Memory processes and virtual environments: I can't remember what was there, but I can remember how I got there. Implications for people with disabilities.

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ABSTRACT

Memory deterioration is often a consequence of brain damage. Successful memory rehabilitation programmes depend upon effective methods of cognitive assessment. This paper considers the potential value of virtual reality (VR) in this context. The effect of active or passive participation in a virtual environment on specific aspects of memory was investigated. It was found that active participation enhanced memory for spatial layout whereas passive observation enhanced object memory. No differences were found for object location memory. These findings are discussed in terms of how VR may provide a means of measuring memory which combines ecological validity with experimental rigour.

Keywords: ecological validity, everyday memory, yoked-control, clinical assessment.

1. INTRODUCTION

> "VR is a computer-based technology which incorporates specialized input and output devices to allow the user to interact with and ... explore a three-dimensional virtual -or artificial - environment. In the virtual world the user can do things as routine as throwing a ball or as fantastic as flying through space. And these things can be made to occur by something as simple as a hand gesture or a nod ... (Middleton, 1992)

There are different levels, or degrees, of sensory immersion which can all be included under the headings of VR. For the sake of simplicity these are referred to as immersion at the space, object, or environment level (Larijani, 1994). Viewing a three-dimensional space, such as a tour of a virtual house before it has been built, is the most elementary level of virtual immersion, that is the space level. If the user can manipulate images or objects within that three-dimensional space then that is a deeper level of immersion, the object level. Finally, total immersion, where all references to the real world are blocked out and are replaced by substitute stimuli (visual, auditory, and tactile) provides immersion at the environment level.

These different degrees of sensory immersion offer a range of ways to provide a safe environment to enable training and rehabilitation of people with disabilities. The first conference on virtual reality and persons with disabilities was held in 1992, and in the intervening years a range of effective VR applications have been developed. These include, for example, a programme for children in special education which has been devised by the virtual reality group at Nottingham University (Brown & Wilson, 1995). This research group has developed a VR system to develop everyday living skills for children with severe learning difficulties. Applications have also been designed for adults with special needs. Mowafty & Pollack's (1995) *Train to Travel* is one such example. This project was devised to enable people with cognitive impairments to use public transport.

However, as Darrow (1995) pointed out, despite the wide range of applications for people with disabilities, the area of rehabilitation of people with specific cognitive disability is under-developed and under-researched. The potential for VR applications in the area of neurological rehabilitation has also been discussed by a number of other researchers (Rose and Johnson, 1994; Rose et al., 1996; Pugnetti et al., 1995). However, in order to develop successful rehabilitation programmes,

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which address individual needs, there remains the need for effective assessment tools. The majority of existing clinically-based assessments of cognitive functioning have internal validity, but may lack both external and ecological validity.

Given that generalisation, for example across settings, is of vital importance in rehabilitation, programmes, then the generalisation of cognitive functioning assessments is also of fundamental importance.

One particular deficit, memory, is characteristic of many medical conditions - especially head injury and neurodegenerative diseases. The debate into how best to assess memory impairments has followed that of mainstream memory research. Cognitive psychologists have placed an increasing emphasis upon the measurement everyday memory - following Neisser's (1978) argument that existing laboratory measures were too narrow and artificial. However, ecologically valid measures have also been criticised, on the grounds that they lacked experimental rigour and control (Banaji and Crowder, 1989).

As previously stated, within the context of rehabilitation the assessment of everyday memory problems is important. Sunderland et al. (1983) investigated the extent to which laboratory tests could predict everyday memory. They found a selective relationship between objective and everyday memory assessments, indicating the need for ecologically valid assessment tools. Wilson (1987) also pointed out that, until the Rivermead Behavioural Memory Test (RBMT) was developed, standard memory batteries failed to identify everyday memory problems.

Andrews et al. (1995) have suggested that measuring memory within a virtual world may be a solution to the problems suggested by Banaji and Crowder. The advantage of using VR is in allowing the assessment of memory to be carried out in the context of interaction with an everyday environment without sacrificing analytic control. Furthermore, precise assessments can be made of the way in which memory and other cognitive processes operate in a multifaceted reality.

While VR environments can be designed to assess a range of memory processes, VR would seem an ideal medium within which assessments of spatial memory can be made. In keeping with the dearth of VR development in the area of cognition, few studies have been carried out to measure spatial knowledge. The acquisition of spatial knowledge is dependent upon navigational experience (Thorndyke and Hayes-Roth, 1982). Thus, passive observation, rather than active experience, may lead to the limited cognitive processing of spatial information.

VR studies in this area have found equivocal results. For example, Wilson (1993), in a series of experiments, found that both active and passive participants obtained similar levels of spatial information from virtual environments. The latter finding differed from that of Peruch, Vercher and Gauthier (1995) who found that spatial memory was superior for the active participants rather than the passive.

However, "spatial knowledge" is a somewhat broad term and the question remains as to what specific aspects of the environment a passive observer can actually encode. The present paper investigated the effects of active or passive participation in a virtual environment on spatial and object memory. It was predicted (following Thorndyke and Hayes-Roth's argument) that spatial memory would benefit from active VR participation, whereas passive observation would allow undivided attention to be focused on the objects and facilitate memory for those items. A prediction with respect to object location is uncertain, following the above assumptions, as both the active and passive conditions could contribute to enhanced object location memory.

2. STUDY 1

2.1 Method

Participants were fourteen female and sixteen male students (mean age 24 years). The study utilised a three-dimensional environment created on an IBM compatible 486dx2, using the Superscape™ modelling software package. This environment comprised of four inter-connected rooms in a house. 25 objects were situated in these rooms. Exploration of these rooms, which were displayed on a 15 SVGA inch monitor, was controlled by using a Gravis proportional joystick. In an adjoining cubicle another identical monitor was "yoked" to the original computer so that the two screens were identical at all times.

Participants were randomly allocated to the active or passive experimental condition, and tested in "yoked" pairs. The members of each pair of participants sat in adjoining cubicles in front of identical "yoked" computer screens. All participants were naive to the fact that they were "yoked". One of the pair negotiated their way through the virtual house while the other was exposed to exactly the same journey but had no control over the interaction. Both active and passive participants were asked to search the objects that they would see in the virtual environment and try to "find an umbrella which may or may not be there". Immediately each active participant had completed a route through the virtual reality rooms, the computer screens were switched off and both members of the pairs were instructed to draw the layout of the rooms in the virtual reality display (spatial memory test). Participants were then given a plan of the correct layout of the virtual reality rooms, with the location and name of one object marked in each room and asked to draw in the correct locations and write the names of any objects that they could recall from the virtual environment (object memory test). Finally, participants were given one minute to study the Rey-Osterreth Visual Memory test figure and five minutes to draw the figure from memory, in order to check whether active and passive participants differed in visual memory.

2.2 Results

Prior to the data being analysed a check was carried out to ensure that the participants did not differ in respect of visual memory scores. There was no significant difference in performance on the Rey-Osterreth Visual Memory test between the active and passive participant pairs [t(14)=0.26, p=0.80].

Spatial layout was scored on a pre-determined criterion which allocated marks according to number and shape of rooms, position of doorways and corridors, and the direction in which doors opened. Data were converted into probability scores so that spatial location and object memory could be compared directly.

It appears from Figure 1 that active participants performed better in the spatial memory task than passive participants (probabilities 0.62 and 0.43 respectively), whereas passive participants performed marginally better than active participants in the object memory task (0.29 and 0.21 respectively).

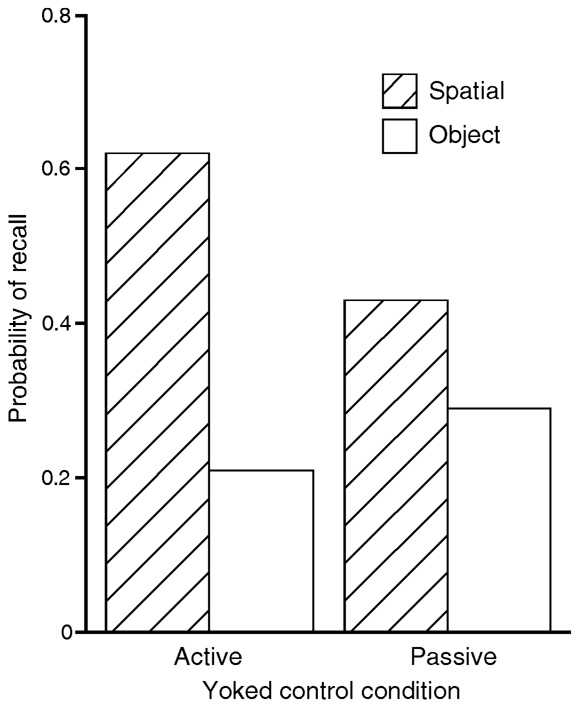

Figure 1. *Mean probability scores for spatial and object memory.*

Statistical analysis supported this interpretation of the data. A 2 x 2 repeated measures[1] analysis of variance (ANOVA) revealed a significant effect of spatial vs object memory [F(1,14)=67.04, p<0.001]. There was no significant difference in overall performance between the active and passive groups [F(1,14)=1.82, p>0.05] but, as expected, there was a significant interaction between spatial vs object memory and the active vs passive groups [F(1,14)=24.24, p<0.001][2]. Subsequent analysis, using a Bonferroni adjustment to control for the familywise error rate, demonstrated that the active group performed better in the spatial memory task (p=0.01), but the passive group's superior performance on the object memory task did not reach significance (p=0.09).

[1] The yoked control data were analysed using a 2 x 2 repeated measures ANOVA following Schweight's (1994) stipulation that "the data from a yoked design are analysed by using procedures appropriate for a within subjects design because matching subjects on a specific variable [i.e. time] relates them".

[2] A between subjects re-analysis of the yoked control condition made no difference to the overall results: a significant effect of spatial vs object memory (F[1,28]=80.95, p<0.001), no significant difference in overall performance between the active and passive groups (F[1,28]=1.18, p>0.05), and a significant interaction between spatial vs object memory and the active vs passive groups (F[1,28]=19.21, p,0.001).

A possible two marks were awarded for the correct location of each object recalled, one mark for the correct room and one for the correct location within that room. (The correct location within a room was measured by dividing each room into sextants and requiring that each object was located in the correct sextant.) Since the correct location of objects was dependent upon prior recall of objects, scores were proportionately adjusted (by dividing by the number of objects recalled) and analysed separately. This analysis showed no significant difference between the active and passive conditions [$t(14)=0.27$, $p>0.05$]. Enhanced memory for spatial layout did not, therefore, extend to remembering the correct location of objects. Neither did enhanced object memory extend to remembering object location.

3. EXPERIMENT 2

Experiment 2 was carried out to investigate whether object memory would be superior in the passive condition using a more sensitive measure of memory performance. Therefore a recognition task was used to measure object memory.

3.1 Method

Twenty-two female and eight male students (mean age 25.3 years) participated in the study. The same virtual house and objects, as used in experiment 1, were used in this experiment. Once again participants were naive as to the fact that they were "yoked", as before they were tested in yoked pairs, in adjoining rooms, with one of the pair negotiating their way through the virtual house while the other was exposed to exactly the same journey but had no control over the interaction. Participants were subsequently given a picture recognition task which comprised cards depicting the 25 objects in the virtual environment and 25 schema-relevant distractors.

3.2. Results

Participants in the active condition recognised fewer objects than participants in the passive condition (probabilities .35 and .45 respectively). Statistical analysis showed this difference to be significant [$t(14)=2.21$, $p<0.05$]. The results of Experiment 2 therefore demonstrated that object memory was better in the passive than in the active condition. Thus, using a recognition test, to provide a more sensitive measure of memory it has been found that object memory is superior in the passive condition.

4. GENERAL DISCUSSION

The main findings of the present studies were that active participants had superior recall of the spatial layout of the virtual environment, whereas passive participants had superior object memory. There was no difference between the active and passive conditions for remembering the location of objects.

The dissociation between spatial and object memory, produced by VR participation, illustrates that negotiating the virtual environment only enhanced the specific memory ability tapped by the task. Active participation via interacting with the spatial environment aided spatial memory but mot object memory. conversely, recognition memory for objects was better in the passive condition, perhaps because these participants were able to concentrate more on the task because they were not interacting with the environment. That is, unlike the active participants, they were not engaged in a divided attention task.

No differences between the groups were found in memory for object location, possibly because active and passive participation may have produced different trade-offs for the two groups. The active participants location memory was expected to be enhanced because they were actively discovering the objects and their relationships. However, the lack of enhancement for this type of memory may have been due to the fact that the active participants were carrying out a divided attention task.

Enhanced spatial memory in the active condition confirms the findings of Peruch et al (1995), who found that spatial memory was superior for their active participants relative to their passive participants. However, the present findings are contrary to those of Wilson (1993), who found no differences in spatial memory between active and passive participants. The different task requirements between these two studies may account for this discrepancy.

There are a number of implications of these findings, for the use of virtual environments for carrying out cognitive assessments. For example, this study has demonstrated how a VR setting can provide the means for the measurement of incidental memory - an aspect of memory which is part of real-life experience. To further investigate the ecological validity of VR assessment comparisons could be made between measures carried out in a real-world setting to that of the same setting constructed within VR.

Another implication of these findings is that visual experience is not the only factor in remembering aspects of a visual medium; passive viewing of an environment leads to different types of memory than that of active exploration - factors that may be important when assessing the internal validity of the test situation.

Clearly there is a need for further research in order to make use of VR technology as a means of an assessment. For example, investigating whether changing the instructions to participants to tap into intentional memory processes would remove the distinction between passive and active participation memory differences. Furthermore, other the assessment of other cognitive functions, such as attention and perception, lend themselves measurement within a virtual environment. Finally, assessments could be made of the types and intensities of environmental factors which could cause cognitive overload, and, thus, affect everyday functioning.

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