Using virtual reality environments to aid spatial awareness in disabled children

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ABSTRACT

Several spatial tasks were presented to subjects in computer simulated environments to ascertain whether spatial skills could be trained and enhanced using this medium. Studies carried out at Leicester University have demonstrated that exploration of a simulated building by disabled and able bodied subjects allows them to acquire considerable information about the spatial layout of that specific building. The present studies extended these earlier findings. In Experiment 1, transfer of spatial skills between different virtual environments was investigated. The results confirmed that the skills disabled children acquired using computer simulated environments improved with exposure to successive environments. To eliminate the possibility that learning was non-specific, Experiment 2 compared 3-D exploration and 2-D (control) exploration, finding the former to be superior. Thus the interactivity and three-dimensionality of virtual environments seem to be crucial to spatial learning. Further research is being carried out to establish the nature and extent of the improvement in spatial skills of physically disabled children after intensive exploration of complex virtual environments and thus the value and limitations of VR as a training tool for children with mobility problems.

Keywords: simulated environments, spatial cognition, 3-D and 2-D tasks, physical disability, children

1. INTRODUCTION

Children with mobility problems are limited in their ability to explore their surroundings independently. Those who use a wheelchair may find some places inaccessible, and when guided by welfare assistants or helpers they may take repetitive routes over which they have no control. Children using walking aids may find it tiring and uncomfortable to walk long distances and they may be unable to explore freely for reasons of physical safety.

Limited independent exploration leaves children with poor spatial knowledge of environments, even familiar environments such as their schools (Foreman et al, 1989), and difficulty in coping with novel environments. They may have problems forming effective cognitive spatial maps, which impairs their ability to interpret secondary sources of spatial information such as cartographic maps, and to make detours or take short cuts when moving about in built environments. This poor spatial knowledge may have educational implications, but it also creates a feeling of disempowerment, adversely affecting the individual's confidence in public places (Foreman et al, 1995.) Thus, if a means can be found to improve spatial knowledge in disabled children, by providing independent exploratory experience from an early age, this could have a substantial impact on their overall quality of life, both as pupils and later as adults.

Computer-simulated environments appear to provide an ideal solution to this problem. Children can explore computer simulated environments independently using appropriate interface devices that are tailored to their particular skills and disability. They can explore freely and safely. Such exploration should increase their confidence in subsequent real life exploration, particularly if they can visit an environment in simulated form before encountering the real one. Moreover, spatial disorientation is not confined to disabled individuals; able bodied people who possess a poor sense of direction may also benefit from virtual exploration. Kozlowski and Bryant (1977) concluded that for people to show a good sense of direction it was necessary for them (a) to make a conscious effort to orientate themselves, and (b) to provide them with repeated exposure to the test environment. Clearly, both of these requirements can be met with ease and safety using virtual environments.

Studies carried out at Leicester University in the past have investigated the transfer of spatial knowledge from a virtual to a real environment, establishing that both able-bodied and physically disabled children can acquire substantial spatial knowledge from virtual exploration alone. Able-bodied 18-year old students from a sixth form college were tested in a first study. They had never visited the Psychology building before. Half of them explored a simulation of the building and half explored the real building. Both groups then completed a battery of spatial tests, which included the use of a pointing device to indicate landmarks (such as emergency exits and fire alarms, to which their attention had been drawn during exploration) which they could not see from the testing location. Half of each group was tested "in" the virtual test room (i.e., on computer) and half in the real test room. They were also asked to estimate distances between various objects and make plan and side elevation drawings of the building. It was found that all subjects were able to draw accurate maps and point to objects with greater accuracy than a control group who made reasoned guesses (Wilson 1993; Wilson and Foreman, 1993).

In a second experiment, ten physically disabled children explored the simulation of the Psychology building and were then given similar tasks to those described above. Exploration was encouraged in the form of a game in which the children had to locate fire alarms and fire hoses and activate them, thus unlocking a virtual fire door, from which they could "escape" from the building. The children were then asked to indicate, using the pointing device and by describing routes, where they thought items of fire equipment were located in the real building. Finally, they were asked to escort the experimenter to the real fire equipment and fire exit. Subjects were generally accurate in their angle estimations and could describe shortest routes to objects. They had clearly acquired a good deal of spatial information. For example, they could readily tell the experimenters which objects they expected to find behind doors as they were taken through the real building (Wilson 1993; Wilson and Foreman, 1993).

Similar results have been reported from the United States Army Research Institute in Orlando, where Regian and colleagues (Regian et al, 1992) evaluated how well able bodied subjects could learn to navigate through a virtual office building. Subjects trained in the virtual building learned better than those in the control group, who were shown a series of photographs of the building, and nearly as well as those who explored the real building. The researchers found that subjects learned both spatial-procedural tasks and spatial-navigational skills within a virtual environment. However Kozak et al (1993) failed to obtain transfer from a virtual environment to a real environment for a pick-and-place task. It is clearly crucial to address the issue of which tasks and skills do, and do not, transfer between virtual and real environments. To date, with a few exceptions (Azar, 1996), little work has been conducted to address such psychological issues concerned with human behaviour in virtual environments and to determine how behaviours in virtual environments may differ from behaviours in the real world.

The present studies extended the earlier work in Leicester, examining whether computer simulated environments could be used to train spatial skills generally, i.e., whether spatial-perceptual abilities per se are enhanced with repeated virtual testing. In Experiment 1 we examined whether skills acquired by children using simulated environments would transfer to others, experienced subsequently.

2. EXPERIMENT 1

2.1 Method

2.1.1 Subjects. These were 8 physically disabled children, 4 boys and 4 girls, having a mean age of 11.88 years. Children selected for the study were those having substantial mobility problems. School staff were asked to rate the mobility of each child on a scale of 0: independently mobile, to 10: completely immobile. The average rating was 4.7. Their conditions ranged from cerebral palsy to a heart condition. Every child was able to use a computer keyboard.

2.1.2 Design. Each subject explored three computer-simulated environments at fortnightly intervals. Each session consisted of an exploration phase followed by a number of tests of spatial knowledge. A different environment was explored in each session but the spatial tests remained the same. The independent variables were the layout of the environments and the positions of six target objects. The dependent variables were the subjects' angle estimations (made using two different types of pointing device), the time taken to find a specified object, and the quality of maps that subjects were able to draw of the experimental environment.

2.1.3 Apparatus. The experimental environments were created using Superscape Virtual Reality Toolkit and were presented on an Intel Pentium 90 with SVGA graphics, displayed on a 14 in. monitor. All three environments consisted of three rooms joined by a T-shaped corridor. Each room was subdivided into smaller sections using two or three walls of ceiling height. In the first environment each room was coloured differently: one burgundy, one pale green and one blue, such that they were clearly discriminable. In the corridor leading out of the central (pale green) room was a START sign. Movements of the viewpoint were controlled using keyboard arrow keys. The viewpoint was 18000 units in height and the walls were 45000 units high. Six objects were placed in the environment, two in each room. These objects were: a piano, an animated shape, a flag, a decorated shield, a camera, and a rotating globe. In order to measure the subjects' estimates of the positions of objects in the environment, three testing viewpoints were programmed, one in each room. At each viewpoint subjects could pan 360 deg. around the Y-axis, direction being recorded in 5 degree steps. These viewpoints were used to record accuracy of pointing using the screen cross-sights. The second pointing device was a hand held pointing device. This was made from a flat, circular piece of board

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coloured blue and red. A full circle was marked on the board, segmented in 5 degree steps and a moveable arrow, rotating about the centre of the circle, was used by subjects to indicate chosen directions/angles. When using the hand pointing device the same three testing positions were presented on the screen as were used for the computer pointing estimates. A schematic plan view of the environment (minus the objects) was generated on A4 paper for an object placement task, in which subjects had to place small crosses to indicate where they thought the objects were located.

The second virtual test environment was coloured differently. One room was pink, one turquoise and one orange, and the starting point was moved from the centre room to the right hand (orange) room. Six objects were placed in the environment, two in each room, in the same positions as those occupied by objects in the previous experiment. These objects were: a tank, a postbox, a traffic cone, a "no smoking" sign, a torch and an animated robot. In the third environment, the rooms were moved so that the room that was originally on the right hand side of the corridor was now on the left, the original left hand room being moved to the centre position and the original central room being to the right hand side. Each room was again coloured differently, one yellow, one dark green and one stone. The starting point was placed in the left hand (green) room. Six objects were placed in the environment, two in each room. These objects were: a rotating fairground wheel, a star, a map of the U.K., a car, a clock and an animated insect. Three testing viewpoints were again programmed; however they were positioned differently from those in the previous two environments. A stopwatch was used to measure the time taken to find a chosen object before and after exploration.

2.1.4 Procedure. Subjects were tested individually. At the beginning of each session the experimenter demonstrated a tour through the environment, beginning at the starting point and visiting each room in turn before returning to the starting point. Subjects were told to explore the environment, find the six objects, and try to remember both where the objects were located and the layout of the envivonment. They were made aware that their memory would later be tested. The subject was then given a demonstration of the type of pointing task that they would be asked to complete following exploration.

Before commencing general exploration, the subject was first asked to locate one object, picked randomly by the experimenter, as fast as possible. Latency to find the object was recorded and the experimenter then reset the viewpoint to the starting point. (On test days 2 and 3, the selected test object was always located in a different position from the one used in the previous session, and was always an object that occupied a location distant from the starting point rather than an adjacent location.) The subject was then asked to explore the environment for as long as necessary for them to feel confident about being able to carry out the tests. The experimenter monitored the subject's exploration to ensure that all six objects had been encountered. When the subject indicated that they felt confident about their familiarity with the environmental layout, the experimenter used the keyboard keys to "transport" them from the starting point to each of the testing points in turn, where they were asked to point toward all six objects in turn, either using the cross sights in the centre of the computer screen (half of the subjects) or the hand held pointer (the remaining half.). The three testing points were then retested in the same order. The subject was then given the same test but using the alternative pointing device (screen-based, or hand-held.) Each subject used the pointing devices in the same order for all three test environments. Note that since subjects were "led" from the starting point by the experimenter to each of the testing positions they could monitor their route through the environment. None of the objects was visible from any of the testing positions.

In the second environment the testing positions were in the same place as in the first, but they were visited in a different order. When the pointing task was completed the experimenter took the subject back to the starting point and asked them to find once again, as quickly as possible, the object that they had been asked to locate before exploration. The experimenter recorded the time taken. Next, the subject was given a blank sheet of A4 paper and asked to draw an outline of the test environment complete with all of the objects correctly positioned. Finally, a plan outline of the environment was presented to the subject who was asked to mark the positions of all objects as accurately as possible.

2.2 Results

A repeated measures analysis of variance (ANOVA) was carried out on median angle estimation error scores using the computer pointing device. A significant main effect was found, $F(2,14) = 6.56$, $p < 0.05$, reflecting significant differences among sessions. A Newman Keuls test showed that session 3 error scores were lower than those of session 1 and 2, but that scores for the latter sessions did not differ (Fig.1.) For equivalent scores using the hand-held device, no significant effects were obtained, $F(2,12) = 0.83$, $p > 0.05$.

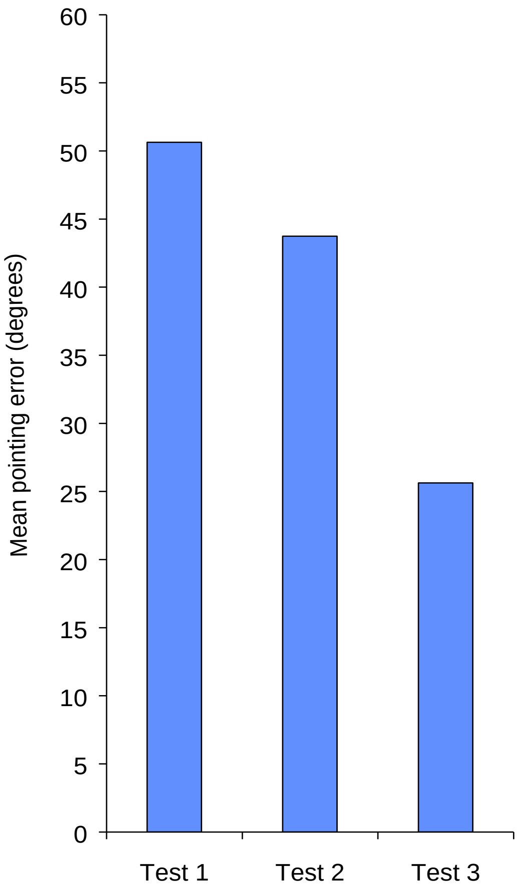

Figure 1. *Group error scores for angle estimations using the computer pointing device.*

The time taken to find a given object before and after exploration is shown in figure 2. One tailed t-tests were used to assess the significance of differences. There was a significant drop in the latency before exploration t (7) =2.64, p < 0.05 and also after exploration t (7) = 1.98, p < 0.05. Error scores for the mapping tasks were computed as the difference in degrees between the actual object direction and the childrens' indicated direction. These were averaged across objects for each map. A paired samples t-test was conducted on the mean error scores for objects positioned on an outline map. The mean error scores for tests 1 and 3 were 55.7 (SD=32.8) and 30.3 (SD=21.0), respectively; a difference that was found to be significant, t (7) = 3.02, p < 0.05. (Fig.4.) There was no significant effect for the hand drawn maps, t (6) = 1.63, p > 0.05.

2.3 Discussion

The results show that on several criteria, childrens' performance on spatial tasks improves with repeated experience of virtual environments. Improvement was evident when measured using the computer screen as a pointing device, but no improvement was seen when the hand pointing device was used. The latter device requires a fairly complex transformation from large-scale locomotor space to a small, artificial device, which proved difficult for the children to use. From their verbal reports, they appeared to have problems relating the direction of the pointer to real world locations. The ANOVA on the median error scores for angle estimations using computer pointing shows that error scores reduced significantly over trials, though post hoc analysis revealed that improvement was evident only by test 3 (which differed significantly from both tests 1 and 2.) Little improvement occurred between the first 2 test sessions, which did not differ significantly. Childrens' positioning of objects on an outline map improved significantly between test 1 and 3, though their hand drawn maps did not show any significant change. The latter measure is subject to great variability and is a less powerful measure of cognitive map formation. The average time the children required to find a selected object was greatly reduced after exploration, indicating that they had learned specific routes. However there was a general practice effect involved, inasmuch as children were faster both before *and* after exploration on the last session when compared with the first.

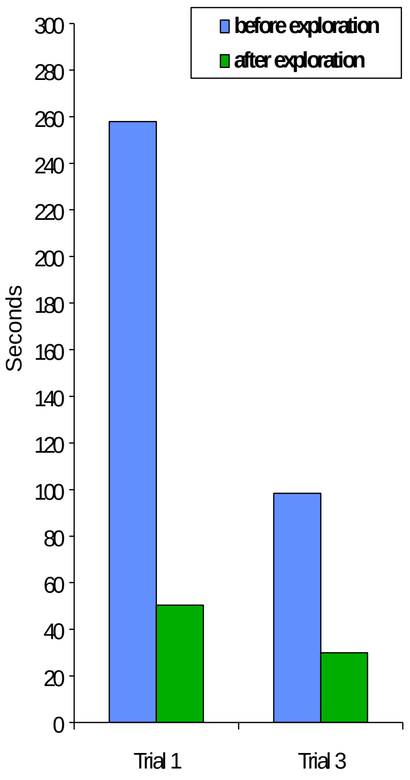

Figure 2. *Time taken to find a given object.*

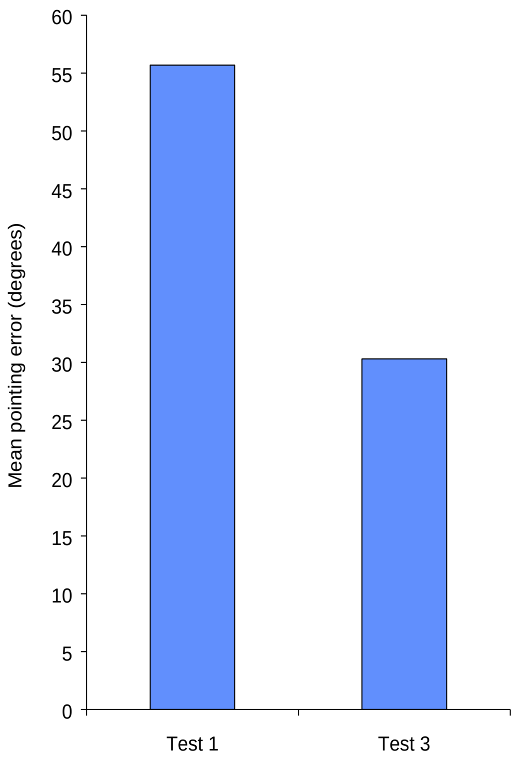

Figure 3. *Mean error scores for objects positioned on an outline map.*

No significant correlation was found between mobility and motor skill, but it is perhaps unrealistic to draw conclusions from a relatively small sample of subjects. A possible confounding factor in the experimental design was that the order in which subjects explored the environments was not counterbalanced. Although there may be differences between environments in terms of their navigability, this is unlikely to have influenced the results since each environment in the present study was constructed from the same basic elements (i.e., the same three rooms and the same corridor.)

The results of this study are very encouraging since diminishing error scores are likely to reflect children's improved use of some form of internal representation (cognitive map) which is necessary for the solution of the tasks. The fact that significant improvement only emerged in test 3 suggests that several exposures are needed for learning to take place. Nevertheless, having shown that childrens' spatial abilities improved after exploring virtual environments, it was necessary to establish that this improvement was due to the interactivity and three-dimensionality of the virtual environments and not to other non-specific factors such as improved confidence and familiarity with the experimenter, or computer and keyboard familiarity**.** This was examined in Experiment 2 by comparing 3-D exploration with 2-D (control) exploration. Navigational measures were supplemented by other spatial tasks, measuring various aspects of visuo-spatial skill, in order to test the generality of cognitive spatial improvement occuring after 3-D training.

3. EXPERIMENT 2

3.1 Method

3.1.1 Subjects. There were 24 subjects, 3 girls and 21 boys, having a mean age of 10.38 years. The subjects were selected on the same criteria as Experiment 1.

3.1.2 Design. A pretest consisting of a battery of three spatial tasks (see below) was followed by four 30 min. sessions of interaction with either two dimensional or three dimensional computer graphics in a "game" format. Subjects were then retested on the same battery of spatial tasks as before. Note that this design ensured that children in both experimental and control conditions spent an equal amount of time with the experimenter and gained an equal degree of familiarity with the keyboard.

3.1.3 Apparatus. The virtual environments used in Experiment 1 were reused in one of the spatial tests in this study, though here they were presented in counterbalanced order to avoid effects due to differential navigability. In addition the *Money Standardized Road-Map Test of Directional Sense* was used and an adapted version of the *Shepard and Metzler Mental Rotation Test*. The Money Road-Map Test requires subjects to follow a route through a stylised street map, and make judgments at 32 turning points as to whether a turn is to the right or to the left. (The difficulty in the task is that subjects have to make these judgments when "travelling" in different directions on the page.) They are not allowed to rotate the paper. The adapted Shepard and Metzler Test consists of thirty two pictures of a geometric shape which is composed of seven cubes. The shapes were created using Superscape Virtual Reality Toolkit and were printed in black and white. One shape was created and eight of the 32 pictures displayed this shape in different orientations, rotated in the (depth) z-plane by various angles about its centre point. Another eight pictures showed the shape rotated through various angles in the (picture) y-plane about its centre point. The original shape was then reflected 180 degrees and eight of the pictures displayed this shape at various degrees of (depth) z-plane rotation, and the final eight pictures displayed this shape at various degrees of (picture) y-plane rotation.

3.1.4 Procedure. Each child attended six test sessions. In the first session the child was given the Money Road-Map and the modified Shepard and Metzler Mental Rotation tests. Before taking the Money test, subjects were asked to indicate first their right hand and then their left ear. (All subjects could do this easily.) The map was then placed before the subject, who was told to imagine that they were following the path shown on the map and at each turn to say whether they would be making a left or a right turn. Subjects then followed a short practice route, the experimenter correcting any mistakes that they made. The full test then followed, during which no feedback or assistance was given.

For the Shepard and Metzler test, each subject was shown examples of the original shape rotating on the computer screen and was then tested on the thirty two pictures. They were provided with a reference picture of the original shape, and they were shown the thirty two pictures one at a time. The subject had to say, for each picture, whether it was the *same* shape as the reference or a *different* shape, the different shape being the reflected shape. Subjects were shown eight depth pictures (four the same, four different), eight picture plane pictures (four the same, four different), and sixteen of the depth and picture plane shuffled (eight the same, eight different). The pictures were shuffled between subjects.

At this point the child explored one of the novel environments used in Experiment 1 and completed the same spatial tests (finding an object as quickly as possible, estimating angles from given positions and drawing maps). Half of the children were assigned to the 2-D and half to the 3-D groups. The next four sessions consisted of individual 30 min. sessions of exposure to either two dimensional, or three dimensional environments which the child explored with the experimenter. The two dimensional environments were selected from the popular games market and consisted of non-violent platform and adventure games. The three dimensional environments were created using Superscape Virtual Reality Toolkit and consisted of large scale and small scale environments (such as a leisure centre or an office) in which the child could explore and interact with objects. The exploration was presented in the form of a game by asking the child to try and find objects and interact with them.

Finally**,** in the sixth session the children carried out the same tests as in the first session (the Money test, the Shepard and Metzler Test, exploration of a novel virtual environment) and was tested in the same way as previously. Note that the novel environment was different from the one explored in the first session.

3.2 Results

A two factor mixed ANOVA was carried out on the median error scores for computer pointing for 2-D and 3-D groups. An interaction was found between the 2-D/3-D factor and test sessions, $F(1, 22) = 6.34$, $p < 0.05$. A one-tailed t-test between two dimensional and three dimensional exposure on the post test revealed a significant effect $t(22) = 2.02$, $p < 0.05$. A related t-test on the two dimensional group from pre- to posttest revealed no significant difference ($p > 0.05$.). However a related t-test on the three dimensional group from pre- to posttest did reveal a significant difference $t(11) = 2.28$, $p < 0.05$. (Fig.4) The time taken before and after exploration at pretest and posttest in both conditions are illustrated in figures 5 and 6. Although the scores for the 3-D group, after exploration, were falling in the right direction, they failed to reach significance when analysed using a two factor mixed ANOVA, $F(1,22) = 2.41$, $p > 0.05$. A two factor mixed ANOVA carried out on the error scores for objects placed on the outline map, and on the hand drawn map revealed no significant differences from pretest to posttest or by condition. Test scores from both the Money and the Shepard and Metzler tests, analysed using a two factor mixed ANOVA, failed to reveal improvement from pretest to posttest.

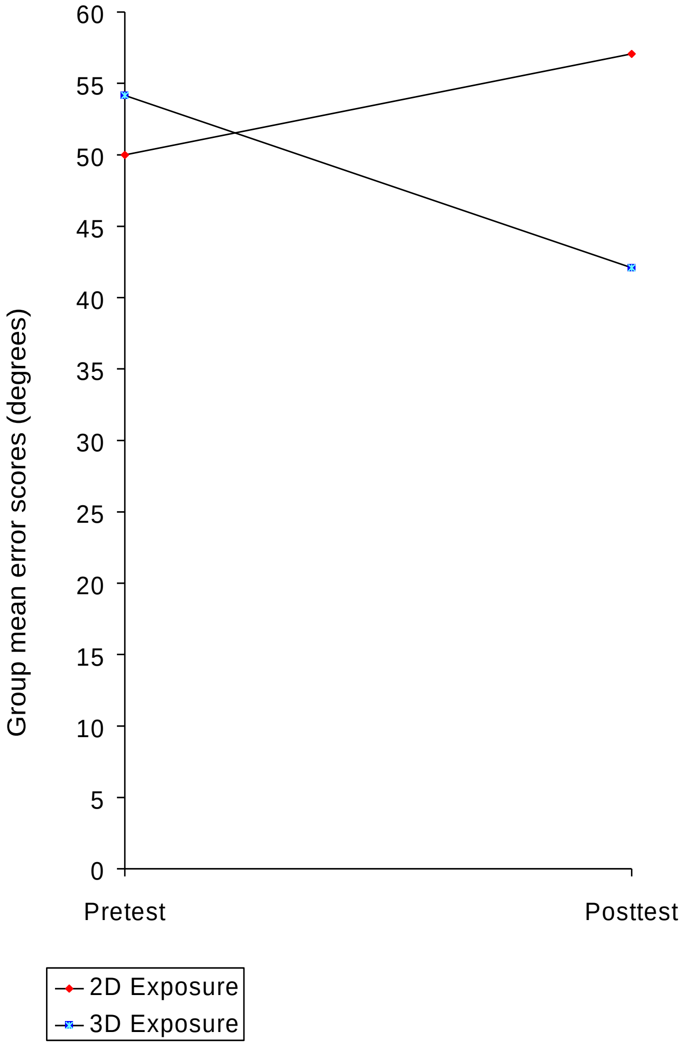

Figure 4. *Two dimensional vs three dimensional interaction for angle estimations using the computer pointing device.*

3.3 Discussion.

The results show that childrens' scores on navigational spatial tasks improve when they use 3-D training but not 2-D training. This was particularly clear from the task which we have found in this and other studies to be the most effective measure of spatial skill, namely the computer pointing task. The data support the notion that improvement in spatial skill seen in this and previous experiments is specifically due to the unique features of simulated environments created using 3-D graphics, and which provide both three dimensionality and real-time interactivity. The interaction reveals a difference between the performance of the 2-D and 3-D groups between pretest and posttest. While the rise in 2-D scores (i.e., a slight worstening in performance) between pretest to posttest was surprising, the significant drop in the scores of 3-D subjects (i.e., significantly improved scores) reflects their improved spatial performance. The reduced time taken to find a given object by 3-D subjects further reinforces this conclusion, suggesting that children in this group had learned routes and acquired navigational information of a kind that would be beneficial in an equivalent real environment. For the 2-D condition the posttest score (after exploration) was actually higher than the corresponding pretest score. This could not be due to differences in the navigability of the pretest and posttest environments, as the order in which they were used was carefully counterbalanced.

Measures of competence in drawing maps and placing objects on outline maps failed to reveal any improvements in the posttest phase, though these measures are subject to considerable variability, largely due to difficulties in choosing appropriate scoring criteria. We are currently investigating alternative criteria. The Money Road-Map and the Shepard and Metzler tests also failed to reveal improvement, after 2-D or 3-D experience, and thus we conclude that spatial skills learned in a virtual environment are fairly specific. There is apparently no generalisation to non-navigational skills, which may reflect a quite different set of underlying visuo-spatial cognitive abilities.

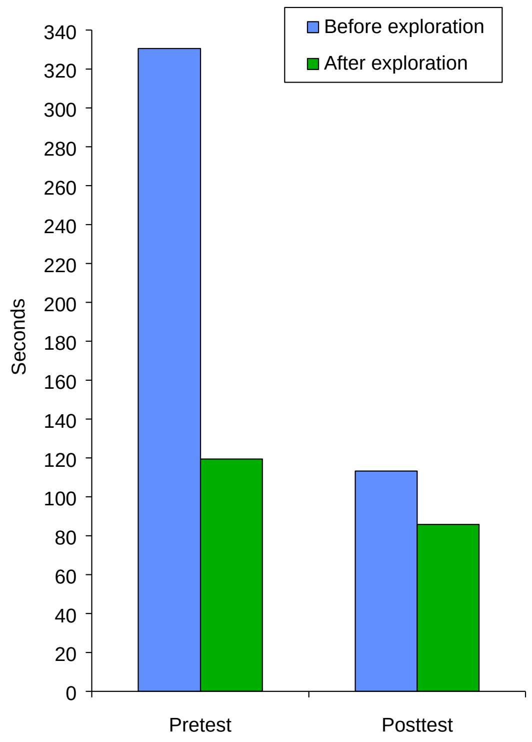

Figure 5. *Time taken to find a given object for the 3D group.*

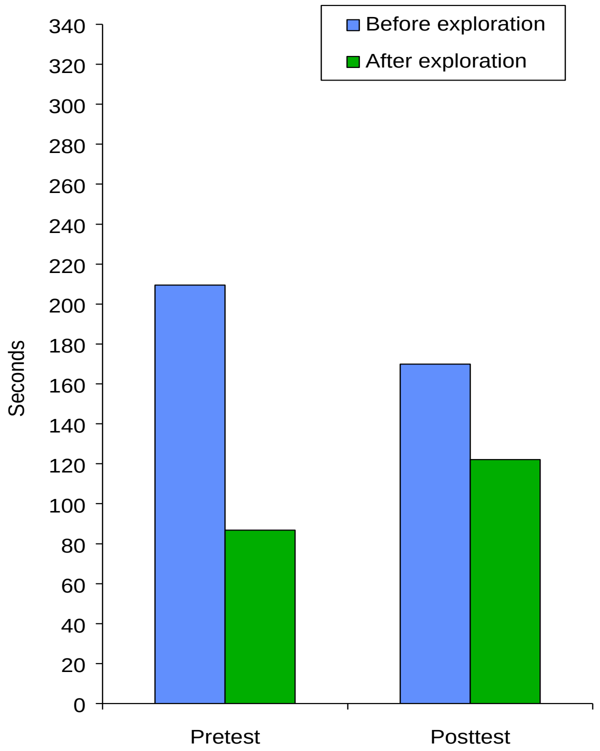

Figure 6. *Time taken to find a given object for the 2D group*

If this design were replicated, the 3-D environments used in the four 30 min. sessions could all be created as large scale environments. In the present experiment in which subjects explored large and small scale environments, it was found that when the subject was in a small scale space (just one room) little exploration took place. The subject spent the majority of the time purely interacting with objects. The problems children are most likely to encounter in reality are more likely to occur in larger scale environments where goals can not be viewed from one point in the environment.

4. GENERAL DISCUSSION

It is evident from the present studies that there is a transfer of spatial skill from one virtual environment to another and that this improvement in spatial ability is primarily due to the interactivity and three dimensionality of virtual environments. These results have important implications for disabled children in that virtual reality is proving to be a potential training medium for skills that could enhance quality of life for many disabled children. The software used in the present study is affordable by many schools. We have shown that subjects acquire information from virtual exploration which enables them to understand the spatial layout of an environment to a considerable degree. However, it is important to discover the optimal ways of presenting virtual information, and the optimal modes of interaction. We are currently investigating alternative input devices, and screen, projection and head-immersion modes of presentation, using a variety of cognitive spatial (detour and short-cut) tests, in order to assess what aspects of spatial skill are successfully acquired when subjects navigate in virtual worlds, and whether alternative modes of presentation and interactivity may be used to provide more comprehensive training.

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