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Using Virtual Environments in the Assessment of Executive Dysfunction

Abstract

A study is reported into the role of virtual environments in the assessment of patients with executive dysfunction. Five patients and five matched controls entered the study. The patients did not differ significantly from normative values on the standard executive dysfunction measure, the Behavioural Assessment of the Dysexecutive Syndrome battery (Wilson, Alderman, Burgess, Emslie, & Evans, 1996); however, care staff reported the patients had problems planning. Patients and controls undertook both real and virtual environment multiple-errand planning tasks. The patients completed significantly fewer errands, and produced significantly worse plans than did controls in both the real and virtual environments. There was a significant correlation between performance in the real and virtual environments. The results suggest that virtual environments may provide a valid means of assessing planning impairments and that there may be patients with executive dysfunction (specifically planning deficits) that may not be detected by the currently available standardized tests.

1 Introduction

Figures from the United States indicate that annually approximately 500,000 individuals sustain a brain injury of sufficient severity to require treatment, and nearly 100,000 sustain injuries resulting in severe cognitive, physical, and psychosocial impairments (Wehman, 1996). Although the physical disabilities associated with traumatic brain injury (TBI) generally recover, there is a far higher frequency of lasting changes in cognitive and behavioral functions (Ponsford, Olver, & Curran, 1996). The latter problems frequently result in a decline in social functioning and employment status. Most patients with TBI are discharged with apparently good recovery, yet receive little rehabilitation for any deficits in cognitive function (Dombovy & Olek, 1997). Persistent neuropsychological deficits often remain, and these may have severe consequences. For example, Dombovy and Olek report that only 40% of those with mild to moderate brain injury were employed six months after the injury. A review by Wehman, West, Kregal, Sherron, and Kreutzer (1995) indicates that a maximum of 30% of individuals with severe TBI return to work. Even five years post injury, many patients show severe deficits on important functions such as financial management, planning weekly activities, and shopping, and these deficits are associated with poor employment outcomes and lack of social autonomy (Mazaux et al., 1997). Crawford (1998) has noted that "ex-

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ecutive deficits can have a much more profound effect on a client's prospects for successful adjustment than the more circumscribed deficits arising from posterior lesions" (p.1).

The pattern of deficits found in many patients following TBI—for example, impaired social functioning, poor control and monitoring of cognition, and inability to inhibit inappropriate responses—has traditionally been associated with damage to the frontal lobes of the brain (Parker & Crawford, 1992; Phillips, 1997a). However, when characterizing patients who have abnormal control and monitoring of cognition, it has been argued that it is more appropriate to describe the behavioral deficit, a "dysexecutive syndrome," rather than rely on anatomical localization, that is, a "frontal lobe syndrome" (Baddeley & Wilson, 1988, Duffy & Campbell, 1994). Poor executive functioning may occur following lesions to other brain sites (such as small lesions in the head of the caudate (Duffy & Campbell, 1994)). Executive dysfunction comprises deficits on real-world tasks that require the generation of novel strategies, forward planning, online monitoring, or inhibition of irrelevant stimuli and responses (Crawford, 1996, 1998). The ability to concurrently perform two tasks simultaneously is particularly impaired in patients with dysexecutive problems (Alderman, 1996).

Assessing executive disorders is fraught with difficulties (Crawford, 1996; Crawford, Venneri, & O'Carroll, 1998; Phillips, 1997a; Wilson et al., 1996). Patients with executive disorders often perform relatively well on traditional neuropsychological tests of frontal lobe function, yet show marked impairment in controlling and monitoring behavior in real-life situations (Shallice & Burgess, 1991, Mattson & Levin, 1990). The types of real-life deficits shown by patients with dysexecutive syndrome include the inability to plan and prepare meals (Cockburn, 1995; Penfield & Evans, 1935) and the inability to plan and carry out a sequence of multiple errands as required in shopping (Shallice & Burgess, 1991).

Shallice and Burgess argue that this discrepancy between poor performance on real-world tasks and good performance on neuropsychological tests occurs due to the differing executive demands of such tests. They argue that, unlike real-world tasks, traditional neuropsychological tests do not demand the planning of behavior over more than a few minutes, or the prioritization of competing subtasks. Shallice and Burgess describe patients who perform well on a standard neuropsychological test of planning (the Tower of London), but show marked impairments of planning in a real-life environment, as assessed by the multiple-errands task. In the multiple-errands task, patients are taken to a shopping center and asked to buy objects and acquire some pieces of information while following specified rules. In the Shallice and Burgess study, patients made numerous errors on the task, such as breaking the task rules (for example, entering a shop without buying something, or leaving without paying for goods), using inefficient strategies (entering the same shop more than once), interpretation failures (where the requirements of a particular subtask were misunderstood), or task failures (where the task was not completed satisfactorily). These types of errors make it difficult for patients to live independently.

Despite arguments that planning deficits lead to an impaired chance of return to work, traditional cognitive tests do not seem to adequately assess planning. The most effective current techniques of assessment involve taking patients into real-world settings and assessing their performance. This is costly and may lead to potential distress or danger. Thus, the diagnosis of patients with executive dysfunction following traumatic brain injury represents an important potential field for the application of virtual environments (Wilson, Foreman, & Stanton, 1997).

Cromby, Standen, and Brown (1996) have highlighted a number of features associated with VEs that make them attractive for rehabilitation and assessment. Firstly, people can learn by mistakes without suffering the adverse consequences. Secondly, the VE minimizes the problems that may be associated with any physical disability. Thirdly, because participants are able to interact directly with the objects in the VE, they are able to discover the properties of objects and the relationships between objects and events without the need for language or other symbolic systems. There is growing evidence that there is a positive transfer effect for training within a VE to real-world settings (for example, Cromby, Standen, Newman, and Tasker (1996)).

Cockburn (1995) argues that most studies of patient deficits in planning are hampered by relying either on real-world situations over which the experimenter has no control, or tightly controlled laboratory measures that are not well correlated with real-life planning problems. In addition, Wilson, Baddeley, and Evans (1994) have suggested that active patient participation—in contrast to simply listening to correct answers or writing them down—is a key factor in successful rehabilitation. Therefore, a virtual environment is an ideal method by which to assess and rehabilitate disorders of planning, because the situation can be experimentally manipulated while simulating as closely as possible the demands of real life, allowing the participant to actively interact with the environment. Further, Alderman (1996) argues that standard rehabilitation environments tend to be noisy and full of potential distracting events. The use of a virtual environment allows much greater control of ongoing irrelevant events, and therefore allows control of the level of distraction in the environment. The links between stimuli can be enhanced to ameliorate some types of cognitive impairment and movement within the VE can be tailored to whatever motor abilities the patient has, thus overcoming some of the physical problems associated with TBI (Rose, Attree, & Johnson, 1996). Finally, pressures on staff time mean that typically patients spend only thirty to sixty minutes each day in formal therapy (Tinson, 1989). The use of virtual environments in assessment and rehabilitation may potentially provide an answer to the logistical problems associated with increasing the level of environmental interaction available to patients (Rose & Johnson, 1994).

To our knowledge, there has been only one published attempt to use virtual environments for the assessment of executive dysfunction. Pugnetti et al. (1995) created a VE that consisted of two very simple elements: rooms and connecting corridors. The task of the participant was to move about within a room and open one of several doorways. The doorway was either a dead end or led to the next room, where the process was repeated. The participant initially proceeded by trial and error until they located the correct doorway. Cues were provided in the form of doors of different colors and shapes, and participants had to make use of these environmental cues to make appropriate choices. The participant was supposed to use the cues to develop a strategy to avoid opening doors that led to dead-end corridors. The choice criteria could be changed requiring the participant to shift cognitive set, analyze clues, and devise a new strategy. The cognitive requirements of this environment are analogous to those in the Wisconsin Card Sort Test (Grant & Berg, 1948; Heaton, 1981).

The ability to plan is crucial in everyday tasks such as cooking, shopping, and holding down a job. Yet standardized test are often poor at picking up planning deficits because they do not mimic the complexities of everyday life. Therefore, the aim of the present study is to examine whether the role of virtual environments in the assessment of executive dysfunction can be extended to include more-complex tasks, specifically planning. To examine the role of virtual environments in assessment, the study will compare performance on the Behavioural Assessment of the Dysexecutive Syndrome (BADS) battery, a standardized test of executive function (Wilson et al., 1996), with both real and virtual environment planning tasks.

2 Method

2.1 Participants

Two groups of participants were studied: a head injury (patient) group and a group of controls matched for sex, age, years of education and handedness.

The patient group was selected from the Brain Injury Vocational Center operated by Rehab Scotland. During the period of the study, approximately 36 clients attended Rehab Scotland (Aberdeen), and all were considered for inclusion. Participants were selected initially using the following criteria: definite evidence of brain injury, minimal interval of six months prior to testing, and subjective reports from care staff that the individual had difficulties planning. Additionally, people were not included if evidence of the following conditions was found: posttraumatic amnesia, severe language or sensory deficits, hemiplegia, vestibular problems, or a prior history of major psychiatric disorders, alcoholism, or drug abuse that could potentially interfere with cognitive functioning.

Participants in the control group were recruited from the subject panel operated by the University Psychology Department and received a small gratuity as reimbursement of traveling expenses.

Based on the inclusion criteria, five patients (two women, three men, mean age 36.8 (s.d. 8.4) years) and five controls (two women, three men, mean age 36.0 (s.d. 8.5) years) entered the study. The patient sample had a mean of 12.2 (1.8) years of full-time education and the control sample, a mean of 11.6 (1.5) years. There was no significant difference in the number of years of full-time education between the patient and control group ($t(8) < 1$, $p > 0.1$).

2.2 Materials

2.2.1 Tests. Initial selection of participants was made on the basis of performance of the Six Elements subtest of the Behavioural Assessment of the Dysexecutive Syndrome (BADS) battery (Wilson et al., 1996) and the subjective evaluation by care staff that the individuals had a planning deficit. The aim was that only individuals scoring below the mean performance of controls on the BADS test (a profile score < 4) would be selected. Those selected were also given the five remaining subtests of the BADS battery and invited to complete the Dysexecutive questionnaire of the BADS. It became apparent during the screening of patients for inclusion in the study using the BADS Six Elements test that few of the patients identified by care staff as having difficulties planning performed below the criterion score and, indeed, below the score of the control group. For this reason, the original BADS inclusion criteria were dropped and patients identified for inclusion on the basis of the subjective assessment of the care staff. The implications of this change to the inclusion criteria are considered in the discussion.

Following this selection procedure, individuals were screened for signs of impairment using the following tests: impairment of verbal comprehension using a short form of the Token test (De Renzi & Faglioni, 1978), spatial neglect using the Star Cancellation subtest of the Behavioural Inattention Test (Wilson, Cockburn, & Halligan 1987), cognitive disturbance using the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975), impaired perception of angular relationships using form H of the Judgment of Line Orientation Test (Benton, Varney, & Hamsher, 1978) and impaired visual acuity using the Snellen eye chart. If an individual demonstrated evidence of significantly impaired performance on any one of these tests, they were automatically excluded from the study.

2.2.2 Computer Hardware and Software. The aim of the study was to evaluate the role that virtual environments could play in the assessment of executive function. It was therefore thought important that the environment that was developed should be capable of running on the types of computing equipment that is generally available to local healthcare staff. Consequently, the virtual environment was constructed to run on a standard PC using Superscape's 3D-Webmaster. The 3D-Webmaster software provides a simple, yet flexible tool for the development of virtual environments that are capable of delivery through a standard Internet browser. The environment was displayed using a 17 in. color monitor running at 75Hz at a resolution of 600×800. The environment was controlled using a Viglen Genie II PC with a 350MHz Pentium II processor and an 8MB ATI Graphics Card. Navigation through the system was controlled by the participant using the Viscape interface (figure 1) operated using a standard mouse.

The three floors of the Department of Psychology at the University of Aberdeen were chosen as the environment to ensure a relatively stable setting for the real-life tasks with as few unforeseen events occurring as possible. The virtual environment was designed to replicate the general layout of the department.

The virtual psychology department environment was contained within a central frame of an Internet browser display, linked to a frame for the presentation of feedback. (Figure 1 shows the standard display.) Feedback was presented within this box indicating when a task had been completed correctly. Frames at the side of the

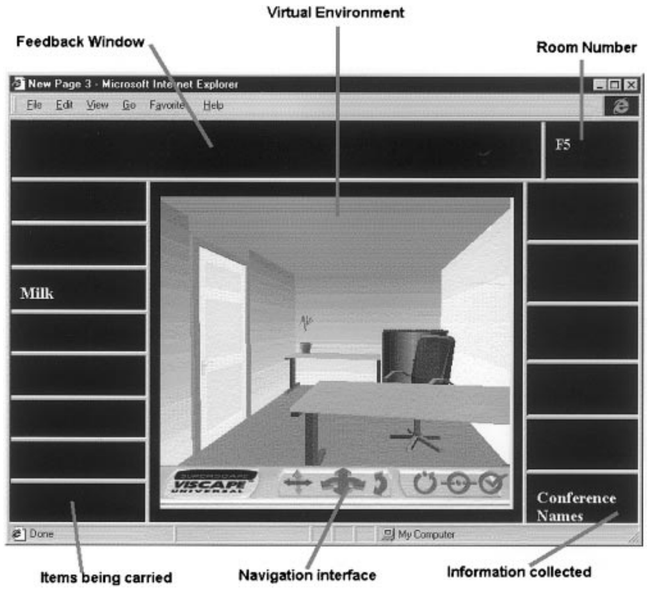

Figure 1. *Sample screenshot showing the environment, the navigation interface, and feedback windows.*

central environment window were also linked to the environment, and these were used to display a list of the items (frames on the left-hand side) or information (frames on the right-hand) that the participant was "holding" at that point in the task. A final frame was used to indicate the last visited location (for example, room number).

2.2.3 Task Performance Recording Apparatus. Throughout the 20 min. duration of the real-life task, the research assistant remained at a distance of 2 m to 3 m from the participant and recorded their movements with a handheld 8 mm camcorder. Video recordings were also made of participants' movements in the virtual environment by projecting the image from the computer monitor onto a white wall and making a video recording using the 8 mm camcorder mounted on a tripod. Herein after, the video recordings were used to code the quantitative measures.

2.3 Procedure

Prior to the assessment, a training session was given in which all participants became familiarized with the real-life environment and learned how to use the interface controlling navigational movements around the virtual environment.

Following the familiarization exercise, all participants were assessed on their ability to plan and carry out tasks comprising multiple subgoal elements. These tasks were formulated as vocationally oriented, errand-planning tasks within a simulated work setting (see detailed description below), and participants were assessed in their ability to perform these tasks in both the real-life environment and the virtual environment. The tasks were completed on separate occasions, and all participants completed the real-life environment task prior to the virtual environment task.

The study utilized tasks based on the multiple-errands test originally devised by Shallice and Burgess (1991) which requires a number of short, shopping-type errands to be planned and scheduled within a limited period of time. The multiple-errands test involves a number of subtasks that vary in complexity. The complexity ranges from simple errands such as buying a piece of fruit to errands requiring more complex problem solving, such as posting a postcard at a specific time with information about the average temperature in a UK city the day before. The multiple-errand test has a unique format that distinguishes it from many other neuropsychological tests, because it requires the multiple subgoal planning of shopping-type errands within a real-life location. Thus, it mimics closely the type of planning and problem solving that one might expect to face in everyday life.

The current tasks were designed to be more vocationally oriented in format containing work-related as opposed to the shopping errands used by Shallice and Burgess. The tasks invited the participant to imagine being a member of staff within the psychology department with a list of errands they would like to do within twenty minutes. Participants were told that there might not be enough time to do all the errands and so they should try to do as many as they thought possible. Following this introduction, a copy of the errand list was issued with the instruction that they may do the errands in any order.

Each task consisted of twelve errands in total. There

start: 3 pm in room **F12** (you have a list of people going to the conference)
end: 3.20 pm in **main office**

Stairwell A = down only. Stairwell B= up only.

- Pick up a borrowed computer disc from room **S15** and return it to room **S12** where it is needed.
- For the telephone call later collect a phonecard from the cupboard in room **T10**.
- Make a cup of tea in room **S5**, you must buy tea bags from the **shop** and collect milk from room **F5**.
- Find out what time the **main office** is open on Tuesday.
- You must find out the date of the memory exam from the door of room **F15** then pass this information on to a colleague in room **F17** before 3.05pm.
- Find out how many chairs are in room **T20** as the conference will be held there later.
- Read a magazine for 10 minutes in **F3**.
- Buy a new notebook from the **shop** and then go to room **F12** and copy out the names and telephone numbers of 3 hotels in Aberdeen from the Yellow Pages before the telephone call later. The **shop** is open for 10 minutes at 3pm-3.10pm.
- Find out which day the laboratory in room **T15** is vacant.
- Collect some exam papers from the head of department in room **T1** and put them in room **S1**.
- You need to copy out the list of names of people going to the conference onto envelopes. The envelopes are on the desk in room **T9**.
- Meet a visitor at room **T9** at 3.15pm and take them to room **T4**.

Figure 2. *Baseline virtual errand task (F* denotes a first-floor room, *S* a second-floor room, and *T* a third-floor room).

was a degree of variation in level of complexity and degree of importance of the errands in each task, and several errands had to be completed at specific times. (Figure 2 shows an example of the errand task used in the virtual condition.) A simple map of the psychology department showing relevant rooms was presented to the subject on a piece of paper for reference purposes. At this point, a rule was also introduced into the task, and subjects were instructed to try to obey it at all times: one stairwell in the psychology department was for traveling up only, whereas the other was for traveling down only. This information was also displayed on the map.

After a thorough reading of the errand list, participants were invited to take as long as they needed to construct a plan for the task using the map. They were provided with a pen to record their plan on paper. The real and virtual environment tasks were very similar in that they all comprised twelve errands, utilized approximately the same number of rooms, possessed equivalent complexity, and contained three time-specific errands.

After formulating their plan, the participants were asked to perform the task within twenty minutes, either in the real environment or the virtual environment. The total number of errands completed by each participant in each environment was recorded.

2.4 Quality of Plan Rating Scale

The quality of the written/drawn plans produced before each errand task was assessed. A six-point rating scale was developed comprising ten questions related to the posttask interview. (See appendix B.) Two independent judges rated each plan produced. The judges were blind to the identity of the plan's author (patient or control).

3 Results

The age-corrected standardized score on the Behavioural Assessment of the Dysexecutive Syndrome (BADS) battery was computed for the patients according to the administration manual (Wilson et al., 1996). The mean age-corrected score for the five patients included in the study was 102.00 (s.d. = 11.64). Comparison of the mean BADS score for the patient sample with the BADS normative sample indicated that there was no significant difference between the patient and normative samples ($t(219) = 1$, $p = 0.388$ (one-tailed)).

For the real and virtual environment tasks, the mean number of correctly completed errands for each group is shown in table 1.

For the number of completed errands, ANOVA with Group (patient or control) and environment (real or virtual) indicated that there was a significant difference in the number of errands completed by the two groups ($F(1, 8) = 8.86$, $p < 0.05$) such that patients performed fewer errands, no significant effect of environment ($F(1, 8) < 1$, $p > 0.05$) and no significant interaction ($F(1, 8) = 3.84$, $p > 0.05$). The correlation between the

Table 1. *Mean Number of Completed Errands and Mean Plan Rating for the Patient and Control Groups*

Group	Mean number of errands: Real environment	Mean number of errands: Virtual environment	Mean plan rating: Real environment	Mean plan rating: Virtual environment
Patient	6.2 (1.9)	4.4 (3.1)	29.8 (4.4)	28.2 (7.0)
Control	9.0 (2.5)	9.6 (1.7)	36.5 (9.2)	36.5 (2.7)

Standard deviations are shown in parentheses.

number of errands completed in the real and in the virtual environments across all participants was high and statistically significant: $r = 0.79$ ($N = 10$, $p < 0.01$).

For each participant, a mean rating was calculated for the written plan completed for the baseline assessment tasks (real and virtual environment) based on the scores of the independent judges. (See table 1.) ANOVA with group (patient or control) and environment (real or virtual) indicated that there was a significant between-group difference in the mean ratings of the plans ($F(1, 8) = 5.66$, $p < 0.05$) with the patient group having worse ratings, but again no significant effect of environment ($F(1, 8) < 1$, $p > 0.05$) and no significant interaction ($F(1, 8) < 1$, $p > 0.05$).

4 Discussion

The aim of this study was to compare the effectiveness of virtual environments and real-life settings in the assessment of planning multistage tasks in patients with head injury.

The performance of the patient group on the standard psychometric measure of executive and planning functions, the Behavioural Assessment of Dysexecutive Syndrome (BADS) (Wilson et al., 1996) battery, was not significantly different from the performance of the normal population sample used in standardization. This is in spite of these patients being identified as having real-life planning deficits of sufficient severity to impact on their daily lives by their care providers and rehabilitation staff. The results suggest that there may be a subset of patients with planning deficits that are hard to detect using the BADS battery. This was unexpected, as the BADS battery had been chosen as the selection instrument for the current research because it represented the most effective screening test for patients with executive dysfunction.

The patients and a control group matched on age and years of education were tested using a real-life and a virtual errand-planning task, which demanded multi-stage planning of vocational-type errands. The patient and control groups differed significantly on both the number of errands completed and the quality of their written plans: patients completed fewer errands, and their initial written plans were rated lower. Both real-life and virtual planning tasks showed similar patterns of performance, with the patient group-showing deficits. In addition, the number of errands completed in the real-life planning task correlated highly with the number in the virtual task. These results suggest that a virtual planning task is sensitive to planning deficits in patients with head injury, and that both real-life and virtual tasks measure similar planning skills.

In clinical settings, the most effective of the current techniques to test for planning problems involve taking patients into real-world settings and assessing their performance. This is costly and may lead to potential distress or danger. The current results suggest that virtual environments would be a more appropriate and safer setting to assess these important cognitive skills. In addition, the nature of the computer interface can be tailored to the individual's physical capabilities in the virtual environment, unlike real-life errand tasks.

A longer-term aim for this research would be to develop a standardized test package to assess virtual planning. This computer-based test could then be used in situ in hospital wards to assess planning ability prior to discharge. Difficulties with planning are currently often only detected after the patient returns home, because, in the setting of the hospital ward, complex planning ability is rarely demanded. Currently, some rehabilitation wards do aim to assess planning ability on site, however, these tests are ad hoc, cannot be transferred from one setting to another, and have no norms against which to compare patient behavior. The current data support the idea that virtual environments could overcome these limitations and provide a better technique for assessing complex cognitive abilities.

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