Virtual environments as spatial training aids for children and adults with physical disabilities

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ABSTRACT

This paper outlines experimental work on the use of virtual environments in assessing and improving spatial skills in people with physical disabilities. New evidence is presented which suggests that the degree of spatial impairment experienced by physically disabled children varies dependent on early mobility, and that this impairment may persist into the teenage years. We also review an experiment demonstrating transfer of spatial knowledge from a virtual environment to the real world, and outline a proposed follow up study examining virtual experience versus physical model experience. Finally, other studies in progress are outlined that focus on vertical spatial encoding in virtual environments based on larger real world environments and include older users as the target group.

1. INTRODUCTION

Children with physical disabilities that limit their autonomous movement in space are often unable to fully explore environments. Even those who have some form of assistance (via the use of a wheelchair, or transport by a carer) may have limited access, and may rely on their assistant to make route choices. Assistants will normally take the shortest available routes, which limits the child's opportunities for spatial choice, error correction, efficient route deduction, path integration and the other learning experiences that are probably crucial to the development of good spatial cognition in able-bodied individuals. Especially in the early stages of development, the cumulative effect of passivity and limited autonomous exploration may deprive the child of the motivation and/or ability to learn about new environments and form effective internal maps with which to navigate (Foreman et al, 1989). To date, little is known about the possible longer term effects of this early limited exploration experience when a greater degree of autonomous movement becomes available.

The few studies that have been carried out examining cognitive mapping skills have provided preliminary evidence that children with mobility limitations have difficulty forming effective cognitive spatial maps (Foreman et al, 1989; Simms, 1987). Foreman et al (1989) found that physically disabled children were worse than matched classmates at drawing plan maps of their classroom, placing missing objects on an outline map and pointing in the direction of landmarks on their school campus. Simms (1987) found that, compared with able bodied matched controls, disabled children took significantly longer to learn a route, their observation of landmarks was poorer, they were less competent at marking routes on a sketch map and produced less comprehensive hand drawn sketch maps.

Simms (1987) also found a difference in spatial skill related to level of mobility. She found that walkers performed better than those who were wheelchair bound. The following study investigated the possible persistence of limited early mobility experience in the current spatial learning ability of a group of disabled teenagers with optimal levels of mobility given their disabilities (Stanton et al, submitted, b).

2. SHORTCUT ABILITY AND EARLY CHILDHOOD MOBILITY

A group of able-bodied children and two groups of physically disabled children explored a simulated "maze" comprising four rooms linked by runways. In a subsequent test, they were asked to take shortcuts between target room locations.

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2.1 Participants

Three groups were tested: One group consisted of 24 able-bodied children with a mean age of 13.6 years. A group of 34 physically disabled children, with a mean age of 14.1 years, was divided into two sub-groups based on their history of mobility. Eleven children were rated by their teacher as more mobile when they were younger and 23 children were rated as less mobile when they were younger. All the children were assessed by their teacher as being within the normal range of intelligence.

2.2 Materials

The experimental environment was developed using the Superscape Virtual Reality Toolkit and was presented on a desktop computer. The environment consisted of five pathways connecting four rooms that appeared identical from the outside (see figure 1). The interior of each room was coloured differently and contained discriminable objects. Large distinctive landmarks were positioned around the environment as spatial cues. A series of pilot studies had established that 4 large cues were optimal for spatial orientation within this environment (see Stanton et al, submitted, b). Barriers were used to limit exploration during the learning phase.

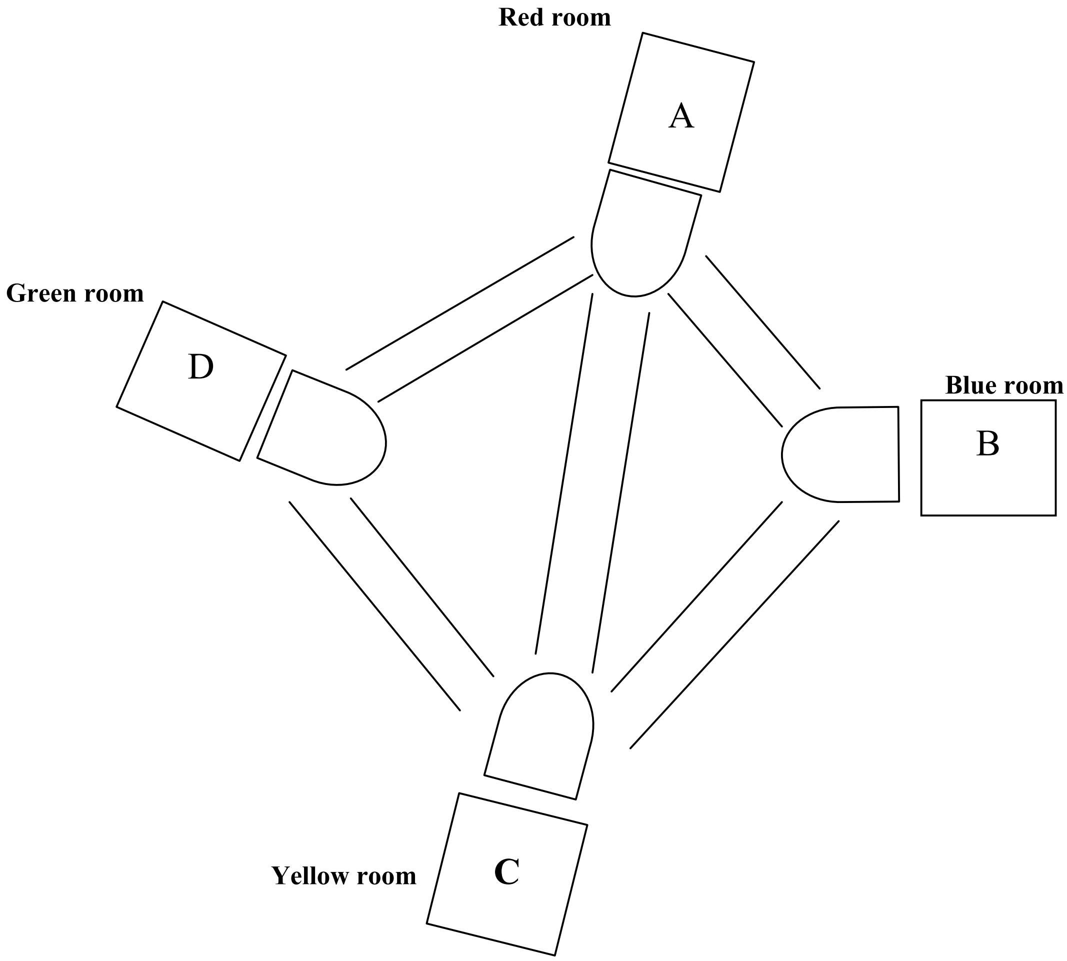

Figure 1. *Plan view of the rooms and pathways in the shortcut study environment*

2.3 Design and Procedure

In a counterbalanced arrangement participants explored three of the outer pathways on a set route determined by the experimenter. For example, they were asked to explore the route between room A and room B (all other pathways were blocked by no entry barriers). They were then asked to explore the path between rooms C and D, and then between rooms A and D. In the testing phase all the barriers were removed and participants were placed in room C and asked to find room B by the shortest route available. If they were successful on this first task they were repositioned in room C and asked to locate room A. If they had not taken the correct route the first time they were asked to locate room B again.

2.4 Results and Discussion

In the first shortcut test the probability of choosing a correct path by chance alone was 33%, while the probability was 50% on the second test. Approximately 70% of the able bodied group selected the shortcut correctly on both tests, significantly exceeding chance levels. The 'more mobile group,' while not performing better than chance on the first test (approximately 45% correct), scored better than chance on the second test with 80% correct. The 'less mobile' group only scored approximately 45% correct on both tests and therefore did not perform better than chance on either test.

This study demonstrates that disabled children are less able to take shortcuts than able-bodied children, and that those children who had had more limited mobility as young children were poorer at a shortcut task than those who were mobile when young. These results add further weight to the argument that early independent exploration is essential for the development of cognitive spatial mapping ability in children, and suggest that these early influences persist at least into the early teenage years.

3. TRANSFER OF SPATIAL SKILL FROM A VIRTUAL TO A REAL SCHOOL ENVIRONMENT

In our previous work we found that children's' ability to orientate themselves and find target landmarks in VEs improved significantly with repeated exposure to VEs of similar complexity (Stanton et al, 1996). However, the acid test for VE efficacy as a spatial training medium is whether children can make practical use of VE training in a real situation.

There are relatively few experiments that address this question of degree of transfer (for some work in this area, see Regian et al, 1992; Ruddle et al, 1997; Witmer et al, 1995). With able-bodied adult participants, Wilson et al (1997) have established that spatial knowledge (of vertical and horizontal positions of targets) in a real two-storey building can be acquired via exploration of an accurate computer-simulation.

The first study to examine transfer of virtual environment knowledge to real life training in physically disabled children was carried out by Wilson et al (1996). They asked their participants to explore a simulated building in the form of a game. Children were required to activate each of several pieces of fire equipment in the course of exploration, and to open a fire door in order to "exit" the building. The children were then asked to indicate where they thought items of fire equipment were located in the real building using a pointing device situated in a room from which the target items of equipment were not visible. They were also asked to describe routes within the building. On completion of these tasks they escorted the experimenter to the real fire equipment. The children were more accurate than a guessing control group on all the tasks, and had obviously gained a great deal of information during their exploration of the simulation.

The following study was designed to replicate the essential transfer of spatial information from a virtual to a real environment in the Wilson et al (1996) study. It also extended the former study in two ways. First, a better rendered and more complex environment was constructed, that incorporated all but the finest detail. Second, the experiment was designed to look at the effects of training on a spatial task in a virtual environment.

A to-scale three-dimensional computer simulation of a single storey real school environment was developed. Physically disabled children from a different school, who had never visited the target school, explored this simulation. They were trained to point to three objects in the environment that were not visible from the testing position. Following this training they were taken to the real school and given the same spatial tests that had been trained in the virtual school, and also some equivalent but untrained tests for comparison. As it was possible that the children could make intelligent guesses about the spatial layout of the environment in the absence of environment-specific experience, an able-bodied adult control group also completed the spatial tests within the real school. They were also unfamiliar with the test environment and had had no exposure to the virtual model (see Stanton et al, submitted a).

3.1 Participants

The participants in the experimental group were 7 physically disabled children, 6 boys and one girl. They had a mean age of 12.3 years. The control group consisted of 7 undergraduate students, 2 female and 5 male with a mean age of 25.6 years.

3.2 Materials

The primary section of Ash Field School in Leicester was created to-scale using the Superscape software. The environment consisted of an entrance door with a corridor leading into a central area and nine rooms.

The storeroom was located off the far end of the corridor. Four classrooms, a library area, a small office and the girls and boys toilets were located around the central area. All the rooms contained distinctive features.

3.3 Design and Procedure

Each child in the experimental group spent five sessions exploring the computer simulated environment. These sessions took place in their own school. During the final three sessions, when the participants stated they felt they now knew the layout of the environment they were asked to point to three target objects (which were not visible from their position) using the cross-sights on the computer screen. If their estimations were inaccurate, they were corrected. During sessions 4 and 5, after exploration of the simulation, the participant was asked to complete a route test. The experimenter positioned the child's viewpoint in a room and asked them to find a target room. Both the computer pointing task and the route test served as a training element. It was expected that participants would be better able to complete these tasks in the real school than new equivalent tests.

Experimental and control groups were subsequently taken to the real Ash Field school. Pointing accuracy was measured from two relative locations from which the children had completed computer pointing tasks in the simulation, along with a third untrained location. They were asked to estimate the direction of target objects from each of these locations using a hand operated pointing device.

Finally, each participant completed two route tests. They were taken to a room and were asked to move directly to a target room. The first route was identical to the one trained within the simulation. The second route taken was between two different rooms.

3.4 Results and Discussion

Children were more accurate than controls in pointing to landmarks that were not directly visible from three separate testing sites ($F(1,12) = 67.54$, $p < 0.01$). They not only completed the tasks previously trained in the virtual school, but they also completed spatial tests that had not been trained in the virtual environment equally well. They were able to point to objects not directly visible, and take the experimenter to places that they had visited whilst exploring, but never been formally tested on.

The most difficult task was expected to be pointing from the third untrained location, as there was a new viewpoint and new target objects to orient to. However, the experimental group were significantly more accurate in pointing than the control group from all three viewpoints, and their error scores from each viewpoint were relatively small and comparable. These results support the conclusion that the children had acquired flexible, effective internal representations of the environment from the virtual simulation, enabling them to orient themselves from a number of different positions within the real environment. Further, their way-finding ability (to adopt the shortest route between two locations) was also found to be more efficient than that of the control group (Mann-Whitney U test, $z = 2.01$, $p < 0.05$). These results add to the accumulating evidence that VE training transfers effectively to the real world and that this effect is evident even for people with physical disabilities whose spatial proficiency may be limited.

4. TRANSFER REVISITED

While this study successfully demonstrated transfer of spatial knowledge, it raised a number of points for further investigation. First, it is not necessarily the case that the unique features of virtual experience (apparent real-time movement, autonomy in directing displacements, experience of a 3-D representation) were responsible for the transfer effects. Possibly, any training that exposed participants to a depiction of the school environment would produce evidence of learning. Second, although an adult guessing control group has been used in related studies (e.g. Wilson et al, 1996), and probably represents a stringent control against which to compare the performance of disabled children, it could be argued that a control group from the same population, who do not have the same VE experience, would be preferable.

Therefore, we are following up this study, using the same school simulation, but with a much larger group of children and a more complex experimental design. In this study, a group of able-bodied children and a group of children with physical disabilities will be split into two subgroups. They will explore either (a) the original VE school simulation, and a physical model of a second school of similar complexity, or (b) a VE simulation of the second school, and a physical model of the original target school. Thus both subgroups will have VE and physical model experience, but only one group will have VE experience of the original school. As in the earlier study, all the children will then be taken for the first time to the (real) original school, and they will carry out the same spatial tasks as before. The results of this study are pending.

5. WORK IN PROGRESS

5.1 Vertical spatial encoding

The next development in our research program is to investigate the way people encode vertical as well as horizontal spatial information from exploration of virtual environments. For these studies we are using both simple multi-level experimental environments and a simulation of a complex shopping area based on a real life equivalent environment.

It may be that physically disabled children find vertical spatial encoding difficult as they are normally restricted to using lifts rather than stairs and escalators when moving between floors in a multi-level building. The lack of flow of visual stimuli could affect their orientation when moving from floor to floor. This may be a less serious problem if the lift is transparent (made of glass) and therefore one can see out of the lift while it is moving. In Wilson et al's (1996) study they found that although adults could point to objects on a different floor of the building, performance was poorer than when pointing to objects on the same floor.

While the shopping centre simulation is still in the development stage, we are using simple multi-level virtual environments to start to examine spatial encoding on the vertical plane. Participants will explore a virtual environment consisting of three floors. Each level contains a number of objects. Dependent on condition, participants will move between levels using either stairs or the lift. Following a period of exploration, participants will carry out spatial tasks which involved pointing to objects not visible from their testing position. Some of these objects will be located on the horizontal plane (the floor from which they will be tested) and others will be located on the vertical plane (on a different floor). The results from these studies are pending.

5.2 Elderly and social inclusion

We are also recruiting an elderly user group to take part in our studies. At the present time there is an emphasis on providing services to the home, for example web based shopping. Although in some cases this may prove efficient and advantageous, there is also the danger of social exclusion. By enabling elderly users to use virtual environments as a spatial navigational tool it is hoped to raise their confidence in visiting the real places, and therefore encourage social inclusion. Our elderly group will take part in spatial studies exploring virtual environments and subsequently visiting the real shopping centre.

6. CONCLUSIONS

We are accumulating evidence of the positive effect of exploration of virtual environments on spatial navigational skills. We continue to examine whether skills learned in virtual environments transfer effectively to real world environments. The challenge is not only to examine transfer from a simulation to it's real world equivalent, but also to examine more generally whether spatial skills in the real world improve after virtual environment experience. Additionally, an interesting aspect of our latest work, involving the simulated shopping centre will be to see how elderly users approach virtual environments and whether these types of environments can be integrated into the public domain.

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