Spatial reconstruction following virtual exploration in children aged 5-8 years: Effects of age, gender and activity-passivity

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Abstract

Children of 5-6, 6-7, and 7-8 years explored a virtual environment (VE) consisting of 8 buildings distributed in a square arena marked off into 4 quadrants, as employed in an earlier study by Herman (JECP, 29, 1980). The children twice experienced a virtual model, actively (operating an input device) or passively (viewing displacements only) in yoked pairs, or individually from selected perimeter viewpoints. Following the exploration phase, all children were asked to use cardboard models to reconstruct the environment. As in the earlier Herman study, performance (judged from placement distance errors) improved with age, and with learning across two successive trials, and no difference was obtained between males and females. However, a dissimilarity from the earlier study was that participants in the active condition showed no advantage over participants who viewed the environment from the perimeter. Participants passively observing displacements demonstrated significantly superior spatial learning. Reasons for the absence of an active advantage and the presence of a passive advantage were discussed.

Key words: children, virtual environment, age, gender, activity, passivity

Running header: children’s active and passive exploration in virtual space

INTRODUCTION

Many studies have shown that when tested in real environments, adults allowed active exploration acquire more spatial information about that environment than those having only experienced it as passive observers (Appleyard, 1970; Hart and Berzok, 1982). This is particularly so in large-scale spaces, i.e., those that cannot be viewed simultaneously from a single vantage point (see Kuipers, 1978), such as when travelling across a town (Appleyard, 1970).

In children, Piaget and Inhelder (1967) emphasised sensori-motor activities as being vital for effective spatial learning. Indeed, Benson and Uzgiris (1985) found very young children to be less successful at finding a key in an enclosed space when they had been previously carried around it than if they had previously crawled around it independently. Lee (1968) proposed that spatial representations can be regarded as the consequences of practical activity in space, and Siegel & White (1975) argued that actual locomotion through space is usually an essential prerequisite for the formation of effective spatial representations (see also Shemyakin, 1962). Consistent with this suggestion, Feldman and Acredolo (1979) found that preschoolers who were allowed to make self-guided locomotor exploration around an environment showed greater spatial memory for the layout of the environment. In particular, children in an ‘active’ condition (who explored alone) were more accurate than children in a ‘passive’ condition (accompanied by an adult) at relocating a lost object in an unfamiliar hallway. Mode of observation has also been found to be important. Herman (1980) found 5 and 8 year-olds' reconstructions of a model town to be more accurate if they had walked through the town rather than viewing from around the perimeter.

Interestingly, despite the volume of research indicating that active exploration especially enhances environmental spatial memory (for layout or survey representations), it remains unclear which aspect of active exploration is key to the formation of mental maps -- whether actual physical movement in space, i.e., motor activity per se, or the cognitive processes that are invoked while navigating in space, such as modes of perception and attention, selection of routes, or other forms of active engagement of thinking processes.

Foreman, Foreman, Cummings and Owen (1990) found that groups of children given completely autonomous active choice in moving themselves autonomously, or directing their displacements while motorically passive performed better on a multiple-goal searching task in a single room environment than did groups that were either purely passive, or motorically active but choice-passive. In a follow-up study, Foreman, Gillett and Jones (1994) confirmed the findings of Foreman et al (1990) and emphasised the importance of autonomous choice in the development of both across-trial and within-trial memory in a multiple-goal task. They emphasised the ecological validity of this kind of task, which is comparable with the behaviour of children when searching for toys, distributing sweets to friends or exploring an unfamiliar environment. On the other hand, McComas, Dulberg and Latter (1997) found, in their partial replication of the Foreman et al (1990) study (but using a single training and test session), that active choice in training was less important than movement, since they found that children denied spatial choice but allowed active movements during training trials performed better than those moved passively.

Other studies have suggested that the importance of autonomous movement in space becomes reduced with increasing age, so that older children appear to be less reliant on self-governed exploration to construct spatial representations. For instance, Herman (1980) found that third graders were more accurate on subsequent tests of spatial knowledge acquisition than kindergarteners, regardless of whether they had experienced active or passive engagement with the test environment, and Herman, Kolker & Shaw (1982) found that 5 to 6 year-olds depend more on motor activity than do 8 to 9 year-olds when learning the position of landmarks in a novel environment. Siegel, Herman, Allen and Kirasic (1979) found that accuracy in reconstructing a small-scale model town increased as a function of developmental level, in addition to familiarity with the environment. This is in agreement with the findings of Feldman and Acredolo (1979), using a relocation of a lost object task. In order to find a theoretical explanation for the age effect, they argued that children at the pre-operational stage should benefit more from self-directed exploration than concrete-operational children because concrete operational children's knowledge of projective and Euclidean space should allow them to more efficiently encode spatial information, regardless of mode of exploration.

Indeed, Piaget and Inhelder (1967) argued that children have the ability to differentiate topological shapes at the pre-operational stage but are unable to represent projective shapes and concepts of Euclidean space until the concrete operational stage. Piaget (1968) went on to suggest that as the most primitive form of memory, recognition memory depends mainly on sensori-motor schemata whilst higher level reconstructive spatial memory can be activated with much less stimulus support. Smothergill (1973) proposed that what he called “visual evocative memory” is the last to develop ontogenetically. In essence, free recall evocation memory refers to the ability to draw on mental spatial representations (perhaps in the form of a cognitive map) without the need for any present stimulus support.

On the other hand, there have been several studies showing that active exploration promotes especially good spatial learning in adult participants. For instance Appleyard (1970) found that 80% of people who commuted by bus were unable to draw a coherent map of the roads on which they travelled, while those driving themselves to work could typically produce coherent maps. Hart and Berzok (1982) pointed out that car passengers learn less about the spatial layout of towns than do drivers.

Research in spatial cognition has benefited in recent decades from the introduction of virtual environments (VEs). Defined as computer-generated three-dimensional environments that can be explored and interacted with in real time (Wilson 1999), VEs offer many benefits for the definitive study of spatial learning and memory. For instance whilst it is difficult to control for all environmental parameters in real settings (Peruch & Gaunet, 1998), VEs allow the experimenter laboratory levels of control whilst offering participants an experience more ecologically valid than any of the 2-D alternatives such as static photographs or non-interactive film. For instance, in a VE it is possible for participants to explore entire buildings or towns, in real time, whilst sitting at a computer in a laboratory. In addition, experimenters can ensure that each participant has exactly the same visual experience whilst being able to manipulate the environment – for example, alter a building's architecture, size, features or lighting – to explore the effects of various environmental changes on spatial learning.

Despite some obvious differences between virtual and real environments – VE presentations involve narrow visual fields, sometimes slow image rendering, optical distortions (Peruch and Gaunet 1998), and lack of vestibular and tactile feedback (Wilson, Foreman, Gillett and Stanton 1997) - studies have indicated that there exists considerable similarity between the spatial knowledge acquired from virtual and real experiences, in particular of the kind required for navigation (see Peruch and Gaunet, 1998 for a review). Foreman, Stanton, Wilson and Duffy (2003) found that disabled children, following exploration of virtual reality simulations, acquired more detailed information about the spatial layouts of real buildings than after experiencing desk-top models. In another experiment, Wilson, Foreman and Tlauka (1996) found that participants who explored a to-scale virtual version of a multi-storey building performed at an equivalent level to participants who had explored the real building on a task requiring pointing judgements to be made to unseen locations task, demonstrating effective transfer of learning from a VE to the real world. Similarly, Ruddle, Payne and Jones (1997), who replicated a real world experiment previously conducted by Thorndyke and Hayes-Roth (1982) but using a VE, concluded that participants who learn the layout of virtual buildings develop route and survey knowledge equivalent to that acquired by people who learn their way around real buildings. Further evidence was provided by McComas, Pivik and LaFlamme (1998) who found that children trained in real space had no advantage over those trained in a VE on a location of hidden objects task.

However, despite the large amount of evidence indicating the equivalence of learning in real and virtual worlds, there is one prominent exception: studies using VEs have rarely reported beneficial effects of active exploration (Wilson, 1999; Peruch & Gaunet, 1998). For instance Wilson et al (1997) found no evidence to suggest that psychologically active (directing the course of exploration) or motorically active (controlling virtual displacements via control of the input device) participants gained any advantage in a pointing to unseen objects task over their passively observing counterparts. Similarly Wilson (1999) reported that active participants were not superior to passive observers on an orientation task and that there were no significant differences between the two groups on memory for objects tasks. In addition, Gaunet, Vidal, Kemeny and Berthoz (2001) reported that they could find no difference between participants who had actively explored a virtual town by directing displacements along a series of streets and passive participants who viewed a route imposed by the computer, on subsequent tests of spatial memory performance.

However, exceptions exist. Peruch, Vercher and Gauthier (1995) did find that participants were better able to reach a specified unseen target using the most economical route after active exploration of a VE than after passive observation of pre-recorded displacements. Supporting data were reported by Pugnetti, Mendozzi, Brooks, Attree, Barbieri, Alpini, Motta and Rose (1998) who found that both healthy participants and those with Multiple Sclerosis benefited on a recall of spatial layout task after active exploration of a virtual house. They did not, however, perform better than their passive counterparts on a recall of virtual objects task. Interestingly, Attree, Brooks, Rose, Andrews, Leadbetter & Clifford (1996) found that under conditions where spatial learning is secondary to another task, passive participants out-performed actives when recalling objects encountered during exploration of a VE. However, this is controversial, since Wilson (1999) failed to find a difference between active and passive participants when a spatial task was secondary to a memory-for-objects test. In this instance all participants were told they would be tested on the number of objects they remembered but not that their memory would also be tested for object location. Wilson concluded that procedural differences such as within-and-between-participant comparisons, measures of spatial learning, and type of task employed may affect the quantifiable benefits of active engagement in a VE (see Wilson and Peruch, 2003).

This issue is important in relation to children, who might require different training regimes from adults when using VEs. In order to make a direct comparison between virtual and real world spatial testing in children, the present study utilised a virtual town similar in design to the model-town used by Herman (1980). In his original studies, Herman investigated cognitive mapping skills in children aged 6 to 9 years, who were required to study a model town, either by walking within it among the buildings or by observing it from the perimeter, from where all the buildings could be viewed. They then had to reconstruct the model from memory, the accuracy of the reconstruction being used to evaluate their spatial learning. Children who actively walked within the town made more accurate reconstructions than the perimeter group. Herman concluded that traversing routes between landmarks within a spatial area is important for the development of cognitive maps and his findings have been cited in much of the subsequent work in the area (e.g., Foreman et al, 1990; McComas et al, 1997, among others) as indicating the benefits of active exploration in spatial learning. Consistent with this interpretation, Lehnung, Leplow, Ekroll, Herzog, Mehdorn and Ferstl (2003) found that when tested in the Kiel locomotor maze, which requires a participant to identify 5/20 floor-level lights as to-be-remembered targets, 5-11 year old-children could acquire considerable spatial information when viewing from the perimeter, but needed to experience locomotor exploration within the maze in order to make "relational place orientation" judgements, i.e., to make judgements based upon a cognitive "map" of the experimental space.

Herman's findings also indicated that accuracy of performance was a function of age (older children performing better than younger ones), that performance improved between a first and second trial, but there was no effect due to gender.

Although a VE was used to reproduce Herman's model, the current study used the same participant age range and included equivalent viewing conditions in which participants experienced the model town by moving through it freely (active) or from the perimeter (reproducing Herman's 'passive' condition). In addition a 'yoked' passive condition was introduced in which participants viewed the displacements, in real time, that were made by participants in the active condition. This methodology is typical of studies using virtual environments to investigate active/passive differences in spatial learning (see Foreman, Sandamas and Newson [2004] and Wilson [1999]).

We investigated whether learning in a VE would transfer to a real equivalent space (cf. Foreman et al, 2003), and whether the findings of Herman (1980) could be replicated in terms of age, practice and activity effects. Although Herman (1980) found no gender effect, males' greater familiarity with computers could influence spatial learning from a VE (cf. Waller, 2000), and sex differences have been said to emerge particularly strongly when VEs are used for spatial training and testing (Astur, Ortiz and Sutherland, 1998). Specifically, we hypothesised, on the basis of the literature cited above, that while effects related to age and practice would emerge in VE testing, no active-passive differences would emerge.

METHOD

Participants

Eighty Six children participated, all attending the same provincial school in England. They were divided into groups according to age and sex: 17 boys and 14 girls were from year two (6-7 years), 14 boys and 12 girls from year three (7-8 years) and 20 girls and 9 boys from year four (8-9 years). The children were tested in same-year, same-sex pairs as appropriate.

Environment

Training and testing were carried out in a school classroom measuring approximately 10m x15m, at the front of which was a carpeted floor area, empty of furniture, approximately 4m square. On to this area was placed a 2m square vinyl floor plan that precisely reproduced the layout of the virtual model town. At the back of the class room the computer and 2 linked monitors were set up. The monitors were 1 m apart. A floor-standing screen prevented a participant seated at the computer from observing the floor plan.

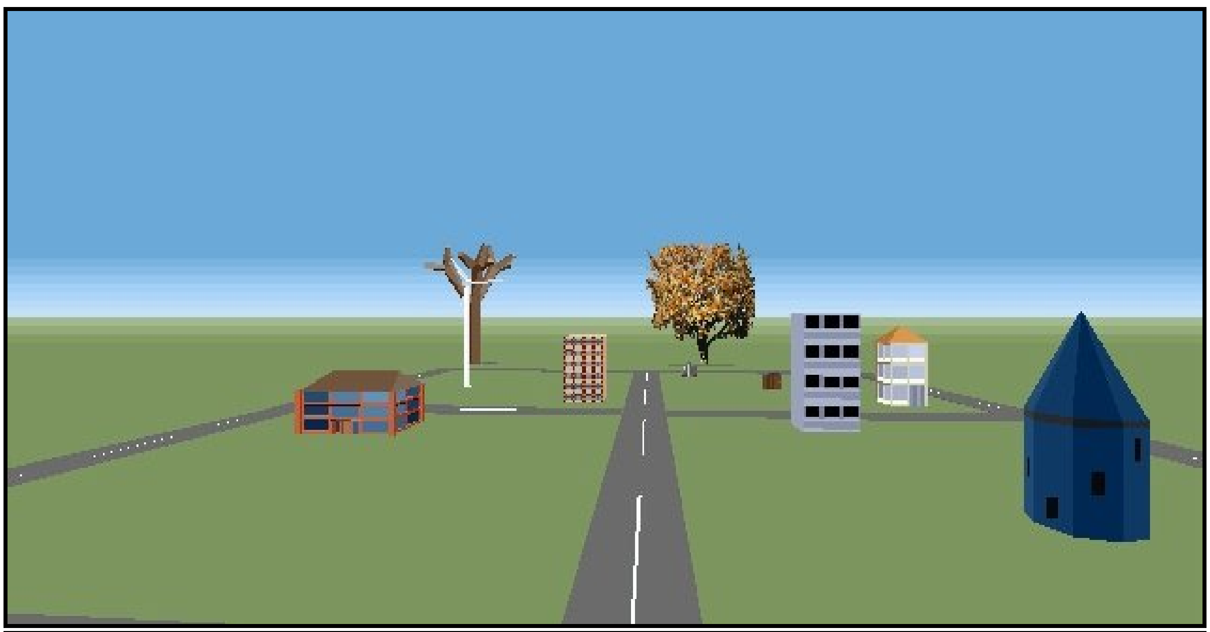
Materials

The VE was constructed and displayed using an IBM compatible desktop PC, driving two colour VGA 14” monitors. A PC Line Tournament PC joystick provided the interface and the environment was constructed using SuperScape 3-D Virtual Reality software. As in the real model used by Herman (1980), our virtual model incorporated eight distinctive model buildings varying in size, shape and colour with the addition of two virtual trees located at the farthest edge of the layout to act as reference points (see Figure 1).

Whilst units of measurement within the SuperScape software are arbitrary the visual impact of the VE was designed to replicate the visual experience of children in the original study. That is to say the viewpoint was set to approximate a child's eye level (1.2 m), looking down on the virtual model buildings.

Figure 1

A view of the experimental VE explored by participants



For the real equivalent environment, a 2m square vinyl floor plan was created of the virtual model town, which was divided by a crossroads into four quadrants, each 75×85 cm. The building models reproduced accurately those in the VE (created by pasting on down-loaded texture surfaces from the VE models, to ensure equivalent appearances): 'School' (20×15cm), 'Round Tower'

(10×10cm), ‘Purple Block’ (10×10cm), ‘Brick Block’ (10×10cm), ‘Apartment Block’ (10×10cm), ‘Shed’ (5×7.5cm), ‘Green House’ (5×7.5cm) and ‘Power Hill’ (10×10cm).

Procedure

As each pair of participants entered the classroom their attention was directed to the vinyl floor plan. The two model trees at the far edge of the floor plan were also pointed out since these were intended to act as fixed reference points for the children’s subsequent reconstructions.

To ensure that the children had no difficulty in recognising the real model buildings from their virtual representations they were shown the virtual models on the computer screens and then asked to indicate their real equivalents. All of the children completed this task without difficulty.

The children within pairs were randomly allocated to either the active or passive conditions and directed to sit at either the computer screen having the joystick in front of it (the active station) or the adjacent remote screen with no joystick (the passive station). Both children were informed that they were going to explore a town on the computer, the same as the floor plan they had just seen, but that the buildings that they had just seen would be in the town. No deception was practiced. They were told clearly to try and remember where the virtual buildings were, so that they could place model buildings as accurately as possible on the floor plan at the front of the classroom. All the children indicated that they understood the task and subsequent observation of their behaviour confirmed this.

Children in the active condition were also told that they had to navigate around the VE using the joystick until they felt they were familiar with the VE and ready to reconstruct the real model version of it. The children in the passive condition were informed that they would be seeing exactly what their active counterparts were seeing. Exploration time was limited to 2 minutes, although there was never a need to enforce this limitation, since all active participants said they felt familiar with the environment before 2 min had elapsed. They were then taken out of the room and brought back one at a time, to reconstruct the environment using the floor plan and models. There was no limit on reconstruction time, though this was typically 2-3 minutes.

Participants in the perimeter condition were given the same basic instructions as participants in the other two conditions. However, they experienced the VE from eight pre-set viewpoints around the perimeter of the main square; therefore they were not free to experience displacements through the VE between and around the buildings. Participants could switch between viewpoints, spaced approximately 45^{o} apart by using appropriate number keys on the keyboard. Viewpoint 1 was from the south-end of the VE looking up the central road towards the trees at the North-end. This was also the starting point for participants in the other conditions, and the point from which all participants were shown the real-space floor plan. The viewpoints were numbered one to eight in an anti-clockwise direction around the VE and participants were encouraged to view the environment from all of them as many time as they liked. As with the other conditions, exploration time was limited to two minutes although there was never any need to enforce this limitation.

All of the participants completed the exploration and reconstruction task twice and, in the case of the yoked pairs the trials were counter-balanced for test order (active then passive, and vice-versa). After each reconstruction had been completed, metric scales were placed at 90^{o} to one another, along two adjacent edges of the floor plan and photographs of the model were taken from above. From these, on completion of the experiment, placement accuracy was measured. Model building positions were transferred from the photographs to scaled graph paper on which the correct building positions were indicated. Measurements for each building were then taken from the centre of the child-placed position to the centre of the true object position. These distances were summed to give a total distance-error score for each child.

RESULTS

Placement error was the dependent variable in a 3 (‘Class Year’ [2,3 & 4]) X 3 (‘Condition’ [active / passive / perimeter]) X 2 (‘Trial’ [trial 1/ trial 2]) 3-way mixed factorial ANOVA with ‘Trial’ as the repeated measure. An initial analysis included gender as a factor, but since this was not significant, data were collapsed across male and female participants in this analysis.

Main effects were evident for: Trial, $F(1, 77) = 75.98$; $p < .01$ (t1 mean: 453; t2 mean: 320) and Class year, $F(2, 77) = 4.8$; $p < .01$. Post hoc Bonferroni multiple comparisons indicated that, across trials 1 and 2 combined, children in year 4 were significantly more accurate than were those in year 2, $p < .05$; however year 3 children were intermediately placed and did not perform significantly differently from either year 2 or 4 children, p’s > .05. This is illustrated in Figure 2, which also shows that error reduction between trials one and two was approximately equal for all three age groups.

Figure 2 **Mean error scores on trials 1 and 2, by age**

A significant Trial x Condition interaction was apparent, $F(2, 77) = 5.84$; $p < .01$. Post-hoc paired samples t-tests indicated that placement accuracy improved significantly across trials for all conditions. However, independent samples t-tests indicated that placement accuracy of participants in the passive condition was significantly superior to those in the active condition at trial 2, $t = -1.98$, df 58, $p < .05$.

Figure 3 **Mean error scores for trials 1 and 2, by condition**

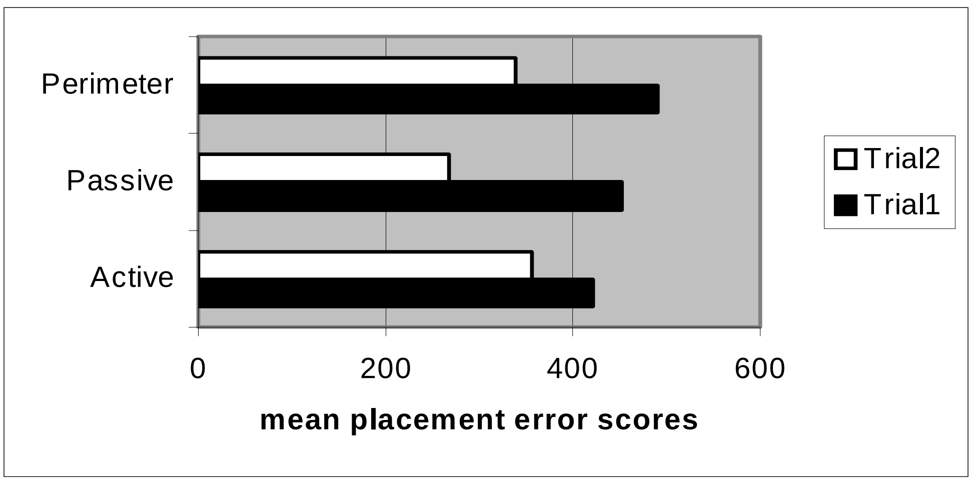
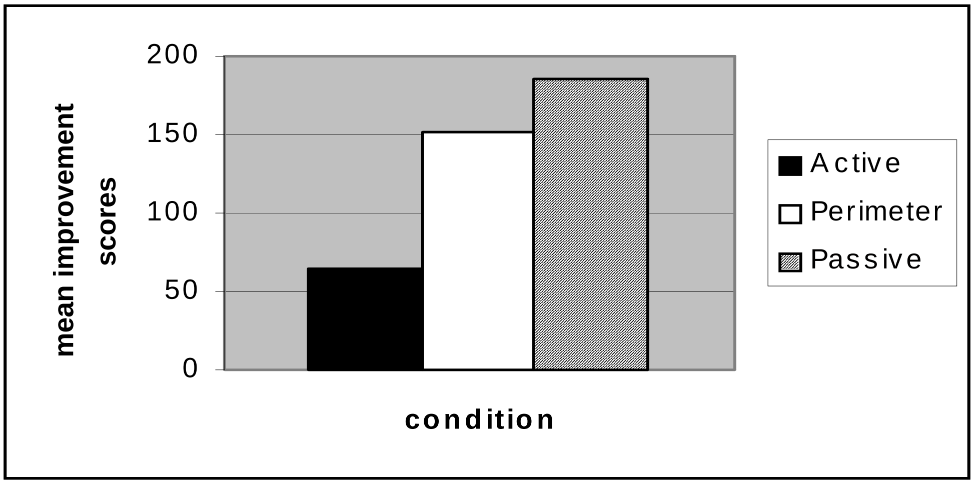


Figure 3 illustrates both that active participants had the highest mean error score for trial 2 (356), but also that they improved the least between trials 1 and 2. In order to further investigate the latter effect, trial 2 scores were subtracted from trial 1 scores, giving 'improvement' scores (score reduction indicating a decrease in error). These were subjected to a one-way ANOVA with Condition the between-subjects factor. There was a significant main effect for this factor, F(2,83) =

5.8; $p < .01$ (Figure 4). Bonferroni multiple comparisons indicated that passive participants' improvement scores were significantly higher than their active counterparts, $p < .01$. In addition the improvement scores of participants who viewed the VE from the perimeter were arithmetically superior to the active participants' scores, the result approaching significance, $p = .07$.

Figure 4 **Mean improvement scores by condition**



Discussion

Most statistically significant effects observed in the earlier study by Herman (1980) were confirmed by these data, derived from the same experimental design, age samples and protocols and differing only in presentation medium. The significant effect for trials indicated that learning took place during the virtual exploratory experiences, so that reconstruction placement accuracy was substantially improved by trial 2. The significant effect of age also replicates that of Herman (1980), who found that third graders (age 8-9 years) reconstructed the model town significantly more accurately than kindergartners (age 5-6) across conditions. In the current study we found that year 4 children (age 8-9 years) reconstructed the model more accurately than year 3 children (age 7-8) and did so significantly more accurately than year 2 children (age 6-7) after exploring the VE. Indeed inspection of Figure 4 illustrates the almost linear relationship between age and accuracy on the model reconstruction task. It would therefore appear that developmental spatial competencies observed in real world studies apply equally to VE-based studies. The absence of a main effect for gender was also consistent with the findings of Herman's (1980) experiment 2, in which children explored alone, as in the current study. The absence of a gender difference here is, however, more surprising in view of the greater familiarity of males with computers, which has been found to give rise to significant gender-related effects in previous studies of virtual spatial learning (Waller, 2000) and may be responsible for similar effects elsewhere (Astur et al, 1998). However, the children in the current study all attended computer classes at school, which may have equalised experience, at least in that context.

Consistent with past work using VEs (Wilson, 1999; Peruch & Gaunet 1998; Wilson, Tlauka and Foreman, 1998; Ruddle, Payne & Jones, 1997; Stanton, Wilson & Foreman, 1996; Tlauka & Wilson, 1996; Foreman et al, 2003, 2005), all of the above results further illustrate that children are able to transfer spatial information from a VE to its real-space equivalent and indicate that a VE is a robust and valid medium in which to test spatial skills of children in the current age range.

Our data depart from those of Herman (1980) only in terms of the influence of activity and passivity. This is the only variable examined for which the assumption that virtual and real spaces are equivalent (Gaunet et al, 1998; McComas, Pivik and LaFlamme, 1998) does not appear to hold. However, our data are consistent with many VE-based spatial learning studies which have yielded ambiguous data regarding active exploratory advantage (Wilson, 1999; Peruch & Gaunet, 1998; Wilson and Peruch, 2002). The present study is unique, however, insofar as it is modelled on a previously conducted real-world study which did show an active advantage (over the perimeter viewing condition).

The data in this study are the more interesting because they indicate a greater improvement across trials in passive ‘yoked’ participants than actives; passive perimeter-viewing participants also showed greater improvement than actives (though not to a statistically significant degree). Figure 3 illustrates the extent to which the learning scores of participants in both passive conditions exceeded those of their active counterparts, further reinforcing the notion that activity in all forms, within VEs, creates no benefit for an exploring child. Among other things, this illustrates that passive instruction with children can be substituted for self-initiated exploration, where it is not feasible for a child to operate an input device (cf. Foreman et al, 1990; Foreman et al, 2003).

In an earlier study in which passives outperformed actives, Arthur (1996) observed that active-explorers might learn less about the layout of a VE due to the extra cognitive effort required using an unfamiliar input device. Certainly in the current study, passive observers could focus on viewing and learning the environment layout whilst the active participants’ efforts were divided between operating the input device, making directional choices while simultaneously learning the task. However, there is a paradox in this argument, since the active drivers who Hart and Berzok (1982) describe as benefiting from active engagement, are having to drive a vehicle, which is arguably a more complex task than operating a joystick. Of course, driving may become an automated skill with time; Ericsson and Delaney (1998) suggest that expert performance reduces the load on working memory through the automatisation of serial processes and so inexperienced drivers who must pay greater attention to vehicle control may learn little about the environment in which they are navigating, though this has not been tested to date. All the children involved in the present study attended computer classes as part of their normal curriculum and many were computer game users outside school. Those few who were unfamiliar with the joystick device were easily able to use it after minimal instruction. Perhaps use of the joystick in itself was not problematic, but rather the use to which it was put – navigating through virtual space. Even a small extra effort may have given actives a disadvantage, in terms of cognitive capacity, over passive participants who had their full complement of cognitive capacity available for spatial information processing.

Clearly, it is important to know more about the relative familiarity of input devices before this hypothesis can be evaluated. Future active participants in spatial VE studies might be given extensive input device training, or passive participants given a task that mimics the cognitive load associated with control of an input device. In a recent study, Sandamas and Foreman (submitted) have found that in adult participants, spatial learning is reduced by having to perform a secondary task when the latter is spatial and complex but not when it is verbal or simple. The basis for such effects may relate to Working Spatial Memory capacity, the limited capacity of which might need to be shared between a central task (spatial learning) and the secondary task (input device control) (Sandamas and Foreman, submitted). It would be valuable to be able to render real and virtual exploration equivalent, to study task engagement independent of motoric control factors.

However, working memory capacity is not the only factor that may influence spatial information acquisition in active and passive conditions. Flach (1990) has suggested that a range of variables could possibly account for such differences, including the control of attention, the kinds of information available, and the kinds of activity involved. Note that the type of spatial information required in this study was the relative positions of a number of landmarks and not wayfinding or route-learning, both of which particularly benefit from active exploration. Siegel and White (1975) suggested that whilst routes are predominantly sensorimotor-driven, landmarks are primarily visual. Thus navigating between landmarks may offer no benefit to the active explorers since the task was predominately reliant on the visual modality, perhaps to the extent of making the motoric interaction redundant in terms of facilitating spatial learning under these conditions. On the other hand, the degree of motoric interaction required to navigate a VE with a joystick may be inadequate to differentiate active and passive participants, particularly when both are viewing the same displacements and learning about a spatial layout. In contrast, Herman's participants walked between the model buildings or viewed them from the perimeter. Those who walked between buildings subsequently demonstrated a greater degree of spatial learning. Herman (1980) concluded that motor activity within a spatial area facilitates spatial learning. Therefore an additional issue to be considered in the current study is that the limited motor function required to use a joystick for navigation may not be as good at reinforcing spatial learning as a more gross and direct form of motoric interaction with an environment such as walking. Notably, Wilson et al (1997) suggested that the lack of vestibular and tactile feedback available to active explorers in a VE might be a contributory factor to the differential results found in real and virtual spatial studies.

Future designs could address this issue by utilising input devices that are more physically demanding but at the same time require more automatic actions from the active explorers. For instance a treadmill with force-feedback capabilities would be ideal as it would provide a more ecologically valid and motorically demanding form of interaction with the VE whilst occupying little, if any, working memory capacity.

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