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Virtual Reality in Everyday Memory Assessment and Rehabilitation: Progress to Date and Future Potential

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Abstract: *Memory impairments are one of the most disabling consequences of brain injury. They can be problematical to assess and rehabilitate, as conventional "paper and pencil" neuropsychological assessments and rehabilitation strategies are often criticised as lacking in relevance to the use of memory in the real world i.e., "ecological validity." Conventional neuropsychological memory assessments and rehabilitation strategies also often fail to cover important aspects of 'everyday memory,' such as prospective memory (remembering to perform actions in the future) and incidental memory (the encoding and recall of information without any instructions from a third party). Unfortunately, it can be very difficult to achieve the ecological validity necessary to assess everyday memory without compromising experimental control. Similarly, it is often difficult to devise rehabilitation strategies that involve real life scenarios owing to practical constraints. Virtual reality (VR) provides an elegant solution to these problems and is, therefore, an ideal tool with which to study everyday memory. This paper briefly summarises the current state of research on the applications of VR to everyday memory assessment and rehabilitation, with reference to some seminal VR work within the domains of spatial, incidental and prospective memory. Some directions for future research are suggested, and issues associated with turning empirical findings into real benefits for patients considered.*

INTRODUCTION

Over the last decade, the potential of virtual reality (VR) has, at last, begun to be realised. In the early to mid-nineties, the aspirations for the technology far exceeded its capacity to deliver on its potentiall.[1] However, massive advances in the sophistication of the hardware that underpins VR and significant reductions in the cost of such hardware have taken VR "out of the realm of expensive toy and into that of functional technology" (p3).[2]

The incorporation of VR into neuropsychological assessment and rehabilitation has possibly attracted the greatest expansion of interest from researchers in recent times. Many authors have argued that the assets of VR are especially well suited to this field.[3-5] VR has been applied to a number of domains of cognitive assessment and rehabilitation, such as: executive functioning;[6] attention ;[7] and spatial transformation.[8] However, as Brooks et al.[9] point out, the application of VR to memory impairments has been of particular interest, as memory disorders are one of the most disabling consequences of brain damage.[10] Therefore, establishing whether a patient has memory impairments is a crucial aspect of cognitive assessment and addressing any such impairment, a crucial aspect of cognitive rehabilitation.

1.1. Reconciling ecological validity and reliability: VR and everyday memory.

There are numerous "paper and pencil" neuropsychological tests of memory, e.g. the Wechsler Memory Scale - Revised,[11] the Adult Memory and Information Processing test,[12] the Recognition Memory Test,[13] and the Doors and People Test.[14] However, conventional neuropsychological tests have been heavily criticized as lacking "ecological validity" or, put another way, relevance to memory under conditions other than the laboratory/rehabilitation ward.[15] Indeed, it was the poor correlations between laboratory tests and 'everyday memory' assessments found by Sunderland, Harris and Baddeley[16] that prompted the development of the Rivermead Behavioural Memory Test (RBMT), which is designed to assess everyday memory. However, it has been argued that the cost of introducing ecological validity into conventional neuropsychological assessment has been a loss of strict control over the test situation.[17]

The problem of balancing the demands of ecological validity with sufficiently rigorous control is also apparent in rehabilitation. Doubts have been raised as to whether rehabilitation strategies that lack ecological validity will transfer to the real world[18] and whether training behaviours in the absence of any change in the environment, or task demands, fosters sufficient intellectual flexibility and creativity to be useful in everyday life.[19] Therefore, of all the assets of VR for assessment and rehabilitation (see Rizzo, Schultheis, Kerns and Mateer,[3] for a comprehensive review) it is perhaps VR's capacity to generate environments that are satisfying from an ecological standpoint, without compromising on experimenter/therapist control, that is most exciting for memory assessment and rehabilitation research. This capacity brings with it exciting opportunities to study everyday memory phenomena. Indeed, applications of VR to memory research to date have predominantly focused on three domains of everyday memory, which have proved particularly problematical for conventional assessment and rehabilitation: i.e., spatial memory, incidental memory and prospective memory. The following provides an illustration of how the assets of VR have contributed to our understanding of the above domains of everyday memory, with reference to some significant VR research.

VR AND SPATIAL MEMORY

A good deal of the developing literature on everyday memory assessment and rehabilitation in VR to date has been directed at spatial memory, arguably for two reasons. Firstly, as Brooks et al.[9] state, adequate spatial memory is a prerequisite for independent living. Secondly, VR spatial memory tasks are particularly amenable to being orientated to utilise users' procedural memory for motor tasks e.g., simulated navigation between waypoints. This has significant implications for the reorganisation of memory function in individuals who have suffered brain damage, which will be elaborated on below.

One of the primary assets of VR in everyday memory assessment is the capacity to perform experiments that, though methodologically desirable, would not be practical in the real world. This is particularly true for research into spatial memory. A good example would be the VR adaptation of the Morris Water Task, an experimental paradigm that had proved highly informative in investigating spatial ability in rodents, to research into human spatial ability. The task involves finding a platform, which is submerged in water, purely by using memory of its position relative to external environmental cues. A desktop VR variant of this paradigm has proved useful in assessing spatial learning decrements in TBI patients, which corresponded to self- reported frequency of place learning problems in everyday life.[20]

Using the control and ecological validity afforded by VR together with fMRI generates unique and exciting insights into the neurological correlates of everyday memory, which would not be possible in the real world owing to portability issues inherent in fMRI equipment. For example, Morris et al.[21] and Paslow et al.[22] used a PC-based virtual reality set up in conjunction with fMRI in order to examine the brain correlates of egocentric memory (spatial knowledge relative to the observer) and allocentric memory (spatial knowledge relative to cues independent of the observer) in patients with anoxic hippocampal damage and normal controls. The results from these studies provided an in vivo demonstration of how anoxic brain damage can affect hippocampal function.

In addition to overcoming practical difficulties with implementing a desired methodology or permitting the incorporation of relatively inaccessible medical technology, a brief look at the use of VR in the rehabilitation of spatial memory reveals that it can also directly facilitate the reorganisation of memory ability. Research has shown that procedural memory for motor tasks can often remain relatively intact, even in individuals who exhibit profound impairments in other aspects of memory- as in the widely reported case of HM.[23] Research has also indicated that one can utilize intact procedural memory to aid or replace damaged memory systems.[24-26] Unfortunately, conducting spatial navigation tasks involving more than one room, or in an environment relevant to the patient's everyday life, can be highly problematical in the real world. This problem is easily rectified within

VR, the question was: is a simulation of a motor activity sufficient to tap into spared procedural memory in an amnesic patient? Brooks et al.[28] used a desktop VR system to train an amnesic patient (MT) to independently navigate between locations within her hospital's rehabilitation unit. When the training was extended to encompass real world and VR based training of routes (matched for complexity) within the ward, it transpired that MT learned the route practised in VR, but not the route practised in the real world. A number of features of the VR rehabilitation may have been responsible for this outcome. For example, MT could perform the route very quickly in VR resulting in more repetitions of the VR route than the route practised in the real unit. The rehabilitation strategy of backwards training was easier to implement in VR than in the real world. Finally, extraneous distractions were easily controlled in VR. A follow up study reported in Rose et al.[28] provides further support for the use of VR for route training in amnesic patients.

Researchers have also shown interest in VR as a means to encourage the development of spatial memory in children whose physical disabilities restrict their mobility. For example, Stanton et al;[29] Stanton et al[30] have conducted experiments featuring a VR model of a real school, which physically disabled children were asked to independently explore with a view to determining whether VR-based spatial memory training translates into improvements in performance in the real environment on which the virtual environment was modelled. Subsequent testing of the children on their spatial knowledge of the real school indicated that they performed better at pointing tasks and showed better route knowledge than undergraduate students who had not used the virtual environment. Similarly, Wilson et al.[31] conducted an experiment, which featured a virtual reality reproduction of two floors of the Astley Clarke building at the University of Leicester, UK. The children were asked to activate fire equipment and open a fire door to escape from the building in VR. Subsequent assessment involved asking the children to identify items of fire equipment that would not have been visible from their vantage points and the identification of the shortest route to the fire exit. The children outperformed a control group of undergraduate students who had not been exposed to the virtual environment. These studies highlight another advantage of using VR in everyday memory assessment; that the spatial memory of physically disabled participants can be assessed using VR in some situations where other forms of assessment might not be possible.

VR AND INCIDENTAL MEMORY

Incidental memory is, perhaps, the type of memory most relevant to everyday life as, unlike in conventional memory tests, often in day-to-day life individuals are not made explicitly aware that they will be required to remember a particular stimulus prior to having reason to recall it. This scenario is difficult to achieve in a laboratory, as an everyday environment is usually an integral part of the task. However, VR is ideally suited to conducting incidental memory assessments, as it can easily mimic real-life environments and tasks, and participants can then be incidentally tested on items encountered during their performance of the tasks. Despite this, the use of VR in incidental memory studies is still rare.

Andrews et al.[32] conducted a pioneering study of incidental memory for objects in VR. Participants examined a series of objects in one of five conditions: during interaction with a four-room virtual environment; in four static displays without any context; in the same four static displays, but where the participants were required to move a cursor over each object in turn; in four static pictures of virtual rooms; and using the same four pictures, but where the participants were required to move a cursor over each of the four objects in turn. Subsequent object recognition tests revealed that the poorest recognition performance occurred in the condition where participants encountered the objects in the virtual environment. Andrews et al. concluded that participants were being distracted by their interaction with the virtual environment and that incidental memory is particularly susceptible to distraction. However, they cautioned that the virtual interaction condition was most representative of participants' real-world memory ability.

Rose et al.[33] conducted an experiment to investigate incidental spatial and incidental object recognition memory in vascular brain injury patients and controls. This experiment involved the presentation of a four room virtual bungalow that participants were asked to search, ostensibly for a toy car. A yoked-control design was used, in which half of each group of participants were assigned to an 'active' condition, which entailed controlling movement through the bungalow via a joystick. The other half were assigned to a 'passive' condition, which entailed watching the active participant's progress on a second monitor in an adjoining cubicle. Participants were assessed via a spatial layout recognition test, in which they were required to assemble 2-D maps of the virtual environment by choosing room shapes and the positions of entry and exit doorways from an array of possibilities. Active experience of the virtual environment was found to improve incidental spatial recognition memory of the layout of the four-room building for both patients and controls. Conversely, passive observation was found to improve controls' performance in the object recognition test, but not patients' performance. Using the same procedure Pugnetti et al.[34] and Rose et al.[35] replicated these findings with multiple sclerosis patients and people with learning disabilities, respectively. Pugnetti et al.[34] also found that the above finding with MS patients could not be accounted for via standard pencil & paper memory assessment tools. Thus, there is evidence that, in addition to providing an experimental tool more amenable to the study of incidental memory per se, VR may also provide a more sensitive test of incidental memory, particularly in impaired populations.

VR AND PROSPECTIVE MEMORY

Impaired prospective memory is a particularly disabling form of memory impairment, and potentially the most hazardous, as often in everyday life actions that one needs to remember to perform at some point in the future are inherently important, e.g. remembering to attend a meeting, or turn off the cooker. Consequently, the need for a comprehensive assessment of prospective memory as part of a cognitive rehabilitation programme is self-evident. However, performing an ecologically valid, yet rigorously controlled assessment of prospective memory ability in a rehabilitation setting is problematical. Kvavilashvili and Ellis[36] classified prospective memory according to the type of cue the particular task to be remembered entailed, i.e. event-based tasks (an action is required to be performed in response to a cue); time-based tasks (an action is required at a previously specified future time); or activity-based tasks (an action is required before or after performing an activity).

Based on this classification, Brooks et al.[9] devised and conducted a desktop VR prospective memory test on patients from a stroke rehabilitation unit and age-matched controls. The virtual environment used in the test was a four-room bungalow. The test involved participants performing a furniture removal task, in which they were required to instruct the experimenter to move furniture and items from the virtual bungalow to the appropriate room (out of a possible eight) of a new house, one piece at a time. This constituted the background task. Before performing this task, they were asked to remember to instruct the experimenter to put "Fragile" notices on five glass items (the event-based prospective memory task); to keep the kitchen door closed to keep the cat in (the activity-based prospective memory task); and to return to a clock in the hall at five-minute intervals and press a button, supposedly to let removal men in (the time-based prospective memory task). It transpired that 14 of the 36 stroke patients and 2 of the 22 control participants were unable to recall all three of the prospective memory task instructions immediately after they had finished the furniture removal task, even though they had been able to recall them immediately prior to beginning the task. A comparison of the results of the remaining stroke patients and controls, who were able to recall all three prospective memory tasks, indicated that the stroke patients were severely impaired relative to controls at the event and activity based tasks, but only marginally impaired at the time-based task. These results were surprising as, based on Craik's[37] theory of age-related decrements in memory, which proposes that self-initiated processing becomes more difficult for the elderly, it was envisaged that impairments in stoke patients would be more apparent in time-based tasks (which involve self-initiated retrieval) than in event or activity-based tasks (which feature external cues). If, as these results of this study indicate, self-initiated retrieval does not become much more difficult for stroke patients, their failure to remember to perform tasks in the future in this study may be attributable to a different impairment, perhaps an inability to multi-task.

Brooks et al's.[9] exploratory study indicates that VR can provide a more comprehensive and controlled assessment of prospective memory ability than would be possible using standard memory assessment. This contributes to our understanding of the neuropsychological consequences of stroke. It also enables rehabilitation to be more effectively directed towards the specific impairments of individual patients.

DIRECTIONS FOR FUTURE RESEARCH AND ISSUES ASSOCIATED WITH TURNING VR'S POTENTIAL INTO BENEFITS FOR PATIENTS

The literature on VR and spatial memory provides a glimpse of the exciting potential of using VR in conjunction with fMRI in order to examine the neurological correlates of different forms of everyday memory.[22] Future studies could utilize this procedure to elucidate the relationship between the area of the brain affected by stroke, traumatic brain injury (TBI), or dementia and impaired everyday memory ability. Quite apart from being theoretically significant, such data would permit therapists to more accurately predict and rehabilitate the particular memory impairments that a patient would be likely to experience on the basis of their fMRI scan.

VR has demonstrated utility in assisting people with memory impairments by utilizing intact procedural memory[29] this learning has translated to improved performance in the real world. However, it is probably true to say that spatial memory tasks are particularly amenable to being broken down into a series of steps that tap into procedural memory.[9] The task of researchers and therapists is now to ascertain whether this use of VR can be successfully applied to other everyday tasks, and whether it can be used to negate some of the other disorientation, disorganization and repetition disabilities which result from different forms of memory impairment. Researchers will also have to be creative in providing ways of overcoming the lack of conscious awareness of learned knowledge common in patients with amnesia who have learned new motor skills.[14] Brooks et al also identified numerous reasons for the greater efficacy of VR training relative to real world training, e.g., less distraction, more frequent repetition, greater amenability of VR training to the errorless learning paradigm etc. It would be useful for the design of future memory rehabilitation strategies in VR to have some data on the relative importance of each of these assets in contributing to rehabilitation outcomes.

The implications of active vs. passive exploration of virtual environments for incidental spatial layout and object recognition are interesting and potentially very significant.[33] The impact, positive or otherwise, of active and passive exploration appears to be contingent on the stimuli and task demands. Rose et al. speculated that active exploration promoted the activation of procedural memory in the active participants, thereby enhancing their spatial memory of the layout of the virtual environment compared to the passive participants. The active participants' advantage did not extend to enhanced recall of the objects in the virtual environment because active participants did not interact with the virtual objects. However, it should be noted that the degree of interaction afforded by VR in memory assessment and rehabilitation is something of a double-edged sword. Increased interaction can have a deleterious effect on memory assessment and rehabilitation, as amnesic patients can have difficulty explicitly distinguishing between correct and incorrect responses/actions[38] and freedom to examine a virtual environment can prove as much of a distraction as an advantage.[32,39] Thus, experimenters/therapists must be careful to ensure that the range of interaction offered by a virtual environment does not detract from the purpose of the exercise by providing careful cueing or adopting error free learning approaches, such as that employed by.[29]

VR has been shown to provide a more comprehensive, ecologically valid, and controlled assessment of prospective memory ability than is currently possible using standard memory assessment tests. However, some questions remain from Brooks et al.[9] Firstly, it is not entirely clear whether the lack of impairment in the time-based prospective memory task in stroke patients relative to controls may have been an artifact of the interval between each retrieval occasion being too short. Thus, this aspect of the results may have been due to the time-based task not being sufficiently representative of an everyday time-based prospective memory task, as opposed to a genuine reflection on preserved prospective memory capacity. Further research, utilizing different time intervals in the time-based task, is planned to investigate this effect.

Brooks et al. also revealed that motivation is important in prospective memory performance, especially for stroke patients. During this study, participants were also given two real world based prospective memory tasks i.e. remember to ask the experimenter to return a personal belonging at the end of the study, and ask for a written explanation of the study. Results indicated that participants were significantly more likely to remember the former task, probably because they were more motivated to ask for the return of their property than for the written explanation. If rehabilitation strategies can encourage stroke patients to be more motivated to remember, it seems logical and reasonable to assume that their prospective memory abilities would improve. VR is particularly well suited to improving motivation in rehabilitation by, for example, introducing gaming elements into rehabilitation strategies.[40] Research is currently underway to determine whether manipulation of the salience of the different types of prospective memory tasks (e.g., time, event and activity based) can influence patients' capacity to remember to perform them. This may be particularly useful for the patients (and controls) in Brooks et al. who were unable even to remember what the prospective memory tasks were.

CONCLUSION

The work conducted to date clearly indicates that VR has very significant potential in the assessment and rehabilitation of everyday memory in individuals that have suffered brain injury. Further work is needed to establish whether VR can be used in the reorganization of everyday memory tasks other than simple navigation.[28] Research is also needed to further elucidate the implications of active vs. passive exploration of virtual environments and the relative contribution of the other assets of VR to everyday memory assessment and rehabilitation scenarios. Additional work involving VR used in conjunction with fMRI is clearly warranted to provide new and exciting insights into the neurological correlates of everyday memory and gain a greater understanding of how damage to different regions of the brain impacts upon everyday memory performance.

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