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A Virtual Reality System for the Assessment and Rehabilitation of the Activities of Daily Living

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ABSTRACT

Successful rehabilitation with respect to the activities of daily living (ADL) requires accurate and effective assessment and training. A number of studies have emphasized the requirement for rehabilitation methods that are both relevant to the patient's real world environment, and that can also be transferred to other daily living tasks. Virtual reality (VR) has many advantages over other ADL rehabilitation techniques, and offers the potential to develop a human performance testing and training environment. Therefore, in this study, the virtual supermarket was developed and the possibility of using a VR system to assess and train cognitive ability in ADL investigated. This study demonstrates that VR technology offers great promise in the field of ADL training.

INTRODUCTION

Traumatic brain injury (TBI) and stroke can be major causes of impairments of cognitive ability and subsequent behavioral difficulties. In the United States, the incidence of TBI resulting from automobile accidents, falls, bullet wounds, and sports injuries is 500,000 to 1,900,000 cases per year,[1] and it has been estimated that 100,000 people suffer varying degrees of permanent disability from TBI.[2] Patients with damaged brain function may face a lifelong struggle with cognitive and functional impairments of vision, memory, attention processes, spatial orientation, problem solving, behavior management, and emotional difficulties, such as anxiety and depression.[3,4] This deficit interferes with daily living and reemployment.[5] In addition, the economic costs in medical care, rehabilitation, and lost productivity are estimated to amount to $48 billion annually, posing a significant burden for both the family and society.[6] Therefore, the need for effective rehabilitation strategies is clear.

Successful ADL rehabilitation requires accurate and effective assessment and training,[7] but standard neurocognitive tests can be insensitive in the presence of executive function deficits. For example, in the Mini-Mental Status Examination (MMSE), all items are not equally sensitive to cognitive impairments.[8] In addition, many traditional methods of assessing brain-injured individuals use either basic pencil and paper techniques or simple motor tasks. For example, in cases of visual neglect, the patient is asked to indicate the center of a straight line or to mark all cases of a specific symbol on a sheet of paper, as quickly as possible. One common criticism of these tests is that the patient is not being tested in a practical manner. A number of studies have emphasized the requirement for rehabilitation

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methods that are relevant to the patient's real world environment and can be transferred to other daily tasks of living.[4]

Virtual reality (VR) has a many advantages over other forms of ADL rehabilitation,[9] because it offers the potential to develop a human performance testing and training environment. Using VR technology, we can produce applications to test and assess patients in ways relevant to daily living, which provides a level of realism unattainable by other techniques, and which have the potential to teach skills of practical relevance. Complete control over content is possible, and performance data may be stored in a database. Moreover, VR provides patients with added motivation by adding gaming factors in a safe virtual environment that eliminates risks caused by errors.

Previous study has produced evidence that indicates the transfer of skills from a virtual environment (VE) to the real world.[10] The VIRART group has created several virtual learning environments (VLE), including a virtual house, a café and a transport system, to help children with learning difficulties. One tester used the café VLE to teach individuals which toilet should be used in a public situation. In her first real world session she tried to enter the female toilet, but the VLE was set up to deny her access because her wheelchair was too large and that she must use a toilet designed with wheelchair access. This knowledge was demonstrated in a second real world session. However, most of the evidence collected by testers was from questionnaire answers, which were often interpreted by a support worker.

Therefore, in this study, we developed a virtual supermarket, and examined the possibility of using the VR system to assess and train the cognitive abilities of brain injured patients with respect to the ADL by having them perform tasks in a virtual supermarket.

MATERIALS AND METHODS

Systems

The VR system consisted of a Pentium IV PC, DirectX 3D Accelerator VGA Card, Head Mount Display (HMD, Eye-trek FMD-250W), 3 Degrees Of Freedom Position Sensor (Intertrax2), and Joystick (Airstik 2000), which could be used as a hand-held control to allow patients to navigate the virtual supermarket comfortably. The PC fitted with a 3D Accelerator VGA Card generates real-time virtual images for the subject to navigate. The position sensor transfers a subject's head orientation data to the computer. Figure 1 shows the hardware for the VR.

Virtual environment

The VE was designed to assess and train cognitive functions involved in basic ADL. This VE simulated a typical supermarket with 4 display stands, 4 refrigerators each with a door, and 2 up-opened refrigerators. In order to pick something up, the subject has to move near the object until it is highlighted by a change in edge color, the subject then presses the joystick button to "pick up" the object. Similarly, to open the door of a refrigerator, the subject has to stand in front of the refrigerator and press the joystick button. After opening the door of the refrigerator, goods in the refrigerator can be selected. after selection, the goods are moved to the shopping handcart from the display stand. A cross was displayed on the center of the subject's view to allow objects to be picked up easily. After shopping, the subject should open the door and exit the store. Figure 2 shows scenes of the virtual supermarket.

Tasks in virtual environment

The subject can adapt to the virtual environment during an exercise stage which trains the subject to navigate and explore the virtual supermarket, and allows the subject to pick up goods and open the door with the input device.

During the main task, the subject should pick up all goods and place them in the handcart. The virtual supermarket has a complicated structure with 10 turns. Figure 3 shows the structure of the virtual supermarket.

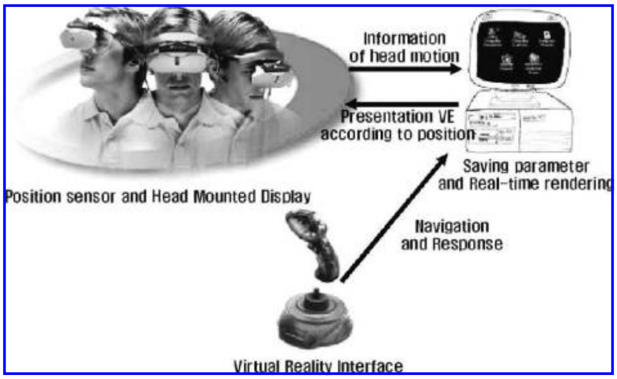

FIG. 1. Hardware for virtual reality.

FIG. 2. Virtual environment.

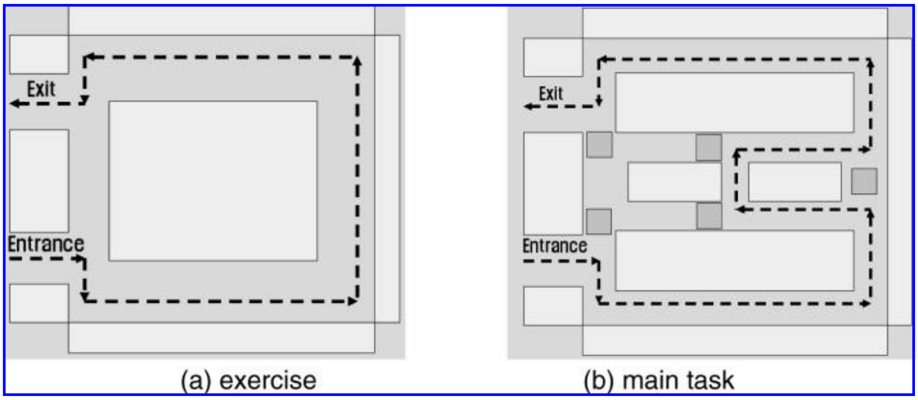

FIG. 3. Structure of virtual supermarket.

Experiment

Subjects. Five subjects with TBI or stroke who were receiving rehabilitation treatment at the National Rehabilitation Center participated in the study (Table 1).

Procedure. Each subject filled up a form, which requested name, sex, age, and diagnosis, and performed psychological tests (MMSE, and Motor Free Visual Perception Test [MVPT]). Subjects then practiced with a VR exercise until they became familiar with the VR interfaces and the virtual supermarket.

TABLE 1. SUBJECTS

ID	*Sex*	*Age*	*Diagnosis*	*VR experience*	*MMSE*
A	Male	42	Lt. hemiplegia d/t Rt. BG, thalamic ICH	No	30
B	Male	41	Lt. hemiplegia d/t TBI	No	28
C	Male	67	Lt. hemiplegia d/t Rt. MCA infarct	No	20.5
D	Female	54	Lt. hemiplegia d/t Rt. thalamic ICH	No	29
E	Male	21	Lt. hemiplegia d/t SDH	Yes	30

TABLE 2. PARAMETERS FROM VIRTUAL REALITY

Parameter	*Method*
Navigation rate	Elapsed time Distance moved Number of collisions with walls
Executive function	Number of selected goods The number of refrigerator doors opened Number of joystick button presses Error rate

All subjects performed the main task 5 times over a period of 5 days. Before and after the experiment, subjects were requested to answer the following questionnaires, the Immersive Tendencies Questionnaire (ITQ), the Simulator Sickness Questionnaire (SSQ), the Presence Questionnaire (PQ), and the Virtual Reality Questionnaire (VRQ).[11] All of these procedures were supervised by a physiatrist.

Measurement

The system measured various parameters while the subject experienced virtual reality (Table 2). As shown in the table, we measured the elapsed time, the distance moved, the number of collisions with walls, the number of selected goods, the number of refrigerator doors opened, the number of joystick button presses, and the error rate.

The error rate = 1 − (the number of selected goods + the number of refrigerator doors opened)/ the number of joystick button presses.

RESULTS

The average (SD) of the PQ scores, which had been obtained by questionnaires before and after the experiment, were 106.4 (47.30) and 112.6 (42.02), respectively, and the corresponding SSQ scores were 21 (6.40) and 17.25 (2.5). The mean scores for the virtual reality task are presented in Table 3. The time, distance, and number of collisions tended to decrease when the data from the first day was excluded. The number of selected goods and button pressings also tended to increase with time, and the error rate tended to decrease. Figure 4 shows the elapsed time, the number of selected goods, and the error rate of each subject. Subject C who was older than the others and subject D who was female had poor performance rates. Subject E with VR experience performed the task better than the others.

The qualitative data was analyzed by a physiatrist who supervised this experiment. He reported that the subjects could not control the VR interface tool, such as the joystick, during the experiment, and had difficulties navigating in the virtual supermarket had paralysis and also to perform both to pick something up and to follow the aisle at the same time. Nevertheless, he stated that in his opinion the VR could be used as an effective ADL training tool if these problems of interface suitability could be resolved.

TABLE 3. RESULT OF PARAMETERS FROM VIRTUAL REALITY, MEAN (SD)

Parameter \ *Date*	*1*	*2*	*3*	*4*	*5*
Time (sec)	174.15 (79.32)	212.11 (103.74)	224.16 (130.47)	135.90 (37.61)	159.10 (86.97)
Distance	252 (58.14)	303.4 (102.45)	319.2 (127.45)	265.8 (68.07)	272.6 (77.51)
Number of collisions	7.2 (7.60)	20.2 (18.19)	27 (26.01)	16.4 (14.69)	20 (20.45)
Number of selected goods	0.8 (0.45)	1.6 (0.89)	2 (1.41)	2.2 (1.10)	2.6 (0.55)
Number of button pressings	3.8 (0.45)	4.4 (1.82)	5.6 (3.58)	5.4 (1.82)	6 (1.87)
Error rate	0.57 (0.18)	0.50 (0.20)	0.59 (0.30)	0.52 (0.18)	0.32 (0.11)

DISCUSSION

The increase of PQ score and decrease SSQ score with experience, show that the subjects adapted to the VE and VR interfaces.

Figure 4 presents the elapsed time, the number of selected the goods, and the error rates of each subject. During the first day, performance rates were lower, and subjects could not coordinate two tasks at the same time, i.e., they tried to follow the aisle

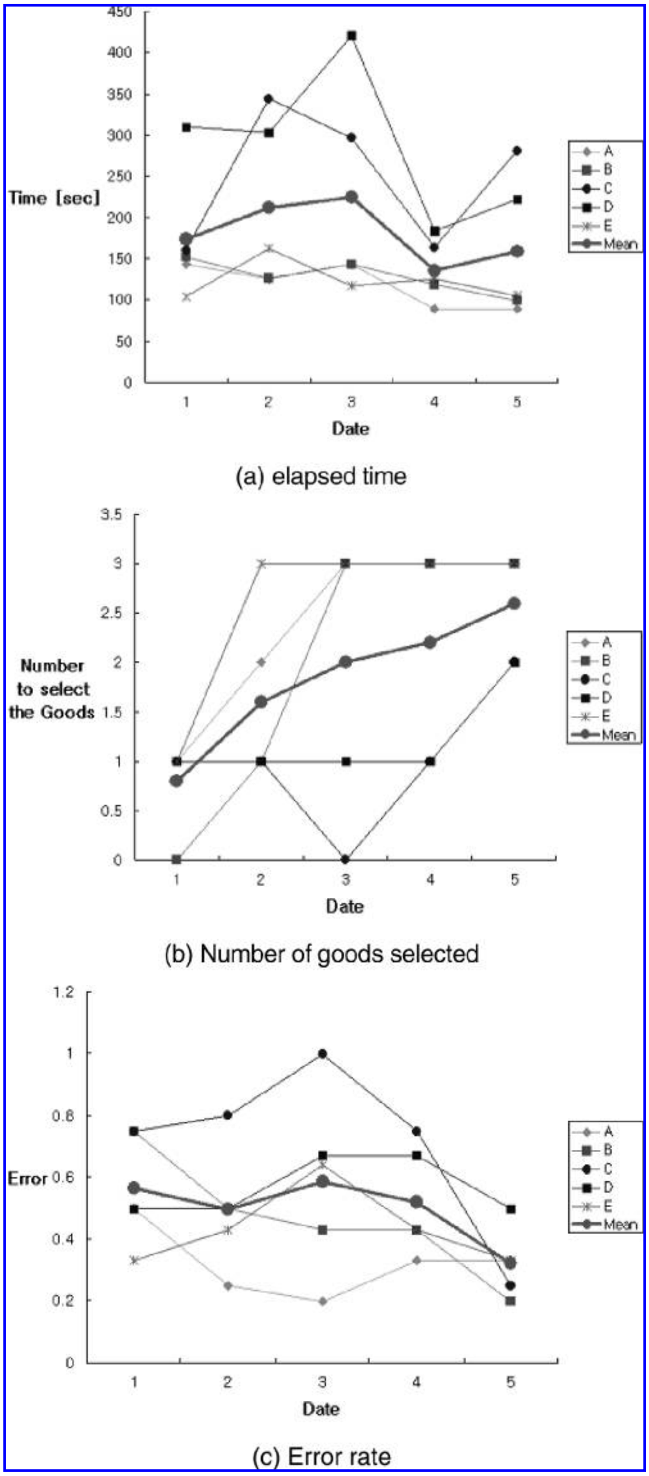

FIG. 4. Performance of the task.

without picking up goods. After the third day, on which they began to coordinate two tasks simultaneously, the performance rates of the subjects improved, although the performances on the third day were worse than on the first and second days. These results show that repeated training in VR is effective.

Personal factors (age and sex) may explain why the performances of subjects C and D were worse than those of the other subjects. Similarly, subject E showed better performance, which was attributed to prior VR experience.

The issue of interface suitability was raised, as subjects experienced difficulties using the handheld joystick, because of its weight and its instability. They also had difficulty navigating the virtual supermarket because of paralysis. These difficulties can be solved by adopting interfaces, which compensate for a patient's physical problems.

Although, the results of this study were not statistically significant, which is attributed to the small number of subjects. The study demonstrates that the VR technology can be applied to ADL training. In the future, comfortable VR interfaces should be designed for patients and future experiments should be performed upon more subjects with more training.

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