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The use of Virtual Reality technologies in neuropsychological studies

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Abstract

The present paper reviews studies that demonstrate the utility of Virtual Reality (VR) in psychology. It starts with an outline of the types of VR technologies and related issues, followed by a description of a number of VR tests developed for assessment and rehabilitation purposes. It then emphasizes one of the main assets of VR simulated environments, namely that they may feature high ecological validity without sacrificing experimental control, and in this way VR may improve the ecological validity of neuropsychological investigations that look in particular, at executive functioning. It is precisely within this context that recent work is reviewed: a set of computer-based tasks that allow carefully controlled, simulated environments, and where participants (a group of patient with frontal lobe lesions and a control group) are faced with 'real world' situations.

Key words: *Virtual Reality, Executive Function, Ecological Validity.*

1. Introduction to Virtual Reality

A distinction between 'immersive' and 'non-immersive' VR environments represents a broad classification of VR systems. An immersive environment exploits sophisticated new technologies to generate a three-dimensional 'world'. In particular, the displayed images of this artificially

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produced 'world' are delivered to the user through special devices such as position sensors and gaze tracking; the sense of 'presence' in the virtual world is thus induced (Steuer, 1992). Furthermore, through visual display units and speakers within a helmet-mounted display (HMD), and through controlling the head sensor, the images in the virtual 'world' appear *stable* while the individual may move in it (Riva, 1998). An environment presented on a conventional desk-top screen is referred to as a non-immersive virtual environment (Rose *et al*, 1996). In this, participants typically use a joystick or other control devices such as keyboard arrow keys to achieve movement and interaction with the environment (*ibid*.).

Three main issues will be considered, namely side-effects of VR usage, development of possible undesirable behaviour, and the issue of transfer of learning. With respect to the first, an extensive literature suggests that users of simulators may suffer from what has been termed simulator sickness (e.g. Regan and Price, 1994; Viirre, 1994; Kolasinski, 1995), however, such concerns are not shared by others (e.g. Rizzo *et al.*, 2001). Additionally, Rose and colleagues (2001) in a review of their studies reported no adverse reactions in their participants, even in studies involving highly immersive situations. Although, less severe problems, such as eyestrain, dizziness or general discomfort may be possible, it is worth noting, that in contrast, simulated environments generated through *desk-top* technology have not been associated with such side effects. Secondly, concerns have been expressed that, where VR games feature violent behaviour, there might be a link between these environments and an increased level of addictiveness and a subsequent risk of developing undesirable patterns of behaviour, especially among children and teenagers (Wilson *et al.*, 1997).

However, the authors do not overlook VR's positive contribution in relation to this; in particular, they recognise the fact that, learning to interact with virtual people may even serve as an intermediate step in acquiring social skills. Thirdly, issues have been raised by Wiederhold and Wiederhold (1998), who draw attention to the possibility of VR applications promoting social isolation, diminished sense of community and also antisocial behaviour. A last point refers to the training programs devised with the aim to teach important life skills to students with disabilities (see 'VR as rehabilitative technique' below). In particular, because in VR training the participant does not suffer the consequences of their errors (this being the underlying philosophy of having VR training), this could potentially lead its users to become desensitised to the hazards of the real life equivalent (Wilson *et al.*, 1997). For instance, in training children to cross the road safely using computer generated environments, if the training is not conducted with the necessary precautions, as Wilson *et al.* (1997) warn, the reverse outcome may be observed.

The issue of transfer of skills and knowledge acquired in VR environments to the real world is central in evaluating the potential benefits of VR procedures (Rizzo and Buckwalter, 1997). The extent to which a rehabilitative intervention can be viewed as successful is reflected in its potential for transfer. Skill transfer or skill generalisation has been classified as: (a) transfer of the training across sessions on the *same* testing materials, (b) transfer on *similar* as well as different materials than the ones used in the training session, and (c) transfer in terms of improved everyday life functioning, as a result of the training (Gordon, 1987). Although there has been evidence not supporting the idea of positive transfer (Kozac *et al.*, 1993), the bulk of empirical evidence demonstrates that skills may indeed generalise from virtual to real life environments (e.g. Lampton *et al.*, 1994; Regian *et al.*, 1992; Rose *et al.*, 1997; Gourlay *et al.*, 2000). Researchers indicate the need for further work with the aim to elucidate the processes through which learning occurs in VR environments; this in order to find ways of maximising transfer of learning to real life situations (e.g. Rose *et al.*, 2001).

2. VR as an assessment tool

According to Lezak (1995) neuropsychological assessment is the process of evaluating the relationship between brain states and observable behaviour. Below are described endeavours to develop VR assessment techniques, immersive and non-immersive, with the underlying philosophy being to add to attempts for finding optimal ways for assessing cognitive function.

2.1. Immersive VR

Pugnetti and co-workers (1995) designed a VR system for the neuropsychological assessment of cognitive functions, and in particular executive functions, in people following brain injury. The test presents a virtual building, which consists of rooms and connecting corridors, the task being to navigate around the building and exit as quickly as possible. The navigation involves choosing to open one of the doors, which may lead either to a room or to a dead-end. In particular, there are three categories of doorway options based on the shape, colour and number of the doors, and the participant is required to look for clues in the previous doorway in order to make the next appropriate choice. Therefore, in order to aid the selection of the correct option participants are expected to use the clues. In addition, they are also expected to develop a new strategy and start selecting according to a different category, following a change of the chosen criteria, which occurred every seven correct selections on the part of the patient. This VR test echoes the widely used Wisconsin Card Sorting Test (WCST) (devised by Grant and Berg in 1948 and testing the ability to show flexibility in the face of changing patterns of feedback).

Rizzo and colleagues (2001; Rizzo and Buckwalter, 1997) sought to expand on the work of Shepard and Metzler (1971), and created a VR analogue of the latter's test of mental rotation ability, *i.e.* ability for 'turning something over to one's mind' (*ibid*.). While conventional two-dimensional tests of this ability have yielded interesting results they do not permit the precise presentation and control necessary for a better understanding of this ability (Rizzo *et al.*, 2001); additionally, they require mental processing without motor involvement (Vandenberg and Kuse, 1978). The above researchers used VR to produce three-dimensional stimulus environments, with precise presentation and control of target stimuli, and behavioural responses. In particular, their approach to mental rotation process began with the construction of a system (virtual reality spatial rotation system), consisting of a table with stereo glasses and magnetic head and hand tracking and a rear projection screen. This system presents the participant with a *target stimulus*, which is a particular arrangement of three-dimensional blocks, appearing to be floating above the projection screen. Following this, the participant is presented with the *control stimulus*, this is the same arrangement of blocks as before, the task being to manipulate the control stimulus and superimpose it on the target stimulus. To achieve this the set of blocks needs to be rotated to the direction of the target stimulus, and this is possible through grasping and moving a sphere-like object resembling the three-dimensional set, which the authors term 'cyberprop'.

When the target object has been successfully placed on the desired position (*i.e.* placed over the target object), participants hear a 'correct' feedback tone to both signal this and start the next trial. In the new trial, another control stimulus appears attached to the sphere (in other words, in the user's hands), with the new target stimulus appearing slightly away. In this type of interaction, the to-be-manipulated stimuli appear attached to the sphere, and immersed in this world participants do not have to press buttons or select objects. Rizzo *et al.* (2001) tested a group of healthy young adults, and reported promising associations with standard neuropsychological tests, which they interpreted as suggesting that their method is a potentially reliable measure and warrants further research. This is being undertaking with a group of healthy elderly participants and investigating more aspects of cognition, for example depth perception.

Parallel to the above project, Rizzo *et al.* (2000) designed the virtual classroom with the aim of targeting attention processes within ecologically valid functional scenarios, through the use of an HMD (helmet-mounted display) system. Specifically, the virtual classroom concerned deficits in attention observed in individuals diagnosed with ADHD (Attention Deficit Hyperactivity Disorder). In this paradigm, the participant is immersed in a classroom, which consists of student desks, a virtual teacher, a blackboard across the front wall, a side wall with a large window looking onto a playground, and a street with people and vehicles; also, on both sides of the opposite wall there are two doorways and through there the activities occur. The assessment takes place in this environment that mimics a typical real classroom. There is a systematic manipulation of a number of variables referring to audio-supported ambient classroom noise, paper airplanes flying around, movement of other children in the classroom and activities in the playground and the street, these serving as the *distracters*. For the assessment, participants are required to perform simple activities, such as press a button when the virtual teacher asks them to do so, or more complex ones, for example, responding only when the child hears the teacher say the name of a colour in relation to an animal (e.g. 'brown dog' and not 'I like the colour brown') (Rizzo *et al.*, 2001). The measures of interest include reaction time, head turning and overall motor movement. The assessment of children with ADHD and of non-diagnosed controls is currently underway. In addition, Rizzo and his team envisage further work targeting memory and executive functioning within such ecologically valid scenarios.

2.2. Non-Immersive VR

Zhang *et al.* (2001) developed a desk-top virtual kitchen to evaluate cognitive functioning in a large sample of patients with traumatic brain injury. The participants were presented with a computer-generated kitchen and were asked to perform a wide range of daily life activities (a total of 30), tapping the following abilities: information processing, problem solving, sequencing ability and also responding speed. The 30 patients were found to be impaired on the above four measures in relation to healthy controls. The authors conclude that non-immersive VR systems may be used to complement conventional tests for assessment and rehabilitation purposes. McGeorge *et al.* (2001) describe the design of a computer-simulated environment of a three-floored college building contained within the frame of an Internet browser window. Embedded in it there was the facility for providing feedback to indicate successful completion of a task. Five patients were tested on the VR environment and the real equivalent that took place at the real college. A research assistant accompanied the participant in the real world task to record his/her movements, which in the VR version was achieved through the use of video recording.

The requirements of both these tests mirror the Multiple Errands Test developed by Shallice and Burgess (1991). In particular, McGeorge and his colleuages gave the participants twelve work-orientated tasks to complete within a fixed time limit, the scenario revolving around the fact that they were imaginary members of staff working at the college and had multiple errands to do relating to organising a conference. Although they were allowed to carry out the errands in any order they wished, they had one rule to follow, namely to use specific staircases for going up and down the floors. Following a careful examination of the tasks listed on a card, the participants were required to generate a plan showing how they planned to complete these tasks. Analysis of the produced plans revealed that patients had produced poorer plans in relation to the controls, as rated by two independent raters. Also, the patients completed a smaller number of errands than the controls, this pattern of results applying to both the real and virtual planning tasks. While these findings indicate that the real as well as the virtual planning task measure similar planning abilities, it was interestingly found that the performance of the patients on the BADS (Behavioural Assessment of Dysexecutive Syndrome, Wilson *et al.*, 1996) appeared normal according to normative data, although these patients showed planning impairments in their day to day living. The authors suggested that the virtual setting may represent a more valid, as well as safer mode of assessing cognitive functioning.

3. VR as a rehabilitative technique

3.1. VR in training people with learning disabilities

The potential of VR technologies has been greatly exploited in certain areas in order to provide initial training (for example, to pilots, divers or surgeons) in simulated, as opposed to real environments, which would be costly and potentially hazardous (Rose *et al.*, 1996). Considerable research has been directed to designing VR training instruments for use in the rehabilitation of individuals with learning difficulties. Perhaps the earliest evidence with regard to this is research by Brown and his colleagues (e.g. Brown *et al.*, 1995) and Mowafy and Pollack (1995). The first group of researchers developed a set of three VR environments (a virtual house, a virtual city, and a virtual supermarket) to be used as teaching aids for children with severe learning disabilities; important every day living skills were targeted such as using a kitchen or the road safely, or buying goods. With the safety issue in mind, Mowafy and Pollack (1995) sought to train students with cognitive deficits to use public transport: using immersive technology participants were allowed to take as many rides as it were required to develop good traveling skills (see also, Strickland *et al.*, 1995).

It was becoming increasingly recognised that VR can be of particular benefit to the training and education of children and adults. With regard to the first, Cromby *et al.* (1996) trained a group of teenagers with learning disabilities in virtual shopping using a virtual supermarket environment; a second group was offered the opportunity to explore environments other than the supermarket (e.g. a house). Both groups were taken to a real supermarket *prior* to the experimental condition and their ability to find certain items was assessed, which revealed no difference between them. In contrast, their performance in the real supermarket was differentiated *after* the training, with the first group performing better, as this was reflected in both, accuracy and speed of task completion. In terms of the role of VR in special education, an early example of this is the 'virtual environment science laboratory' whereby students with learning difficulties received help to understand the laws of physics. Within such learning programmes, the students were encouraged to initiate actions, these tendencies showing an increase as the lesson progressed (Standen and Low, 1996).

Moreover, it has been argued that VR skill teaching in people with learning disabilities may prove a particularly efficacious method. Three main features of VR training are highlighted as important: the first is that it allows the practising of skills without suffering the consequences or the humiliation of errors; secondly, the virtual environments can be manipulated to gradually increase in complexity to reflect the level of acquired skills by the learner; the third advantage represents the absence of language or symbols, and the reliance of learning on the direct *interaction* with the virtual word (Cromby *et al.*, 1996). These studies and a number of other projects listed here, comprise the first wave of virtual environments applications in the field of learning difficulties, the main objective of which was the development of important daily life living skills. Specific projects were aimed at: (a) teaching individual language skills (Standen and Low (1996) yielded data that people with learning difficulties can learn use of the Makaton signs); (b) educating people on health and safety matters within sheltered employment schemes (Cobb and Brown, 1997); (c) teaching tenancy right to people in sheltered housing (Brown and Englefield, 1997); and (d) teaching appropriate responses to children when approached by strangers and general independent skills using the virtual city programme (Brown and Stewart, 1996; Brown *et al.*, 1999).

Perhaps one of the features of the new developments in virtual learning environments was the underlying philosophy of promoting *employment* related skills, hence, facilitating job finding in people with learning disabilities. The VIRT was aimed at designing desk-top simulated environments for use by trainers and educators of people with learning disabilities seeking employment in sheltered factories. Mendozzi *et al.* (2000) describe three VR training environments on which a total of 30 individuals with learning difficulties were trained. The first, the warehouse environment, featured two 'poles of attractions', namely an array of shelves and a weighing platform situated at either side of a spacious room. The purpose of this setting was to familiarise users with the general virtual system and how interaction can be achieved, and specifically with the activities that one can perform, these typically including selecting objects from the shelves by clicking on them, and placing them at certain locations. A number of object characteristics, such as colour or size, can be manipulated and many variants of the task can be generated to make the task engaging. The second, the workshop environment consists of a similar room; it contains a workbench at one side and a conveyor belt at the opposite side, the task simulating the assembly of a torch. The torch must be assembled from scratch; therefore the trainee must make sure that all relevant material are available and ready to be used, because certain components need processing and refining (for example, painting). On the workbench there are containers where all relevant material can be found. The trainee has access to instructions, in the form of hints, but no immediate feedback is given. The difficulty of the task can be controlled, with the difficulty level spanning from only having to check that the batteries are charged, to being requested to correctly carry out all 39 steps in order to assemble the torch.

The third, the office environment was designed to tax the cognitive system more heavily, but this was not eventually used as an experimental training tool, due to time constraints. This environment shows incoming and outgoing conveyor belts carrying parcels, which the user has to process by ordering new material, printing labels for outgoing parcels and making lists for incoming ones; all this should be performed using a virtual computer. Trainees had daily training session that lasted from 45 min to 1 hour, completing a total of 96 hours of training. Prior to the commencement of the training and following its completion, participants were tested on real tasks mimicking those in the training. Even individuals with severe learning disabilities were able to learn task procedures. Transfer in the warehouse was assessed by asking the trainees to retrieve certain objects from the real warehouse. Following the virtual training, the trainees performed significantly better, as they retrieved more objects and faster compared to their performance prior the training.

To test the extent to which the learning gained through the virtual training could transfer to a real situation, participants were required to assemble a real replica of the virtual torch, without help to guide performance. Transfer was measured by assessing the number of components assembled and the time required to complete the assembly. There was a mixed pattern of results, in that certain groups of trainees showed a significant improvement, while others did not. The environments just described constitute perhaps the first such application to aid people with severe learning disabilities, now serving as training tools for people who fulfill the criteria for employability. Mendozzi *et al.* (2000) conclude that, even though the results on transfer of learning cannot be seen as conclusive due to the absence of a control group, however, they hint towards positive transfer from VR to real tasks.

A further project assessing the feasibility of VR use in vocational training of students with learning disabilities was carried out by Rose and his colleagues (2000). A questionnaire survey involved analysing the responses of forty-nine trainers of people with learning disabilities for vocational purposes. They were mainly asked to respond as to their preferred training methods and to rate the importance of each response. It appeared from this survey that the training most often undertaking by the trainers was vocation specific, with the two most popular vocations being catering followed by horticulture. In terms of the training methods used, these included demonstration, systematic instruction and task analysis. They were reported as time-consuming methods, unlike the workshops and videotapes, which constituted the most frequent learning aids. The survey also revealed that learning was mainly hindered by memory and attentional difficulties as well as lack of confidence.

Subsequently, and based on the findings of the survey, a non-immersive virtual kitchen was designed involving four food preparation and cooking tasks (using meat, fish, vegetables, and fruit). An added task referred to hazard detection training. For this the students were trained to recognise three potential hazards allocated in the virtual kitchen. Twelve students took part in the virtual kitchen training task, all participants with learning disabilities. Before and after the virtual training, the performance of the students was assessed on a real kitchen training, and a workbook training. Each individual received one session for each of the three types of training (*i.e.* real, virtual, and workbook training), each session lasting for 15 minutes. The results of this preliminary investigation suggested an improvement from before- to after- real and virtual training conditions. This improvement was higher relative to the workbook training and no training conditions. Moreover, there was a significant difference between the virtual and the workbook training, and between the virtual and no training condition, with the virtual training being more efficacious in both cases. With regard to identifying potential hazards, however, no difference emerged between virtual and workbook conditions. Rose and colleagues proposed the adaptability of VR training to individual functional profiles as a potential asset of a virtual training methodology in developing catering-related skills in people with learning disabilities.

Brown *et al.* (2001) addressed the development of horticultural skills through the construction of a virtual environment, which involved training on seven tasks targeting skills relating to use of protective clothing, clearing up glass, first aid, lifting heavy weights with safety, spraying safely, clearing up equipment and washing hands prior to eating food. The researchers wished to assess the usability and effectiveness of the virtual glenwood growers setting. To this end, six students performed the above tasks and were subsequently interviewed. Content analysis was applied on the interview data indicating there exists good validity, and that the task also has an excellent usability status. Thus, the authors continue developing this methodology.

Further promising projects are being developed, including the virtual courtroom, seeking to train individuals with disabilities in giving evidence in court or being cross-examined, and also a travel training environment aimed at teaching people use of public transport (Brown *et al.*, 2001). Based on the acknowledgement that there are number of people with profound and multiple disabilities, who cannot benefit from training tools such as those described in this section, researchers are at present working on environments which would incorporate learning goals appropriate for individuals with more severe disabilities.

3.2. VR in training people with physical disabilities

The rehabilitation of spatial awareness in physically disabled individuals, an ability reported to be poorly developed (Foreman *et al.*, 1989), has been the target of research performed mostly with disabled children. This work suggests that it is possible to teach spatial skills to people, who are disabled. One of the earliest studies is that of Regian and colleagues (1992) who demonstrated skill acquisition using a task involving spatial *procedural* learning (in particular, learning a sequence of knob or button activations on a simulated consul). It was also shown in this study that children with physical disabilities, who have learned to *orientate* themselves in simulated environments, showed transfer of this skill to a real world setting.

In another experiment, it was found that VR training can promote *spatial* learning in disabled children (Wilson *et al.*, 1997). Using non-immersive simulation, the children were allowed to explore a virtual building, which was based on a real building. After the session, their knowledge of the layout of the real building was assessed. In this assessment, they were placed in the real building and were required to point to the location of certain items, which were however, not visible from the test site. The results of this study showed that they were able to point to the correct direction, this suggesting that spatial knowledge had been gained during the exploration session. In comparison, control adults with no disability and who had not received the training performed worse than the experimental group (see Peruch *et al.* (2000) for a review of studies concerning the transfer of spatial knowledge from a virtual representation to a real environment).

At the same time that Wilson and colleagues were conducting the above experiment, Stanton and her colleagues (1998) sought to investigate whether VR training could be further enhanced through *repeated* rather than single exposure to virtual environments. The researchers presented children with non-immersive environments, which depicted three rooms inter-connected by corridors with a number of target objects being allocated throughout the rooms. The children were firstly allowed to explore the virtual environment and then were tested on their ability to rotate their direction of view, so as to point towards the objects, which were not visible from the test site. After three exploration sessions, the errors made by the experimental groups had significantly decreased. A following experiment in the same study investigated orientation ability in two groups of disabled children. They were tested in a simulated orientation task, prior and after four sessions of computer experience. The experimental variables were: using a three-dimensional environment and playing a two-dimensional platform game. It was found that the group that had received the three-dimensional training performed better than the group with the two-dimensional training. Taken together, the results of these studies are suggestive of a significant improvement in the disabled children's ability to find target landmarks and orient themselves. Moreover, Stanton *et al.* (2000) wished to replicate the findings of the Wilson *et al.* study described previously. They designed the more complex environment (the virtual school), which consisted of a front door with a corridor leading into a central area with nine rooms (e.g. four classrooms, a library area, an office). The physically disabled children received five exploration sessions, at the end of which (and after they became familiar with the layout) they were asked to point to three target objects from three different testing sites, from which none of these landmarks could be seen. In relation to the control group, superior performance of the experimental group was demonstrated when tested on the tasks previously trained in the virtual school. Of note, however, superior performance was also shown on spatial tasks for which no virtual training had been provided.

3.3. VR in brain damage

Rose *et al.* (2001) emphasised that, in spite of the number of papers making a case for the potential of VR in brain damage rehabilitation, '... there are, as yet, few objectively derived data sets on which to base even the most tentative of conclusions' (p. 347). As a result, the authors claim that considerable efforts still need to be devoted to the research and training of patients after brain damage. These patients may suffer from various debilitating conditions, such as those involving loss or reduced levels of muscular control, those associated with neglect or cognitive deficits. When considering also the social isolation or dependency usually linked with such problems, the need for effective rehabilitation is self-evident.

4. VR and hemiparesis

With regard to movement disorders, a large proportion of patients will experience some loss of muscular control on the side opposite to the damage, contra-lateral *hemiparesis*; while general posture may be reasonably re-established, hand and finger control, and also control of the contra-lateral foot is poorly regained (Wann *et al.*, 1997). Hence, what is needed is an environment where the patient can practise limb movements, and which also provides feedback relating to the errors made (for example, in speed and smoothness) (Wann, 1996). The work of Wann and co-workers is based on the idea that, because computer simulated environments can recreate a therapeutic 'reality' tailored to the ability of the patient, they can guide the re-learning of the movements towards optimal patterns of movement (Wann *et al.*, 1997). Wann (1996) proposed also that the game-like format of the exercises may help maintain the motivation needed for taking part in prolonged exercises. The 'arena' is an example of such an environment, in which the motion of a puck is connected to the patient's manual input. According to the task, patients must try and 'score a goal', thus encouraging limb practising. The exercises can be done using immersive or non-immersive apparatus and can also be graded in difficulty (Wann *et al.*, 1997).

Published data of a case study describing VR-based lower extremity training are reported by Deutsch *et al.* (2001). The patient completed a 6-

session program targeting ankle rehabilitation, through the use of a system that provides resistive force on the patient's foot. The exercise involved: firstly, introducing the patient to the procedure and setting the resistance level for the ankle baseline motion; secondly, selecting the difficulty level; thirdly, performing the exercise. For this, the patient viewed a virtual airplane on screen, which he had to pilot by steering it so as to pass through designated loops. The target loop was initially coloured yellow, and turned green upon successful performance. The results indicated an improvement in terms of strength, endurance, and the patient's ability to walk and climb stairs. Although these are preliminary results based on a single patient, it is interesting to note that this is probably the first reported attempt of VR based use of force feedback for the rehabilitation of lower limb, and the authors put forward ideas for future work.

In a similar line of research, others have looked at VR methods with the aim of rehabilitating hand movement (Jack *et al.*, 2001). In particular, three chronic stroke patients received daily rehabilitative sessions for two weeks. A non-immersive system was used, with input devices capable of providing feedback and creating an interactive VR environment. The rehabilitation program incorporated four parameters of hand functions namely, range, speed, fractionation and strength, with each of these parameters being the focus of separate routines. The results demonstrated improvement on most of these parameters for all three patients, thus reinforcing current claims on the potential of VR in rehabilitating post-stroke patients to re-learn specific movements by exercising their limbs (e.g. Deutsch *et al.*, 2001).

5. VR and neglect

In terms of visual disorders, *neglect* is often among the sequelae of brain injury (Lezak, 1995). In this condition the deficit rests with focusing attention, and so patients attend only to objects or people that are present on the same side of their body as the brain damage (Wann *et al.*, 1997); this can be potential dangerous when, for example, crossing a road. It has been argued that VR generated environments may provide effective training in the remediation of neglect. For example, Wann and colleagues (1997) designed different variants of a 'maze' environment that require various levels of attention and decision making on the part of the patients. They are required to perform a variety of activities, drawing upon simple sequencing skills (e.g. having to follow a colour sequence within the maze), recognition ability (e.g. letter recognition maze), or semantic processes (here the maze contains words relating to animals with phonetic distractors (for example, dog versus dig). The underlying idea is to present patients with neglect a challenging environment that requires the formation of an opinion. As indicated above, patients with neglect may be faced with increased hazard as pedestrians, or when in a kitchen. In addressing the former, Naveh *et al.* (2000) employed VR to train stroke patients with spatial neglect to cross the road safely. The patient was presented with an avatar representing an individual at the front of a pedestrian crossing; they were then instructed how to turn the avatar's head, by using the arrow direction keys, to check for oncoming traffic. The patients could make the avatar commence crossing when they thought it was safe to do so. If no virtual accident occurred and patients had succeeded in crossing the road, they would automatically proceed to the next trial, which would typically correspond to a more difficult situation. The number of training sessions ranged from 1 to 4 sessions, as required. Measures taken included the time taken to complete each trial, the number of accidents and the number of times patients looked to the left and right for oncoming vehicles. The results of the 12 participants suggested that it is possible for patients with neglect to complete all levels of the training, provided they receive a sufficient number of training sessions. The authors concluded that such training environments hold a promise in becoming powerful teaching tools to be used in patients with neurological disorders.

6. VR and cognitive rehabilitation

As far as *cognitive* rehabilitation is concerned, a preliminary investigation into memory re-training with patients following brain injury is reported by Rose *et al.* (1999). Forty-eight patients and the same number of matched healthy controls performed a task that involved entering and exploring a virtual bungalow, in search of a toy car. The researchers sought to examine the effects of active involvement in exploring the bungalow (a single-story building with four-interconnected rooms and a hallway), as opposed to passively observing the active participant perform the task. Therefore, in order to complete the task participants were grouped into pairs, with one participant being the active member and the other the passive. Following this, spatial and object recognition ability was tested. The findings showed that active participation enhanced spatial memory but not object memory for patients and controls. The authors interpret the results in terms of a paradigm, which has potential for use with patients for the purpose of memory rehabilitation.

Furthermore, a non-immersive VR setting has been used by Brooks *et al.* (1999). The authors describe a patient who presented with memory impairments, and in particular amnesia, after a haemorrhage. The patient received a two-week training in route finding, which consisted of the following two phases: during the first the patient was practising two of the ten routes around the real hospital unit, while the second phase involved virtual route training, using a non-immersive environment designed after the real rehabilitation unit. The results showed that the virtual training succeeded in teaching this patient certain routes. It was also demonstrated that the virtual route learning was more beneficial compared to training session in the real unit, at least for this specific patient. The authors attribute the effectiveness of the virtual training partly to the fact that it allows a route to be practiced many times, without distractions. This study, albeit with a sample size of one, suggests rehabilitation gains using VR in amnesia.

A non-immersive method was also employed by Grealy *et al.* (1999), who sought to investigate the effects of a virtual exercise intervention program. Thirteen patients following traumatic brain injury were tested prior and after the intervention program. The latter was intended to improve four aspects of cognition, namely, attention, information processing, learning and memory. Outcome measures of reaction and movement times were computed. Grealy *et al.* compared the performance of the patients after the intervention to that of no-intervention control group. The analysis revealed that the performance of the patients was significantly better than the controls on the digit span, verbal and visual learning tasks; importantly, a significant improvement was observed in the patients even after a single bout of VR exercise on the reaction and movement times. These results are suggestive of the benefits that can derive from VR learning exercises.

7. The role of a VR approach in neuropsychology

The preceding sections sought to give an indication of the growing research in the field of VR-based assessment and rehabilitation. Here, advantages of VR suggesting a potentially useful role in neuropsychology are outlined. For example, Rizzo *et al.* (2001) describes the key features of VR systems as including the ability to allow for precise presentation and control of dynamic stimulus environments, and accurate recording of behavioural responses.

In particular, that VR lends itself to enhancing environmental *interaction* (*i.e.* interaction between the patient and the environment) makes it a potentially useful aid in the rehabilitation of neurological patients (Rose *et al.*, 1996). The interactive nature of VR generated worlds provides the user (patient or learner) with an opportunity to have control over the learning process (Pantelidis, 1993). Because VR-based procedures are highly flexible and programmable, they can offer a wide range of input *stimuli* capable of monitoring and giving precise measurements of the responses made by the user (Riva, 1998). The stimuli can be tailored to fit the specific needs of the user, resulting in a more comfortable interaction and appropriate rehabilitative intervention (Strickland, 1997). The diversity of possible stimuli is also emphasised by Glantz *et al.* (1997), who point out how a number of imaginary places can be created, in accordance to the user's needs. The requirement for individualized treatment has been known to derive from the heterogeneity of abilities and impairments among people with various disabilities; people may vary widely in terms of their abilities and skills, even between different days (Gregory, 1991). Additional contributions of VR systems are in terms of cost-effective rehabilitation; also individuals may receive rehabilitative sessions, at times even in the safety of their homes (Gourlay *et al.*, 2000), but in any case, in environments free of danger.

A further characteristic of VR, which is of particular value to individuals with sensory deficits, is that the *feedback* provided could be translated by the VR systems into alternate senses. VR goes beyond the modality of vision in representing information and providing feedback. Sounds can be translated into vibrations, or into another easily understood register, while environmental noise could be left out. With the incorporation of rich stimuli, and a number of modalities providing feedback, a 'realistic' reality is possible (Rizzo and Buckwalter, 1997). The same researchers warn about using paper and pencil neuropsychological tests, in the sense that these may not offer any certainty in terms of the degree of relevance between participants' performance on the tests and how they behave in their daily life. Rizzo and Buckwalter's comment is in keeping with a number of criticisms that traditional paper and pencil neuropsychological tests for lack of *ecological validity* (see Kotitsa (submitted) for a review of the issue of ecological validity in psychology).

In addressing the need for procedures high in ecological validity, some researchers made use of *naturalistic* observation. Shallice and Burgess (1991) developed the Multiple Errands Test, a procedure carried out in a pedestrian area and which successfully detected executive dysfunction in the context of everyday life, multi-tasking scenarios. The demands of this influential test were reflected in a later procedure (see Knight *et al.,* 2002), exploring the utility of a simplified Multiple Errands within a hospital setting. Another test that sought to imitate real life activities is the Route Finding test (Boyd and Sautter, 1993), which examines executive impairment as it is manifested when required to find a specific location in an unfamiliar campus. Although taking experimentation out of the laboratory does provide ecologically valid data, yet this happens at the expenses of rigorous experimental control typically found in the lab.

In relation to this, VR methods may provide a more fertile means, since as indicated earlier, they do not comprise experimental control. Further advantages of VR based tests, when compared to the above 'real life' tests, is the fact that the former are more convenient to administer (in terms of time or staff requirements) and lend themselves to standardisation. A set of VR procedures were developed recently (Kotitsa, 2005; Kotitsa *et al.,* in preparation a, b) aimed at exploring aspects of planning and problem solving ability in a naturalistic manner. Typically, participants are presented with a computerized environment, where navigation is possible using a joystick and interaction is achieved by touching the screen (Figure 1). More specifically, for the first procedure, involving a house removal scenario, participants are required to go into the 'bungalow' and 'select the furniture for removal'. The furniture are allocated in the four rooms of the bungalow and must be collected according to a certain order, pre-specified by the 'owners'; this enables the exploration of rule breaking and strategy formation, while further requirements relating to putting 'fragile' notices on certain items, keeping certain doors always shut after opening, and having to check the front door for the 'removal van' at regular intervals allow the investigation of prospective memory. The second task models a real life industrial scenario, in that the participant is presented with a factory warehouse room and is required to perform certain activities involving the selection of boxes and reels in a par-

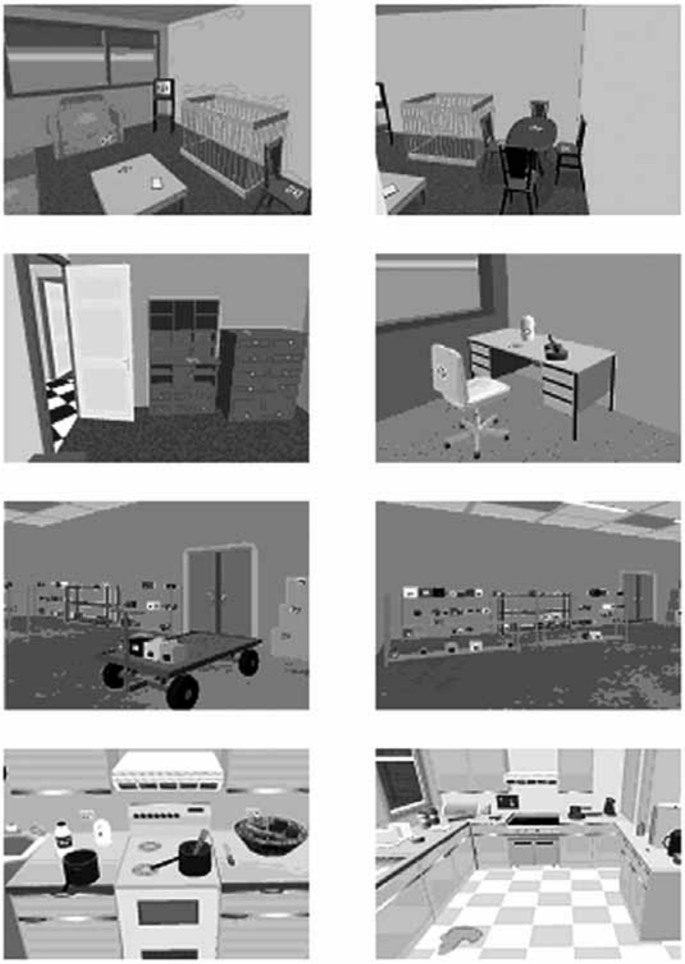

Figure 1. *The virtual reality environments. The first two sets of pictures show different views of the 'house removal' scenario: the participant is asked to go from room to room collecting the furniture in a pre-specified ordered, whilst at the same time s/he must check the front door, because the 'removal van' should arrive at any minute (and 'the door bell does not work'). This type of requirements measure of strategy formation, rule following and prospective memory. The third set of illustrations show a factory environment, whereby a total of six activities need to be performed, whilst again obeying certain rules: here the participant collected items and placed them onto a trolley. The bottom set of pictures relates to hazard detection and evaluation: a sample of the hazards is shown here.*

ticular manner. This test looks at multitasking and rule following ability. The third test features a domestic setting, ie. a kitchen, and seeks to explore safety judgment and in particular, the detection and assessment of health hazards.

The findings revealed significant deficits in strategy formation and application, increased rule breaking and prospective memory impairments in the patient with frontal lobe damage, compared to well-matched controls. In addition, the patients were impaired in their ability to follow rules and allocate effort across a number of specified tasks. Importantly, the patients did not show deficits when tested on traditional validated procedures (*ibid*), this indicating VR based tests may be more sensitive to planning and problem solving deficits in a particular clinical population (ie, patients with frontal lobe excisions).

8. Conclusion

In recent years the rapid advances in VR technologies has greatly influenced a number of fields in psychology. This review focused on the contribution of VR based procedures in assessment and rehabilitation settings, and it also discussed the role of VR in neuropsychology. Recent studies employing VR concentrate on the issue of ecological validity; indeed, data from patients suffering frontal lobe damage show that VR may be a particularly promising avenue for designing ecologically valid tasks to investigate components of executive functioning, in that a large array of cognitive abilities can be elicited and successfully measured in these real-life mimicking scenarios.

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