

Retraining Movement in Patients with Acquired Brain Injury using a Virtual Environment

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Abstract. We report preliminary results of an ongoing study in which a virtual environment (VE) system is used to facilitate motor relearning of a pouring task in patients with Acquired Brain Injury (ABI). Four subjects were evaluated pre-and post-VE training using virtual-world and real-world tests in which subjects performed a pouring motion while holding a cup. Standard clinical tests of motor and functional ability were also used. Three of four subjects demonstrated improvement in end-point trajectories (cup path) performed during the virtual and real world tests. Clinical test scores also improved. Results indicate that subjects with ABI were able to learn a movement in VE, and generalize this ability to real-world performance of similar and unrelated tasks. VE training appears to be a feasible and promising approach to the rehabilitation of subjects with ABI.

1. Introduction

Acquired brain injury (ABI) is one of the leading causes of death and disability in the United States. Every 15 seconds, someone suffers a head injury and every five minutes a person becomes permanently disabled by ABI. Survivors with severe ABI typically face 5-10 years of intensive health related services with an estimated lifetime cost of \$4 million dollars[1-3]. Individuals who survive severe ABI face long-term problems with impaired motor control and cognitive function. The gravity of this problem calls for new ideas and methods in the rehabilitation of these individuals, particularly in the area of motor control.

Recent findings in the field of neuroscience, from animal studies of motor control, suggest that both the normal adult brain and the damaged brain are capable of much greater plastic change than was previously thought possible. In addition, the nature of physical rehabilitation following injury has been found to be an important variable in the type and extent of plastic changes that occur during the recovery process [4-8].

One new method that may allow us to develop this untapped potential for motor recovery in patients with brain damage is the use of computer generated virtual environments (VE) for training. By VE we mean an interactive computer technology that is capable of creating the illusion of being in an artificial world in which one can move around, and examine or manipulate objects. In VE, the visual aspects of the computer-generated environment can be presented via a head-mounted display or on a conventional desktop monitor. In the latter case, the user feels as if he is looking through a window at the virtual environment [9-10].

Several reports describing the potential usefulness of VE in ABI rehabilitation [9-12]. However, to our knowledge, no studies which examine the effects of VR training on motor rehabilitation in actual individuals with ABI have been published. Several reports of

VE use in the rehabilitation of individuals with other types (i.e., not ABI) of disabilities have appeared. For example, Wilson et al. reported successful learning of a spatial task (directional pointing to object location in a 3-level building) in physically disabled children as compared to untrained normal controls, following VE training [13]. Holden et al. reported improved reaching ability in stroke patients following a course of training using VE [14]. Burdea and colleagues have reported on the use of VE for orthopaedic rehabilitation [15]. In normal subjects, several reports of motor learning following virtual practice have been reported [16-18], but transfer of motor learning in VE to real world performance has not always been found [19].

In this paper, we report preliminary results from an ongoing clinical study in which we use a novel motor-training system based upon augmented feedback in a virtual environment (VE) to facilitate motor relearning in patients with acquired brain injury (ABI). The purpose of our study is to assess the feasibility of VE training with the ABI population, to test whether motor learning can be achieved in VE, and to assess whether motor skills acquired in VE can generalize to similar real world tasks, or to untrained tasks.

2. Method

2.1 Design

A single-subject AABABAA design was used. Subjects received an evaluation battery 2x, 1-2 wk. apart prior to treatment (AA), followed by 16 one-hr. treatment sessions, (frequency 3x/week) (B), a mid-way evaluation (A), then a second block of 16 treatments (B), followed by 2 post treatment evaluations (AA).

2.2 Subjects

Four male subjects w/ chronic ABI have been tested and trained thus far. Duration post-injury ranged from 3 yr. to 18 yr.; ages from 16 yr. to 37yr. Three subjects had much greater impairment on the right (R); one on the left (L).

2.3 Apparatus

The VE training system consists of a computer, specially developed software [20], and an electromagnetic motion-tracking device. A central feature of the system is the simultaneous display on the computer screen of the prerecorded arm movements of a "teacher" and the arm movements of the patient using the motion tracking device. During training, the patient is asked to imitate the teacher's trajectory, as it is displayed ("learning by imitation"). The difference between the teacher's trajectory and that of the patient's provides the augmented feedback. This feedback can be enhanced in a variety of ways by optional features. For example, distance and orientation error can be highlighted, the teacher speed can vary, sound cues can be added to enhance timing, a static trace of the teacher trajectory can be used to enhance spatial learning.

2.4 Treatment

Subjects were trained in VE on the functional task of pouring from a cup through practice in virtual scenes. A desktop display was used. In each scene, a 'teacher' was displayed performing the pouring movement. During practice, subjects' held a real cup in their hand, and tried to imitate the teacher by watching their 'virtual' cup as it moved on the computer screen in concert with their movement. For subjects 1 and 2, only two pour' scenes were used for training; for subjects 3 and 4, some additional scenes were added.

These scenes worked on the control of wrist motion and repeated reciprocal movements of the elbow. Only the near center workspace location was trained in VE.

2.5 Measures

Four tests were used to evaluate motor performance: 1) a "Virtual" motor test; here the subject performed the trained movement in VE (pouring from one virtual cup to another), but without teacher feedback; 2) a "Real World" test, in which the subject performed the same task as that trained in VE, but in the real world. In our case, the subject poured real oatmeal from one cup to another. This was performed at the trained location (center-near), and at five other workspace locations. During both virtual and real world tests, 3D kinematics of the arm were recorded using a motion tracker. Finally, two standard Clinical Tests were used: 3) the Fugl-Meyer Test of Motor Recovery (FM) [21]; and 4) the Emory test of Upper Extremity (UE) Function (timed tasks)[22].

The 'Virtual' motor test was administered at regular intervals during VE training sessions; the 'Real World' (RW) and Clinical Tests were administered before and after each 16 session treatment block.

3. Results

Subject 1 (S1) had 32 sessions with no midway testing. Subject 2 (S2) dropped out following the first 16-session treatment block. Subjects 3 (S3) and 4 (S4) completed the two 16 session blocks for a total of 32 sessions. We now present the results of our VE training in three sections: Virtual performance, Real World performance, and the Clinical Tests (FM and Emory).

3.1 Virtual Pouring Performance

Qualitative analysis of the end point trajectories (cup path) during virtual 'pouring' indicated an improvement following training. Trajectories performed in VE become straighter, especially during the first 3/4 of the movement. An example is shown in Figure 1 below.

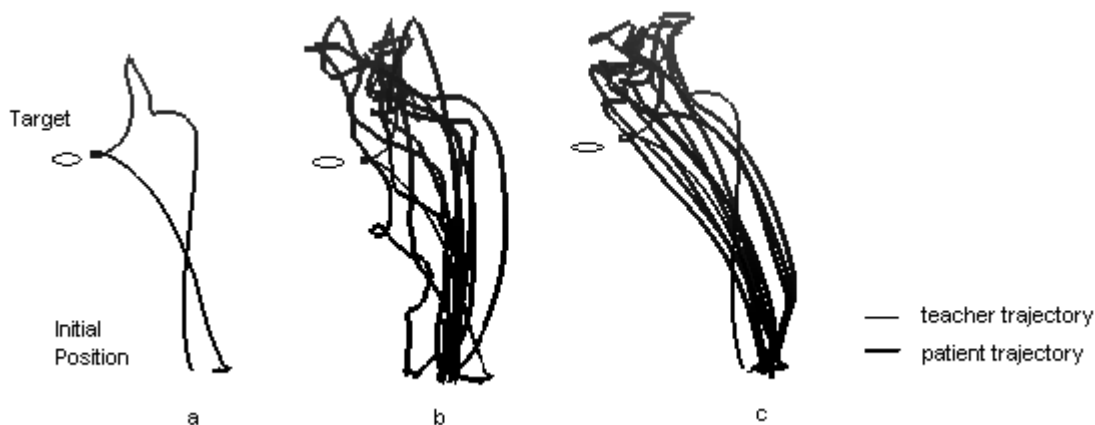


Figure 1. Raw data graphs of endpoint trajectories for S4 during 5 repeated level 1 pouring motions of 1st block of 16 training sessions. Circles represent the location of the container towards which subject was performing the pouring motion. a) teacher trajectory; b) teacher trajectory with five superimposed end-point trajectories of pre-training session, involved upper extremity; c) teacher trajectory with five superimposed end-point trajectories of post-training session, involved upper extremity.

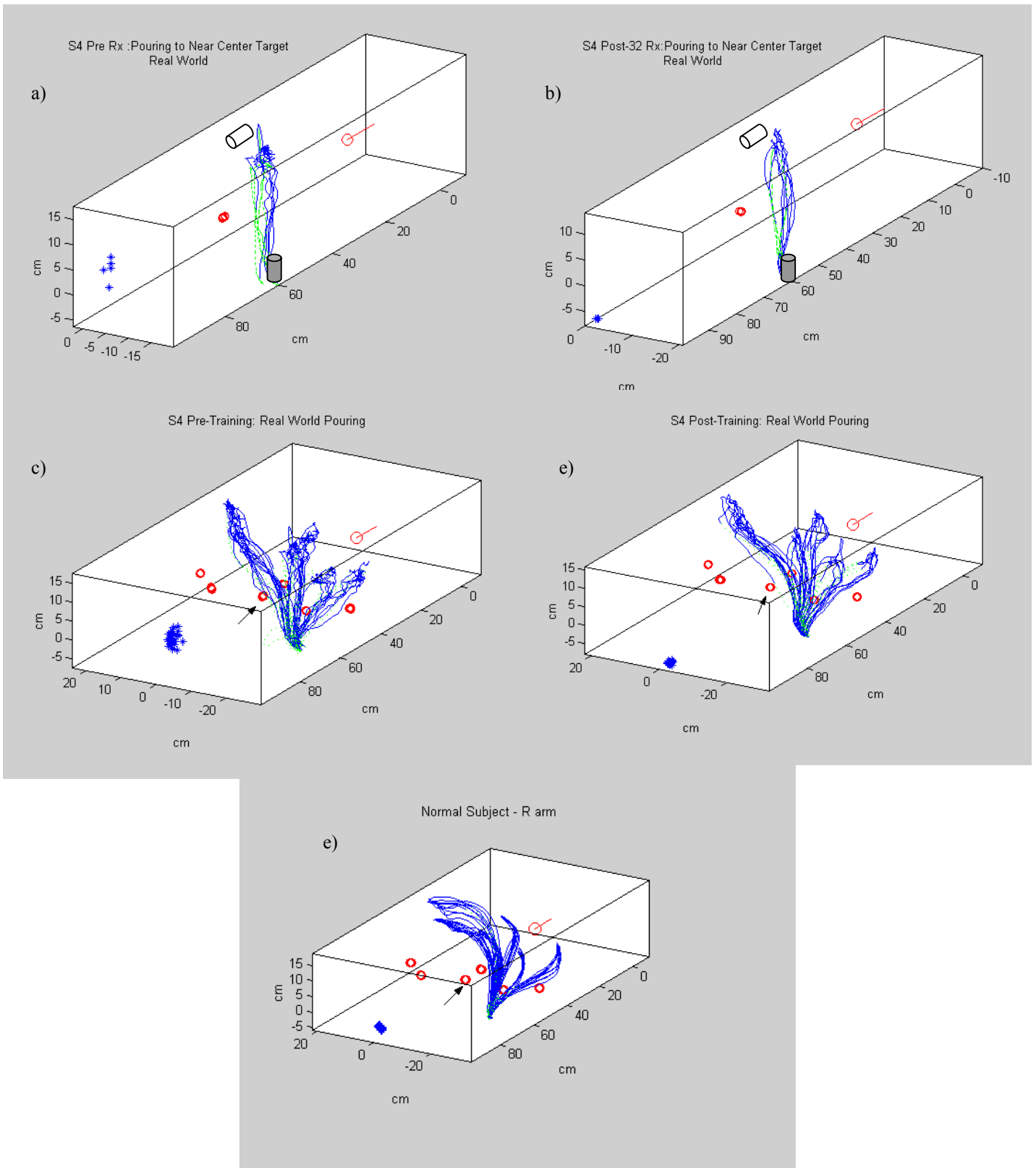


Figure 2. Trajectories (cup path) for S4 while performing the pouring task in the real world. Perspective is as if one were looking downward over the subject's right shoulder. For top 2 panels, dark gray cup shows starting position of held cup (hand by the side); white cup shows its end position for the trained location (near-center). The red circles indicate the target cup positions; arrow indicates trained location. Crosses near front indicate trunk position; red sphere in back shows transmitter location; a) pouring to midline center with right arm Pre-Training and b) Post-Training; c) pouring to 6 workspace locations (5 were untrained) Pre-Training and d) Post-Training; e) normal subject performing same task for comparison.

Three of the 4 subjects (S2, S3 and S4) showed qualitative improvement in their trajectories when performing the pouring movement in the real world near the same location trained in the VE (i.e. to midline center, 8 cm. from table edge). The trajectories were smoother, straighter and more accurate. Of the three subjects who improved, S4 showed the most change. While improvement was greatest near the trained location, improvement was also noted for pouring performed in the five workspace locations that were not trained in VE (i.e., 20 cm to right and left of near center targets; 30 cm to either side of the far target; far target was 20 cm. from table edge). For S3 and S4, these changes were fairly large. For S2, they were slight; S1 showed no change. Figure 2 illustrates the changes in real world pouring performance for S4. Data from a normal subject, performing the same tasks, is shown for comparison. Quantitative analysis of these data are currently underway.

In addition to the trajectory changes, we noted that all subjects displayed fewer spills during real world pouring following VE training. (Oatmeal was substituted for liquid during pouring because of the proximity to electronic equipment.)

3.3 Clinical Tests

Results for the upper extremity portion of the FM test of motor recovery are shown below in Figure 3. Total FM includes the pain, range of motion, sensory and motor subscores; Motor FM is motor subscore only. The test assesses active movement control, quality of movement, intralimb joint coordination and reflex function.

S1 and S2 showed less than 5 % improvement (essentially no change) on the FM. S3 showed little change after the first treatment block, but improved by 21% on his Motor score and by 11% on his Total FM score following the second block. S4 improved the most, by 40% Motor, 17% Total in block 1, and by an additional 14% Motor, 5% Total after treatment block 2.

Results for the Emory UE Functional test are shown in Figure 4. The test measures the time required by subjects to perform fifteen different functional tasks. S1 had slightly slower median times following treatment. S2 improved the most, by 48%. S3 worsened slightly in block 1, but improved by 36% in the 2nd half of training. S4 had little change in the first block of treatments, but improved by 34% following the second block. S4 also improved his total time Emory score by 50% across the two blocks.

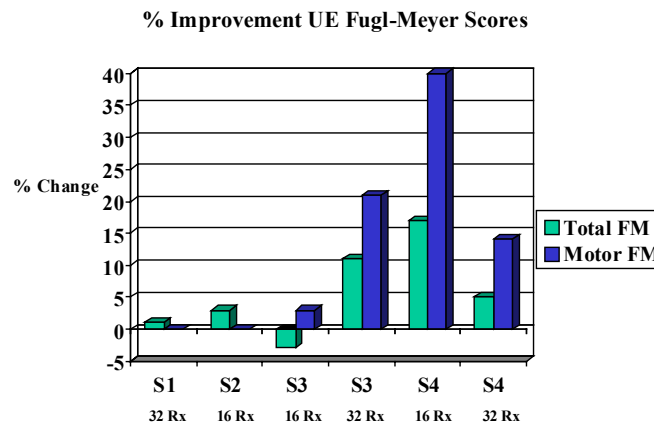


Figure 3. Fugl-Meyer Test Scores, expressed as % improvement from pre to post VE training. Note that S1 had the 32 Rx as one block, S2 had only block 1 of 16 sessions. S3 and S4 had both treatment blocks and results are shown separately for each block.

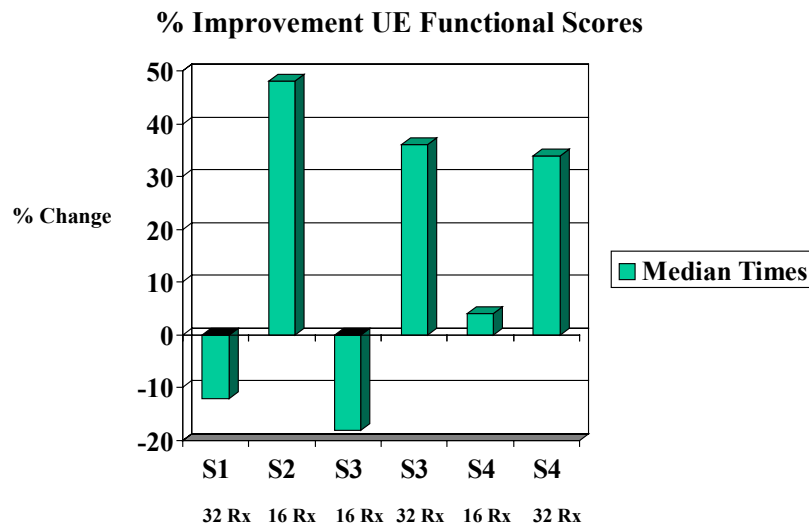


Figure 4. Emory Test Scores, expressed as % improvement from pre to post VE training. Note that S1 had the 32 treatments as one block, S2 had only block 1 of 16 sessions. S3 and S4 had both treatment blocks and results are shown separately for each block.

4. Discussion

We found improvement for 3 of the 4 subjects trained in VE for all of our measures: motor performance of the trained task in the virtual world, motor performance in the real world for similar and related tasks, and for standard clinical tests of UE motor recovery and function. Since all our subjects sustained their brain injuries between 3-18 yr. prior to the study, it seems reasonable to attribute the improvements we found to the VE treatment, as the expected time for spontaneous recovery had passed.

The changes in performance in VE (Fig. 1) indicate that subjects with ABI, despite significant impairments and time post injury, *can* learn motor tasks in VE. Even more encouraging is the transfer of this improved performance to the same task in the real world. All three of our subjects who 'learned' in the virtual world achieved this transfer. Two subjects also improved their trajectories for real world pouring performance in parts of the workspace which were not trained in VE, i.e., forward and to the right and left of the trained location (Fig.2). If these findings are confirmed in additional subjects, and by quantitative analysis, it would imply that therapists could achieve improvements in many related functional movements by training just one type of movement. Our most intriguing finding is the improvement on the standard clinical tests. These results indicate a greater degree of motor generalization, as tasks tested on these clinical measures were very different from our training task, in terms of limb configuration, workspace location, and muscle activation patterns required. Given that we trained only the pouring movement and its components, this degree of generalization is very surprising.

The greatest changes were seen in S3 and S4. Several factors may have influenced this result. For these subjects, we added some additional scenes to the training. These scenes were designed to address the specific deficits of each subject in performing the pour movement. For S3, this was reciprocal movement at the elbow; for S4 it was control of wrist extension while maintaining a grip. These elements were practiced however, in the same general workspace as the pour movement, and in combination with similar movements at the other UE joints. Differences in other clinical factors may have accounted for the greater success of these subjects, e.g. initial Emory scores were lowest (better) for S3 and S4. However, S1 and S3 had the highest pre-training FM scores. We are currently investigating whether cognitive and perceptual impairments account for the differences in effectiveness of the VE treatment in our subjects.

5. Conclusions

VE motor training appears to be feasible for use with ABI subjects. We believe this new method holds promise for improved neurorehabilitation outcomes in patients with ABI.

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