Interface familiarity restores active advantage in a virtual exploration and reconstruction task in children

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ABSTRACT

Active exploration is better than passive observation of spatial displacements in real environments, for the acquisition of relational spatial information by children. However, a previous study using a virtual environment (VE) showed that children in a passive observation condition performed better than actives. The active children were unpractised in using the input device, which may have detracted from any active advantage, since input device operation may be regarded as a concurrent task, increasing cognitive load and spatial working memory demands. To investigate this hypothesis, 7-8 year-old children in the present study were given 5 minutes of training with the joystick input device. When compared with passive participants for spatial learning, by having them reconstruct in reality the environment explored virtually, active participants gave a better performance than passives, placing objects significantly more accurately. The importance of interface training when using VEs for assessment and training was discussed.

Running header: interface familiarity and virtual spatial learning

Key words: spatial learning, virtual environments, activity and passivity, children

Introduction

A controversial finding in several recent studies using virtual environments (VEs) is that active participants can learn less about the spatial layout of a VE than passive observers (Arthur, 1996; Sandamas & Foreman, submitted; Wilson & Peruch, 2002). This may be due to the cognitive effort required in using an unfamiliar input device to navigate virtual space. Passive participants, who view the displacements of an active participant, have a full complement of cognitive capacity to apply to learning the spatial layout of the VE, but active participants must attend to the spatial learning task while simultaneously operating the input device (joystick, mouse) to make directional choices.

A passive advantage contradicts many real world studies in which active participants apparently benefited from their high level of engagement with the spatial task. However, the latter studies have usually involved adults moving in large spaces such as towns (Appleyard, 1960). Where smaller scale experimental environments have been used these have usually not involved adults, but children, who have explored by either walking (e.g., Feldman and Acredolo 1979; Herman, Kolker & Shaw 1982; McComas, Dulberg & Latter 1997) or crawling (Benson & Uzgiris 1985). Walking and crawling are obviously natural movements, which once mastered require little, if any, cognitive effort, allowing active explorers a nearly full complement of cognitive capacity to apply to the spatial learning task. Therefore, a major confounding influence that differentiates being active in real space and in virtual space is mode of exploration and the relative cognitive effort that it demands.

When tested with cognitively demanding modes of exploration, children may be especially vulnerable to interference, due to the immaturity of their attention span and working memory capacity. Pascuell-Leone (1970) has suggested that children’s information processing rate is limited due to restricted working memory or ‘M-space’ capacity, which may be occupied by one concurrent task, reducing performance on another. Case, Kurland and Goldberg (1982) similarly suggested that children’s short-term storage space (STSS) is limited, so that attentional resources must be divided between information processing and storage. They proposed that if resources are utilised to conduct difficult operations, fewer remain available for storage of novel cognitions. Such a model would explain why active children are unable to form accurate spatial representations of a VE, compared with passives (Sandamas & Foreman, submitted) and why older children performed better, since they have greater capacity in reserve for information storage.

Working memory capacity limit per se may not be the only constraint affecting active and younger participants. Cowan (1997) suggests that the critical variable changing with age could be the ability to carry out two tasks concurrently, depending on how competently the focus of attention can be switched or divided between them. Note that Flach (1990) has previously suggested that control of attention could be one of a range of variables potentially accounting for differences observed between active explorers and passive observers. This could apply particularly to children. Bjorklund and Harnishfeger (1990) argued that children are less able than adults to inhibit irrelevant information from working memory and that this places extra demands on available storage space. Indeed, Yakovelev and Lecours (1967) have shown that the frontal lobes, structures implicated in the simultaneous holding and inhibiting of diverse information (Goldman-Rakic, 1992), do not mature completely until adolescence.

Interference between “attention-demanding” tasks, and the reduction in performance of one as performance on the other increases, may be explained in various ways (see Meadows, 1986; Baddeley, 1993; Cowan, 1997 for reviews) but there is general agreement that the phenomenon exists and is robust (Baddeley, Lewis, Eldridge and Thomson, 1984), especially in children (Guttentag, 1989).

The dual-task approach is the most commonly used paradigm for gauging resource demands on working memory. For example, Murdock (1965) had participants learn a list of unrelated words while performing card-sorting tasks of varying complexity, finding that words successfully recalled was inversely proportional to the difficulty of the particular card sorting task. Guttentag (1984) showed that the speed at which children tapped a computer keyboard key reduced by as much as 40% when they were required to concurrently learn a word list. Miller, Seier, Probert and Ayers (1991) found that a secondary finger-tapping task was disrupted when young children were required to learn the spatial locations of a number of target pictures fitting a particular category.

In the context of navigation and wayfinding, Garden, Corwoldi and Logie (2002) found that in adults, both spatial tapping and articulatory suppression tasks interfered with the primary task of route learning from a segmented map (experiment 1) or in a real town centre (experiment 2). Interestingly however, whilst spatial tapping impaired the main task to a greater degree in experiment 1 it did so only for participants who had rated themselves highly on visuo-spatial abilities in experiment 2. For participants who did not rate themselves highly, the articulatory suppression task caused more interference with their route learning ability. Garden et al (2002) concluded that whilst maps are an almost completely visuo-spatial medium, real environments offer more varied cues to the different components of WM, although high spatial ability participants still rely heavily on the visuo-spatial component of WM.

It is possible for humans to overcome working memory limitations. Baddeley (1993) suggests that 'over-learning' may be a crucial factor in determining the extent to which concurrent tasks interfere with each other. For instance, anecdotal evidence would suggest that experienced drivers are able to drive competently while maintaining a conversation, but a novice driver may need to devote all their attention to controlling the vehicle. Experimental evidence has shown that with sufficient training humans are able to perform extremely complex concurrent tasks with minimal or no interference (even when those tasks are not normally practiced together). For instance, Allport, Antonis and Reynolds (1972) had a number of skilled pianists sight read and play a piece of music, and Shaffer (1975) had a skilled typist copy type, whilst simultaneously listening to and repeating back a continuous stream of prose. Spelke, Hirst and Neisser (1976) trained participants to perform concurrent tasks in which they were not previously especially skilled, finding that after 20 weeks of practice participants could take dictation whilst reading and comprehending a story totally unrelated to the dictated material, which they could nevertheless comprehend. Schneider and Shiffrin (1977) coined the phrase ‘automaticity’ to describe the absence of interference between the seemingly automatic performance of a well-trained or over-learnt task and concurrent activities, and Ericsson and Delaney (1998) concluded that expert performance reduces the load on working memory through the automatisation of serial processes. In summary, training or over-learning on a task would appear to reduce the cognitive effort required to perform it, freeing-up working memory and/or attention to perform a simultaneous concurrent task.

The aim of the current experiment was to apply this model to virtual spatial reconstruction by children (Sandamas & Foreman, submitted), by providing participants with a suitable period of training in operating the device used to navigate the VE. The children were familiar with such devices from home computer use, and thus the purpose of training here was to familiarise them with the device in the context of VE navigation. Our pilot studies had shown that this occurs after about 5 minutes of practice, and Tlauka, Brolese, Pomeroy and Hobbs (2005) found that a period of 4-4.5 minutes was typically required for participants to become familiar with keyboard-based navigation of a VE. We hypothesised that providing this training would reduce the cognitive load on participants in the active condition who should therefore show improved performance, rising to the same, or a better, level of performance than participants in the passive condition.

METHOD

Participants

Forty-two children (26 females and 16 males) aged between 7 and 8 years old and all in class year three of a London junior school. All had normal or corrected to normal vision.

Test environment

The school provided a classroom $4m^2$ in which to undertake the study. The room, used to teach children with special educational needs, was well lit with fluorescent lighting but had no source of natural light. In the centre of the room were 2 tables, each 60 cm high and measuring 50x100 cm, combined to form a continuous surface area of 1 m^2. A floor plan of the VE was placed on this surface, on to which participants could conveniently place models of the objects that they had encountered within the VE. In one corner of the room, as far as possible from the floor plan, was the computer system on which participants experienced the VE. When sitting at the computer desk participants were facing away from the floor plan.

Materials

The VE was created using SuperScape 3-D virtual reality software, run on an IBM compatible laptop computer (Toshiba Satellite Pro 4600) with a Pentium 3 processor, and displayed on a 14 inch colour television monitor (Minoka MK 1499) having video in and video out facilities. A view of the environment is shown in Sandamas and Foreman (submitted). Movement through the VE was controlled using a PC Line Tournament six-button joystick allowing forward and backward movements and lateral translational movements. The virtual exploratory displacements of participants in the active condition were recorded using a Sony Handycam Digital Video Recorder (9DV PAL).

A floor plan of the VE, measuring 84 x 70 cm., was printed on to card on to which a $1cm^2$ grid could be overlaid for the recording of object positions. Each quadrant of the plan was 36 x 31cm, the dividing roadways being 4cm. wide.

The same ten models were used as in our previous study (Sandamas & Foreman, submitted), but these were recreated to match the scale of the new floor plan. Images of the virtual objects were printed, mounted on card and cut to shape. These flat 2-dimensional models stood on to-scale bases in order to provide appropriately sized footprints.

Procedure

The participants were randomly allocated to either the active or passive condition (both N’s = 21, 8M, 13F), and were tested individually. Each participant received 2 trials: they experienced the VE twice, and reconstructed it in real space on each occasion using the plan and models described above. A one-minute delay was interposed between trials, so that the procedure closely followed that of Sandamas & Foreman (submitted) in which participants experienced the VE in active/passive pairs.

When each participant entered the classroom their attention was directed to the floor plan of the VE. They were directed to stand in front of the floor plan (at the South end) where their attention was guided to its features. The positioning of the trees in relation to the floor plan was emphasised, since these provided particularly salient orienting features for subsequent reconstructions.

The child’s attention was then directed to the model buildings. These were placed along one edge of the floor plan, not in the locations that would later be experienced during testing. In order to ensure that the children had no difficulty in recognising the real models from their virtual representations they were shown each individual virtual model on a computer screen and asked to indicate the real space equivalent by pointing to it on the table. All of the children completed this task with ease.

After the recognition task all participants were given 5 minutes of practice using the joystick to navigate around a VE that was created as a training environment. It consisted of a flat circular area on which were placed a number of unusual objects such as boats, planes cars, statues and fairground rides, down-loaded from the SuperScape object warehouse. Participants were encouraged to navigate around the VE, viewing as many of the objects as possible from as many angles as possible, both in order to familiarise themselves with the 3-dimensional nature of the VE, and obtain ‘hands on’ experience in using a joystick.

Following training, participants were informed that they were going to experience a computer representation of the floor plan they had been shown earlier, on which would be virtual representations of the model buildings they had previously identified. They were told to try and remember the positions of the virtual buildings so that they could put the model buildings in the correct places on the floor plan. All the children indicated that they understood the task.

Each active participant’s exploratory displacements (viewed at eye height) were taped and then viewed by the subsequent passive participant. Active participants were allowed to explore the VE for 2 minutes on trial 1 and for 1 minute on trial 2. Passive participants were told that they would be watching a film of somebody exploring an environment. They observed both trials.

After each trial, each participant was asked to reconstruct the VE by placing the models on the floor plan. The experimenter recorded the positions of the participant-placed objects using the grid to note down their co-ordinates. An object placement error score was calculated by summing the distances in cm between the participant-placed objects at test and their true positions on the original floor plan, using the centres of the footprints as the reference points.

RESULTS

Figure 1 Mean error placement scores for male and female participants, in active and passive conditions by trial

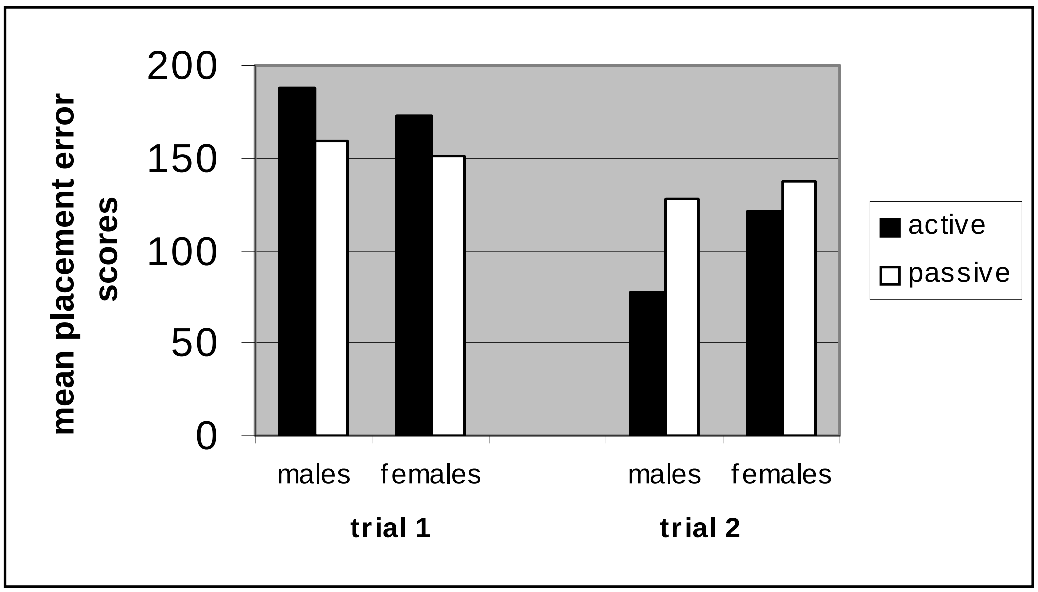


Figure 1 shows the performance of male and female participants on trials 1 and 2.

Placement error scores were the dependent variable in a 2 x 2 x 2 (gender x condition x trial) 3-way mixed factorial ANOVA, the conditions being active versus passive, and trial being trial 1 versus trial 2, the latter being a repeated measure.

The analysis revealed a significant main effect for: Trial, $F(1,38)=25.75$; $p<.01$, error scores reducing significantly (trial 1 mean: 165; trial 2 mean: 119) but not for Condition, $F(1,38)=0.03$;$p>.05$ or Gender, $F(1,38)=0.11$;$p>.05$.

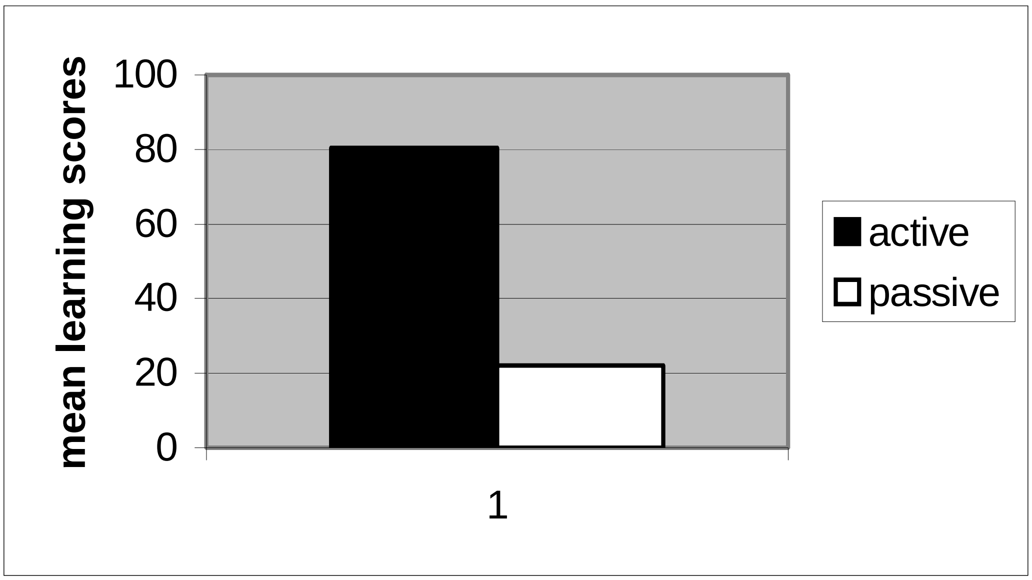
A significant interaction between Trial and Condition was revealed, $F(1,38)=8.36$; $p<.01$, but the Trial by Gender, $F(1,38)=3.60$;$p>.05$, and Trial by Gender by Condition, $F(1,38)=1.10$;$p>.05$, interactions were non-significant.

Post-hoc paired samples t-tests, for the Trial by Condition interaction indicated that placement accuracy improved significantly across trials for both conditions, Active $t(19)=3.94$, $p<.05$, Passive $t(21)=2.24$, $p<.05$. Independent samples t-tests did not indicate a significant advantage for either condition at either trial, Trial 1: $t(40)=0.26$, $p>0.05$, Trial 2: $t(40)=0.21$, $p>.05$. Inspection of the means however, indicates that arithmetically, active participants improved to a greater extent than passives (Figure 1).

In order to further investigate this finding, trial 2 scores were subtracted from trial 1 scores and the difference between the two scores designated ‘learning’ or ‘improvement’ scores. These were subjected to a univariate ANOVA with Condition and Gender the between-subject factors. There was a significant main effect for Condition, $F(1,38)=8.36$; $p<.01$, and an effect approaching significance for Gender, $F(1,38)=3.60$; $p<.07$. Active participants' learning scores were significantly superior to those of their passive counterparts, while male participants’ learning scores tended to be higher than those of their female counterparts. The Gender x Condition interaction was not significant, $F(1,38)=1.10; p>.05$.

Figure 2

Mean learning scores in active and passive participants.



DISCUSSION

The present study has shown that spatial learning transfers successfully from virtual exploration of a VE to a real space, which is consistent with many previous findings in children and in adults (Foreman et al, 2003, 2005; McComas et al, 1998; Tate, Silbert & King, 1997; Wilson et al, 1996, 1997), and in this case to a model space, as in an earlier study (Sandamas & Foreman, submitted). The present data also reinforce those of Sandamas & Foreman (submitted) who found that children significantly improved their reconstructions between trials 1 and 2. The significant effect of Condition for learning scores here indicates that the accuracy of active participants' spatial representations improved to a significantly greater degree across the two trials than did those of their passive counterparts.

The findings support the hypothesis that appropriate training in the use of an input device used to navigate virtual space would lead to an increase in the spatial learning of active participants. In the earlier study of Sandamas and Foreman (submitted), active participants were given only brief instruction on how to use the joystick, on the assumption that the use of such a simple and familiar device in VE navigation would not be problematic. However, the experimental hypothesis advanced in that study, that active participants would perform better than passives, was not confirmed, since a passive superiority was obtained. The present data have confirmed the most likely explanation to be that the input device (used in the specific context of VE navigation) was sufficiently unfamiliar to have occupied working memory capacity or attention, thus depressing performance in active participants. Training in the use of the input device, in the present study, restored the active advantage. This may be because training rendered the use of the joystick less cognitively effortful for active participants. Indeed, it might be argued that by reducing the cognitive effort associated with virtual displacements, the experimental task was made to resemble more closely the spatial tasks conducted in real space that have shown benefits of activity (Feldman and Acredolo 1979; Herman et al, 1982).

In particular the current findings are now consistent with those of Herman (1980), who found that activity within a real environment facilitates spatial learning of that environment. The results illustrate that similar results can be obtained by training children in a real environment and in a VE; Herman's active participants walked around the real to-be-learned environment, while participants in the current study used a joystick to explore an equivalent VE.

While many studies have shown that the spatial learning attained from VEs can be equivalent, or nearly equivalent, to that obtained in real space (Ruddle et al, 1996; Wilson et al, 1997; Witmer et al, 1996), differences between real and virtual experiences cannot be ignored (Peruch and Gaunet, 1998) and these differences must affect learning. For instance, McComas, Pivik and LaFlamme (1998) reported that children after VE training performed comparably to those trained in the equivalent real environment but only after three practice trials, before which real environment-trained children were superior. These findings could be interpreted as indicating that while equivalent real and virtual environments offer equivalent spatial information, this information may not be as readily available to explorers of virtual space as it is to explorers of real space. This in turn may reflect the fact that explorers of virtual space must first adjust to mode of exploration (i.e. type of input device) and the type of space being explored (i.e. virtual space) whereas explorers of real space are already familiar with the mode of exploration (i.e. walking) and the world in which they find themselves, if not the particular experimental environment.

Satalich (1995), who used a complex virtual building to compare navigation conditions, reported that VE training might only be advantageous over map-based training when long training periods are allowed (around 4 hours, depending on environment complexity). This suggests that real and virtual media are qualitatively different, and that participants may need time to adjust to the uniqueness of virtual exploration. That a VE can have disorientating effects, at least on initial exposure, was reported previously by Arthur and Hancock (2001). They found that in adult participants, activity promoted a more robust knowledge of the spatial layout of a VE compared with experiencing the layout in map or static VE form (i.e. a single screen shot), but that the active participants took significantly longer to learn the layout. This may be another example of the need to adjust to input device control where a VE is explored (see also Waller, 2000). The idea that active explorers are more prone to initial disorientation than passive observers but go on to develop better spatial knowledge of a VE is supported by the current findings. Here, active observers were arithmetically worse than their passive counterparts at trial one but underwent significantly greater improvement by trial two. It could be argued that passive participants are able treat the virtual display as a standard televisual presentation of a kind with which they are all familiar via television viewing and therefore are not prone to initial disorientation.

The results of Sandamas and Foreman’s (submitted) study might be taken as evidence against using VE training with children. Yet the present study indicates that active experience can have the same conventional beneficial effects in a VE as in a real environment and may thus be used to educate spatial cognitive systems in children whose immaturity limits their use of spatial strategies. Siegel and White (1975) concluded that for children the development of spatial representations is greatly facilitated by and possibly even dependent on actively moving through the environment, and this feature of spatial exploration can be built into VE experience, by ensuring familiarity with the input device that is employed.

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