Multisensory virtual environment for supporting blind persons' acquisition of spatial cognitive mapping, orientation, and mobility skills

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ABSTRACT

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. Blind people lack this crucial information and in consequence face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating efficiently within these spaces. The work reported in this paper follows 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. The main goals of the study reported in this paper were: (a) The development of a multi-sensory virtual environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings); (b) A systematic study of blind people's acquisition of spatial navigation skills by means of the virtual environment; (c) A systematic study of the contribution of this mapping to blind people's spatial skills and performance in the real environment. In the paper a brief description of the virtual learning environment is presented, as well as preliminary results of two case studies of blind persons' learning process with the environment.

1. RATIONALE

The ability to navigate spaces independently, safely and efficiently is a combined product of motor, sensory and cognitive skills. Normal exercise of this ability has direct influence in the individuals' 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, in consequence, lack this crucial information and face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in 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).

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. 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 alternative channels. 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 (1993), as "of, or relating to, the sense of touch". Fritz, Way & Barner (1996) define haptics: " tactile refers to the sense of touch, while the broader

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haptics encompasses touch as well as kinesthetic information, or a sense of position, motion and force." Haptic information is commonly supplied by the cane for low-resolution scanning of the immediate surroundings, by palms and fingers for fine recognition of objects' form, textures, and location, and by the legs regarding surface information. The auditory channel supplies complementary information about events, the presence of other people (or machines or animals) in the environment, materials which objects are made of, 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 two main scanning strategies used by people: route and map strategies. Route strategies are based in linear (therefore sequential) recognition of spatial features. 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 for recognizing and navigating new spaces (Fletcher, 1980).

Advanced computer technology offers new possibilities for supporting visually impaired peoples' acquisition of orientation and mobility skills, by compensating 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).

Following the assumption that the navigation in a virtual haptic environment may support blind peoples' cognitive mapping of spaces, the main goals of the study reported in this paper were:

(a) The development of a multisensory virtual environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings).

(b) A systematic study of blind people's acquisition of spatial navigation skills by means of the virtual environment.

(c) A systematic study of the contribution of this mapping to blind people's spatial skills and performance in real environment.

In the following sections, a brief description of the virtual learning environment will be presented, as well as preliminary results of two case studies of blind persons' learning process with the environment.

2. THE VIRTUAL ENVIRONMENT

For the study we developed a multisensory virtual environment simulating real-life spaces. This virtual environment comprises two modes of operation: Developer/Teacher mode, and Learning mode.

2.1 Developer/Teacher Mode

The core component of the developer mode is the virtual environment editor. This module includes three tools: (a) 3D environment builder; (b) Force feedback output editor; (c) Audio feedback editor.

<u>3D environment builder</u>. By using the 3D-environment editor the developer defines the physical characteristics of the space, e.g., size and form of the room, type and the size of objects (e.g., doors, windows, furniture pieces)

<u>Force feedback output editor</u>. By this editor, the developer is able to attach Force-Feedback Effects (FFE) to all objects in the environment. Examples of FFE's are vibrations produced by ground textures (e.g., stone, parquet, grass), force fields surrounding objects, or tactile characteristics of structural components such as walls and columns (e.g., friction, texture). The attraction/rejection fields are of crucial importance to support the user's perception of the objects' (virtual) envelope, and the recognition of structural components is essential for the construction of an appropriate map of the whole space.

<u>Audio feedback editor</u>. This editor allows the attachment of sounds and auditory feedback to the objects, e.g.: "you re facing a window" or realistic sounds (e.g., steps). Additional auditory feedback is activated whenever the user enters an object's effect field, supplying important information with regards to the objects form (e.g., a cube, a cylinder), or aspects of its envelope (e.g., a corner, a turn).

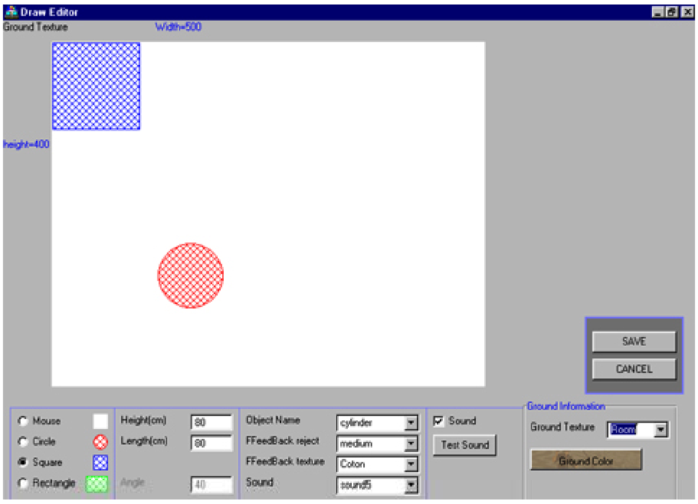

Figure 1. *3D environment builder.*

Figure 1 shows the environment-building-editor screen. The developer mode allows the researcher or teacher to build navigation environments of varied levels of complexity, according to instructional or research needs.

2.2 Learning Mode

The learning mode, or the environment within which the user works, includes two interfaces: User interface and Teacher interface.

The user interface consists of the virtual environment simulating real rooms and objects to be navigated by the users using the Force Feedback Joystick (FFJ). While navigating the environment the users interact with its components, e.g., look for the form, dimensions and relative location of objects, or identify the structural configuration of the room (e.g., location of walls, doors, windows). As part of these interactions the users get haptic feedback through the FFJ, including foot-level data equivalent to the information they get while walking real spaces. In addition the users get auditory feedback generated by a "guiding computer agent". This audio feedback is contextualized for the particular simulated environment and is intended to provide appropriate references whenever the users get lost in the virtual space. Figure 2 shows the virtual environment.

The teacher interface comprises several features serving teachers during and after the learning session. On-screen monitors present updated information on the user's navigation performance, e.g., position, or objects already reached. An additional feature allows the teacher to record the user's navigation path, and replay it aftermath to analyze and evaluate the user's performance. Figure 3 shows one user's monitor data, and her navigation paths within the room's space and around some objects.

3. BLIND SUBJECTS' PERFORMANCE WITHIN THE MULTISENSORY VIRTUAL ENVIRONMENT AND IN THE REAL ENVIRONMENT

The research goals were to collect information on two main aspects:

1. The user's ability to construct a cognitive map of the simulated room. Two issues were addressed:
   - User's verbal description of the simulated room.
   - User's ability to construct a scale model of the room.
2. The user's ability to navigate in the real environment.

3.1 Method

Two subjects' data are reported I this paper. G., is a twenty-five years old late blind, (G. became blind at the age of twenty). He has been a computer user for more than three years using voice output. G. uses a guide dog for outdoor mobility. N., is a twenty-seven years old congenital blind. She has been a computer user for one year using voice output. N. uses a long cane for outdoor mobility.

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3.2 Procedure

The study consisted of three stages:

(a) Familiarization with the virtual environment.

(b) Navigation tasks in the virtual environment.

(c) Navigation tasks in the real environment.

At the beginning of the familiarization with the virtual environment stage the subjects received a short explanation about its features and how to operate the FFJ. The series of tasks which were administered at this stage included: (a) free navigation; (b) directed navigation; and (c) tasks focusing on emerging difficulties. Data on the subject's performance was collected by direct observation, an open interview and by video recording. This first stage lasted about three hours (two meetings).

The navigation in the virtual environment (Figure 2) stage included three tasks: (a) exploration and recognition of the virtual environment; (b) a target-object task (e.g., walk from the starting point to the blackboard in the room); (c) a perspective-taking task (e.g., walk from the cube -in a room's corner- 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 model of it (selecting appropriate components from a large set of alternative objects and models of rooms).

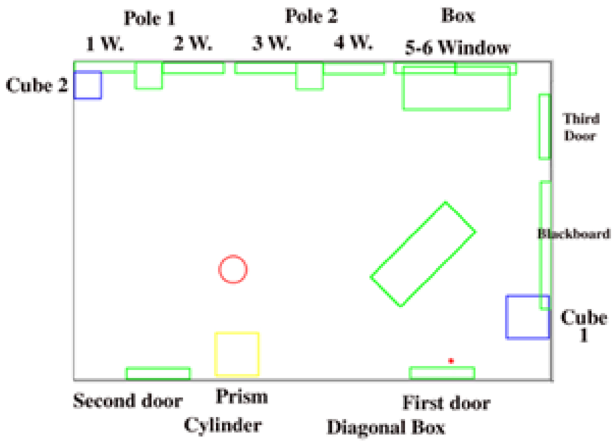

Figure 2. *The environment.*

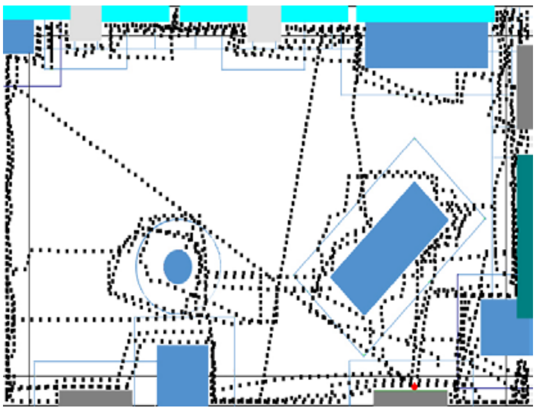

Figure 3. *Subject's navigation path.*

Several data-collection instruments served this stage: a log mechanism built-in in the computer system which stored the subject's movements within the environment; video recording; recording of the subject's verbal descriptions; the physical model built by the subject. The second stage lasted about three hours.

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

4. RESULTS

4.1 Familiarization with the Virtual Environment Components

G. and N. 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. and N. could identify when they bumped into an object, or arrived to one of the room's corners. From the very first tasks they could walk around an object's corner along the walls, guided by the FFE's and the audio feedback.

4.2 Navigation tasks in the virtual environment

G. And N. navigated the environment in rapid and secure movement. G. first explored the room's perimeter, (familiarization of the four walls) walking along the walls. After two circuits he returned to the starting point, and begun to explore the objects located in the room. In contrast N. explored only the room's perimeter, walking along the walls.

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4.2.1 Target-object task. The Target-object task was : "walk from the starting point to the blackboard in the room". Both subjects reached rapidly the target, by choosing a direct way.

G. performed the task applying the object-to-object strategy (knowledge of spatial relationship among two or more objects or places) and N. used the trailing strategy (Figure 6 and 7). G. and N. reached rapidly the target (20-22 seconds respectively).

4.2.2 Perspective-taking task. The perspective-taking task was: "Find the door that served as starting point in the previous tasks", the new starting point at this task was the cube in the left corner. Here once again G. performed the task applying the object-to-object strategy, and N. used the trailing strategy (Figure 8 and 9). G. reached the target in 52 seconds, and N. reached the target in 64 seconds.

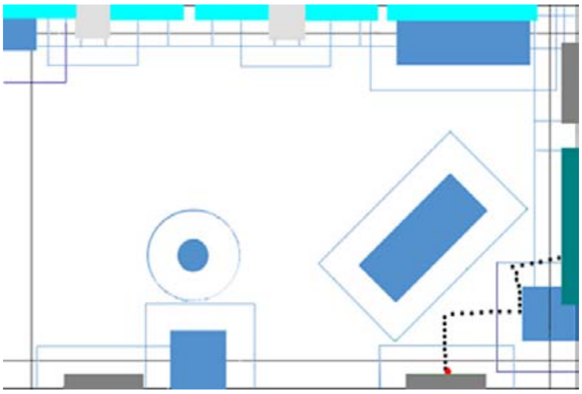

Figure 4. *G. in Target-object task.*

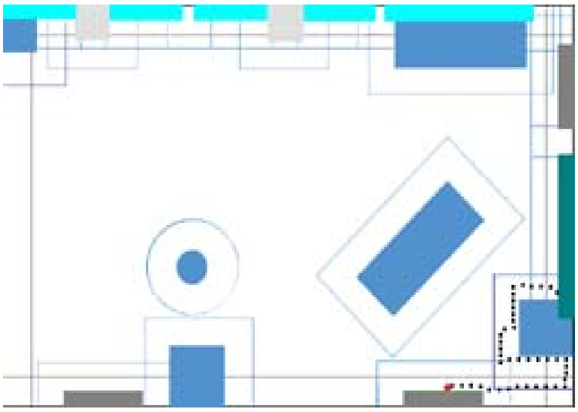

Figure 5. *N. in Target-object task.*

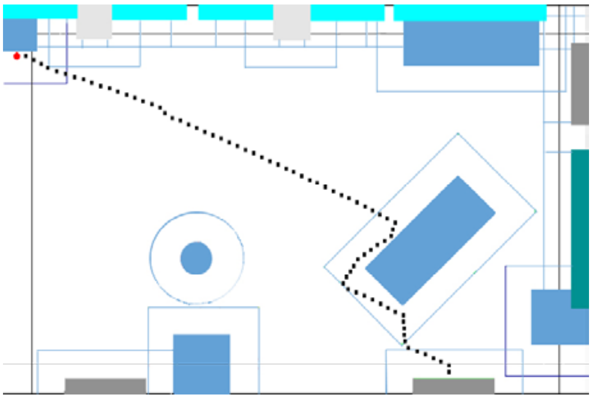

Figure 6. *G. in perspective-taking task.*

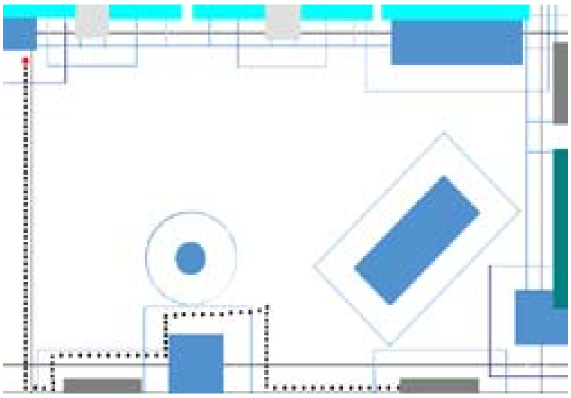

Figure 7. *N. in perspective-taking task.*

4.3 Cognitive map construction

After completing the virtual environment exploration task the two subjects were asked to give a verbal description of it. Table 1 shows both subjects' reference to structural components (e.g., columns) and objects (e.g., cube, box) in the environment.

Table 1. *Verbal description*.

Subject's name	Structure components	Objects	Location of objects
G.	41%	71%	29%
N.	77%	86%	86%

After the verbal description, the subjects were asked to construct a model of the environment. As shown in the pictures of the models composed by G. and N. (Figure 10-11), the subjects 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 well as the relative form and their location in the room.

Figure 8-9. *Subjects' models of the virtual environment (left: N's model; right: G.'s model).*

4.4 Navigation tasks in the real environment

The subjects walked through the real environment from their very first time in it in a secure and decisive behaviour. At the first task ("reach and identify an object on the rectangular box"), G. used the entrance door as initial reference, and he used the trailing strategy in direct way to the box (Figure 10). He completed the task in 32 seconds. N. walked in direct way to the box using object-to-object strategy (Figure 11), She completed the task in 20 seconds.

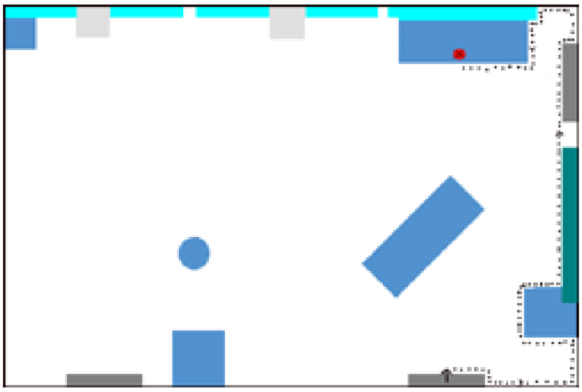

Figure 10. *G. Target-object task.*

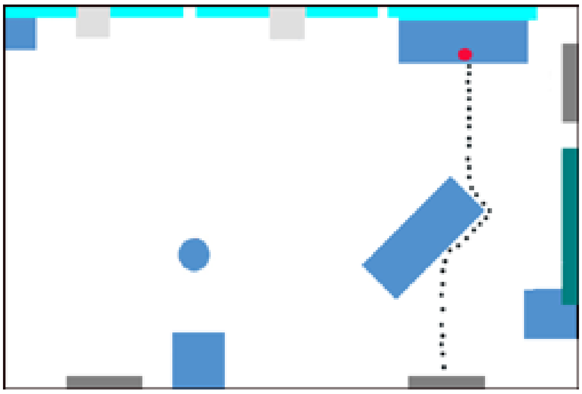

Figure 11. *N. Target-object task.*

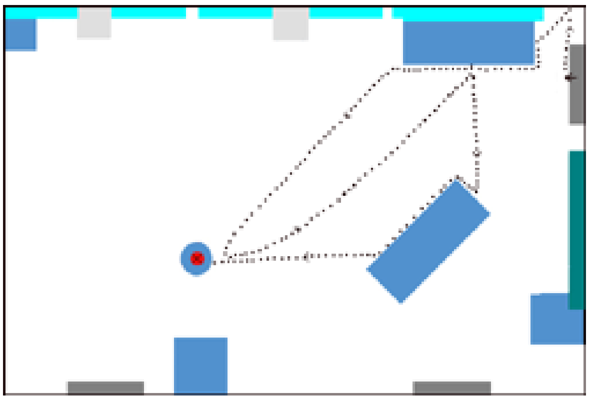

Figure 12: *G. Perspective-taking task.*

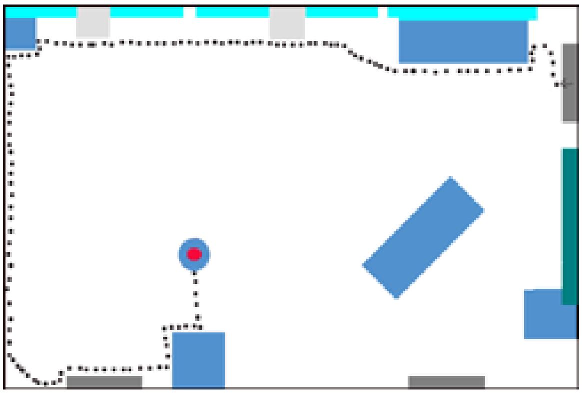

Figure 13. *N. Perspective-taking task.*

At the second's task, perspective-taking ("walk from the rightmost door to the cylinder"), G. used the object to object strategy (Figure 12) walking in direct way to the cylinder and completing successfully the task in 49 seconds. N. used indirect way and trailing strategy (Figure 13), and completing successfully the task in 64 seconds.

5. DISCUSSION

The research results are encouraging, and the completeness and spatial accuracy of the cognitive map became evident in three revealing situations.

Navigation within the virtual room - The subjects mastered in a short time the ability to navigate the virtual environment

Cognitive map construction - after navigating the virtual room, the verbal description and the physical models built by G. and N. showed that they have developed a fairly precise map of the (simulated) space they did not know before.

Navigation in the real environment – G. and N. entered the real room which they had not known until then, and which they were not given the opportunity to explore, and they walked in it in a secure and decisive behaviour.

Based on these and other preliminary results, a systematic empirical study (involving 30 subjects) of the effects of the haptic environment on blind people's navigation abilities is currently being conducted. The results have potential implications at varied levels, for supporting blind people's acquaintance with new environments, their acquisition process of spatial knowledge and skills, and their learning of concepts and subjects for which spatial information is crucial.

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