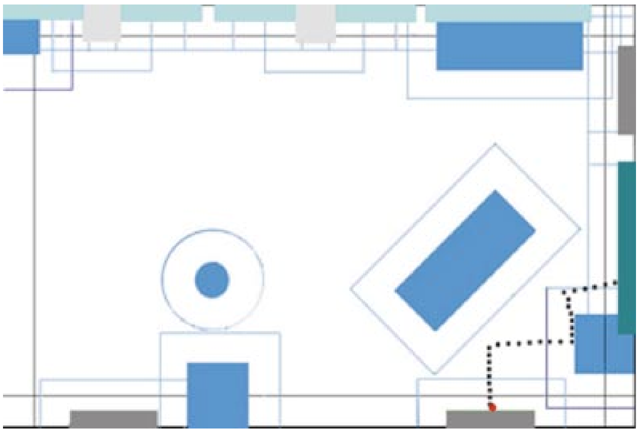
G learned to work freely with the force feedback joystick within a short period of time, walking directly and decisively towards the objects. Regarding mobility, G could say when he bumped into an object or got to one of the room's corners. From the first tasks in the process G could walk around the objects (cube or cylinder) and alongside the walls, by using the FFE and the audio feedback.

Navigation within the virtual room

Exploration task G navigated the environment with rapid and secure movements. He first explored the room's perimeter, walking alongside the walls. After two circuits he returned to the starting point and said: 'I did only a circle, I did not finish yet, I have the objects in the centre …' While talking, G began to explore the objects located in the inner part of the room, that is, the cube and the cylinder. Figure 5 shows G's intricate walking paths in the exploration task, navigating between the cube, the cylinder and landmarks left on the room's perimeter. During his exploration G made many pauses (more then ten seconds for each pause), supposedly used for cognitive processing (e.g., G: ' … we had the fifth window, box, and the sixth window, corner, after the corner we had the third door and the blackboard … '; his verbal description is accompanied by virtual finger-drawing on the table's surface). The exploration session lasted about 43 minutes.

Figure 5: Subject's navigation in the exploration task

Figure 6: Target-object task in the virtual environment



Target-object task The target-object task was presented as: 'Walk from the starting point to the blackboard in the room.' In this task G navigated the environment applying the object-to-object strategy. From the door (the starting point) G walked to the cube and from the cube to the target – the blackboard (Figure 6). G reached the target rapidly – in 20 seconds – in a fairly direct way.

Perspective-taking task The perspective-taking task was: 'Find the door that served as starting point in the previous two tasks'; the starting point this time being the cube in the left corner of the room. Here once again G applied the object-to-object strategy (Figure 7): he went from the cube (the starting point) to the box, and then to the target door (which was the starting point in the previous tasks). G chose a direct way, and completed the task in 52 seconds.

Figure 7: Perspective-taking task in the virtual environment

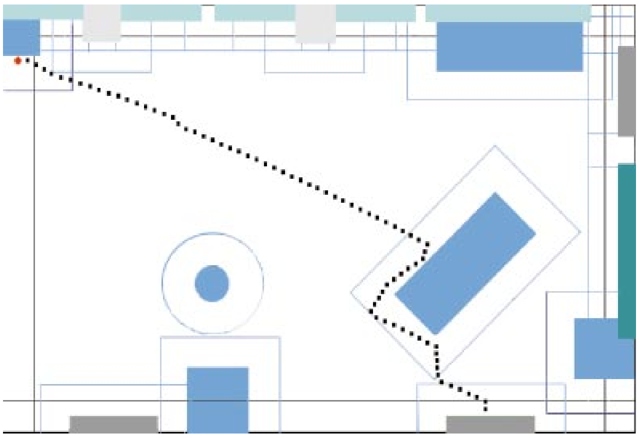


Figure 8. Subject's model of the virtual environment

Cognitive map construction After completing the virtual environment exploration (the first task), G was asked to describe the environment verbally. In his description G included 41% of the relevant information related to the structural components of the room (e.g., shape, windows, doors), 71% of the relevant information related to the objects present in it (e.g., cubes, boxes), and only 29% of the relevant information on the location of these objects in the environment. G used in his description the route strategy. After the verbal description, G was asked to construct a physical model of the environment. As shown in G's model in Figure 8, he acquired a highly accurate map of the simulated environment. All salient features of the room are correct (form, number of doors, windows and columns), as is their location. As regards the objects within the room's space, for five out of seven G identified their exact form and size, and located all of them in the correct place and position.

Navigation in the real environment From his very first time in the real room G walked in it with secure and decisive movements. In the first task ('Reach and identify the object on the rectangular box'), G used the entrance door as initial reference and walked alongside the walls directly to the box (Figure 9). As he reached the box he said: 'I had this box … now I need to find it. OK I arrived … are you looking for this?' (G touched the object on the rectangular box.) He completed the task in 32 seconds. In the perspective-taking task ('Walk from the rightmost door to the cylinder'), G applied the object-to-object strategy, walking directly to the cylinder and completing the task successfully in 49 seconds (Figure 10).

Figure 9. Target-object task in the real environment

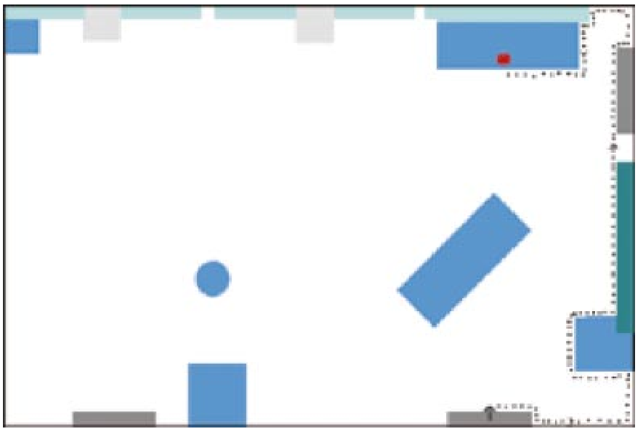
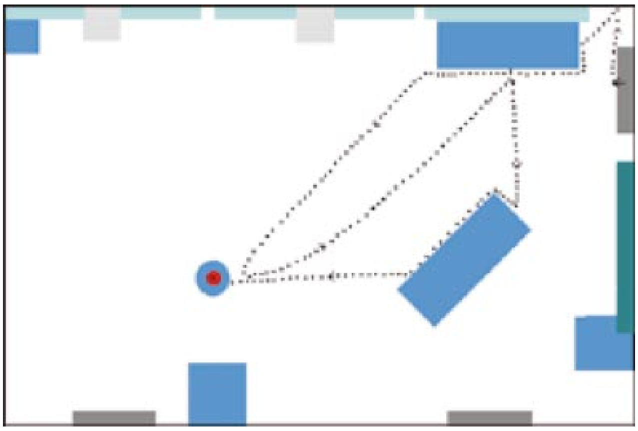


Figure 10. Perspective-taking task in the real environment



Concluding remarks

The case study reported here is part of a wider research effort aimed to understand if, and how, work with a multisensory virtual environment supports blind people's construction of spatial cognitive maps and, consequently, their navigation in real environments.

The case study results are encouraging. First, G mastered in a short time the ability to navigate the virtual environment. After navigating the virtual room, G generated a verbal description and a physical model which reflected a fairly precise map of a space he did not know before. And, finally, G showed impressive performance in the real space. G entered a real room which he was not given the opportunity to explore, and walked in it in a secure and decisive manner. He used for the navigation tasks in the real room all the landmarks set by him in the exploration of the virtual environment (which in turn became components of his cognitive map). As a result G completed the different navigation tasks in the real room efficiently and in a very short time.

Several properties of the virtual environment might have contributed to G's successful cognitive mapping and performance. Among these are: the 'safety' of the virtual environment which allows secure examination of the space and its objects; the accessibility to every corner and object without effort, allowing the recurrent scanning of the whole space in varied strategies and navigation paths; the varied feedback modalities which supply the user with rich information to be integrated in the cognitive mapping process; and the content of the multisensory feedback related to explicit information about the room's structure and the objects in it, thus allowing the user to concentrate on spatial features (e.g., objects' location, distances estimation, orientation).

We foresee many different continuations of the line of research initiated in the reported case study. Future studies should examine large populations while considering relevant variables, for example, impairment period (whether the subjects are congenitally or late blind), gender and age. Additional variables should relate to properties of the environment, for example, indoor or outdoor spaces, large public spaces (such as campuses, museums, shopping centres), and irregular surfaces. Finally, a comparison with traditional methods used by the blind to learn about unknown environments (for example, tactile maps, verbal descriptions, human guidance) may serve for comprehensive evaluation of the contribution of the virtual tools to people's spatial performance. We expect these virtual environments to become powerful tools for the blind in learning processes in which spatial information is crucial, both for understanding new concepts and phenomena, as well as for acting and performing in the real world.

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