Interactive virtual environment training for safe street crossing of right hemisphere stroke patients with unilateral spatial neglect

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ABSTRACT

The goal of this study was to determine whether non immersive interactive virtual environments are an effective medium for training individuals who suffer from Unilateral Spatial Neglect (USN) as a result of a right hemisphere stroke. Participants included 19 patients with stroke in two groups, an experimental group we were given VR-based street crossing training and a control group who were given computer based visual scanning tasks, both for a total of twelve sessions over four weeks. The results achieved by the VR street crossing intervention equalled those achieved by conventional visual scanning tasks. For some measures, the VR intervention even surpassed the scanning tasks in effectiveness. Despite several limitations in this study the present results support further development of the program.

1. INTRODUCTION

The overall goal of this study was to determine whether non immersive interactive virtual environments are an effective medium for training individuals who suffer from Unilateral Spatial Neglect (USN) as a result of a right hemisphere stroke. USN is a major syndrome that affects rehabilitation outcomes (Katz, Hartman-Maeir, Ring & Soroker, 1999).

Although there are various treatment methods that aim to remediate this deficit and to teach compensatory strategies, only some have shown hard evidence of effectiveness. While there is evidence of improvement according to results of impairment assessment, much less evidence exists for increased functional performance at the disability level (Bowen, Lincoln & Dewey, 2003; Cicerone et al., 2000). VR technology may provide a promising method to treat patients who suffer from USN due to its well-known attributes (e.g., ecological validity, the ability to grade the level of difficulty and motivate the user) (Rizzo, & Kim, in press; Rizzo, Schultheis, Kerns, & Mateer, 2004). A PC desk top computer Virtual Reality (VR) technology was the platform of choice in this study as it is more easily available in clinics and rehabilitation units. A screen shot of the initial view of the virtual street is shown in Fig. 1.

Figure 1. *Initial view of street crossing environment.*

The objectives of this study were to 1) to use the virtual street environment developed in a previous study (Naveh, Katz, & Weiss, 2000; Weiss, Naveh & Katz, 2003) to train subjects with USN to become more aware of stimuli in the neglected field of vision and to learn to compensate for their deficit in a safe and graded environment, 2) to compare performance USN measures of subjects with USN who received the VR training to a control group who received computer visual scanning training. 3) to compare subjects' ability to carry out a functional task (crossing a street) prior to and following training in the virtual environment.

2. METHODS

2.1 Participants

Participants included 19 patients in two groups: 1) 11 experimental: 7 men and 4 women, mean age = 62.4 ± 14.0 (SD) years and 2) 8 control: 5 men and 3 women, mean age = 63.3 ± 10.8 years. All participants had a first right hemispheric stroke (RCVA) with persistent USN, 6 to 8 weeks since onset. Included in the study were participants who use any type of mobility aid, but have difficulty in crossing streets in a safe or confident manner. All participants in this study used a wheelchair for mobility.

2.2 Instruments

2.2.1 Virtual environment. A street crossing virtual environment was programmed via Supers cape's 3D Webmaster and run on a desktop computer, with successively graded levels of difficulty that provide users with an opportunity to decide when it is safe to cross a virtual street. It was initially tested on 12 subjects, six patients with stroke and six matched controls (Naveh et al., 2000; Weiss et al., 2003). Results showed that the program is suitable for patients with neurological deficits in both its cognitive and motor demands. In the current study the virtual street was used to assess the performance within the environment as well as a treatment tool.

2.2.2 USN measures. Severity of USN was measured with conventional paper and pencil measures, Star cancellation from the Behavioral Inattention Test (BIT) (Wilson, Cockburn & Halligan, 1987), Mesulam Symbol Cancellation test (Mesulam, 2000). For each of these tests the number of items cancelled correctly on the left side was calculated and the time it took to complete the test was measured. In addition an ADL checklist was used to measure the affect of the USN on daily activities. For this measure lower scores represent higher performance (Hartman-Maeir & Katz, 1995).

2.2.3 Functional performance. Functional evaluation of the ability to cross an actual street was evaluated from video-taped records. Since the participants were in wheelchairs, an occupational therapist wheeled their chair to cross the road only when they told her that it was safe to do so. The street crossing was performed on a divided road so that the participants first had to cross the lanes where vehicles were approaching from left to reach a central island. They then continued to the other side where cars came from right. Participants then re-crossed the road to return to the start point. In this way we observed and videotaped two pre- and post intervention street crossings, with vehicles approaching the crosswalk twice from the left and twice from the right. Since an essential difficulty for right hemisphere stroke patients with USN is the leftward gaze and consideration of objects on the left, their ability to look to the left was considered to be an especially critical indicator of safety during street crossing.

Since at any given point in time the number of vehicles passing on a road varied, performance scores were normalized by dividing the time it took for a patient to decide to cross the road with the number of vehicles that passed during that time. This measure was termed the "Decision time per vehicle prior to initiation of street crossing". An additional score was the number of times the participant looked to the left.

2.3 Procedure

The study took place originally at Loewenstein Rehabilitation Hospital, with additional participants from Hadassah Medical Center rehabilitation department and Beit Rivka Medical and Geriatric Center. The study was approved by the Institutional Review Boards of the respective hospitals. In each facility participants were randomly assigned to either group: VR training (experimental) and computer visual scanning tasks (control).

In the current controlled clinical trial, the virtual reality training protocol continued for 4 weeks, with 3 sessions per week, each of 45 minutes duration, for a total of 9 hours. The timing of the control group computer scanning training protocol was identical. Prior to commencement of training and subsequent to it, all participants were assessed with the USN measures, a virtual street crossing test and a real street crossing test.

2.4 Data analysis

The data were analyzed using group means to compare pre-post differences within each group and between groups at each testing time. In addition, in order to demonstrate the change occurring due to intervention, we calculated and compared the mean pre- and post differences for each variable. A one tailed t-test was used as the VR experimental group was expected to show greater improvement than the control group.

3. RESULTS

As is the case for most desktop VR systems, no cybersickness-type side effects were noted for any of the participants; all enjoyed using the program and willingly participated in the intervention. The pre- and post-test results for both patient groups are shown in the Table and include scores for the USN measurements, the VR measurements, and the real street crossing measurements.

3.1 USN measures

We first noted that the VR group performed lower at pre-test on most measures which is indicative of a more severe USN. Thus, although participants were randomly assigned to each group, the USN for the VR group was, on average, more severe. Both groups, regardless of intervention type, improved in their scores on the paper and pencil tasks, namely the number of correctly cancelled items on the Star cancellation and the Mesulam random cancellation test. The difference for the Mesulam was significant at $p<.01$ as indicated in the Table by the two interconnected arrows.

Both groups took less time to complete the test following intervention but the difference was not significant. It is interesting to note that, on average, the VR group required much more time to complete the Mesulam during the pre-test (mean = 519 s) than did the control group (mean = 353.9 s). However, the mean pre-post test difference for the VR group is more than twice as large as that of the control group (137.5 s versus 52.7 s). Although there were no pre-post significant differences in the Star cancellation scores (number of stimuli correctly cancelled), the VR group took less time to complete this task at post test whereas the control group needed longer time to complete it at post-test. Performance on the ADL checklist, that is a patient's ability to cope with daily living skills (which reflect the functional implications of USN) showed significant improvement for both groups from pre- to post-test ($p<.05$). Note that lower scores indicate improvement on this measure. This result together with the cancellation tests shows that patients from both groups decreased in the severity of USN, although all patients still showed persistent USN at time of the post-test.

3.2 VR Street crossing measures

The VR street crossing performance of both groups showed the effects of training. Specifically, there was improvement in the number of times participants looked to the left for the VR group; this difference was significant at $p<.05$. More importantly, in the VR group, most patients made fewer accidents (about 50%) during the virtual street crossing at post-test which was significant at $p<.035$ (one tailed). In contrast, only one member of the control group had fewer accidents while the others did not change their performance from pre- to post-test. Their mean pre- and post-test number of accidents was similar. Comparing the two mean differences (4.1 to -0.2) between groups was significant at $p<.035$ (one tailed, see Table).

3.3 Real Street crossing measurements

Pre- and post-test real street crossings were videotaped and then analyzed using the two measures indicated above, the number of times a person looked to the left and the decision time per vehicle prior to initiation of street crossing. For the VR group, the mean number of times participants looked to the left before crossing increased from pre- to post-test, whereas for the control group this number decreased slightly. This difference was not significant but the direction of the results indicates that there was greater improvement for the VR group. The difference between the two groups is highlighted in Fig. 2 which shows that a greater number of participants in the VR group looked to the left at post-test as compared to the control group who demonstrated no change. The decision time to cross the street per vehicle showed no change in the VR group and a slight decrease in the control group. Mean differences were not significant.

Table 1. *Measures of USN, VR street crossing test and real street crossing. Note that arrows between two means indicate significant results.*

	VR Group (N=11)			Control Group (N=8)		
	Pre-test Mean(SD)	Post-test Mean(SD)	Difference Mean(SD)	Pre-test Mean(SD)	Post-test Mean(SD)	Difference Mean(SD)
Attention measures						
Star Cancellation						
Score – # correct Left	9.2 (9.7)	14.8 (12.9)	-5.6 (11.0)	14.6 (10.4)	18.1 (10.2)	-3.5 (4.8)
Time in seconds	249.8 (211.8)	213.3 (137.6)	36.5 (149.1)	181.1 (112.7)	194.2 (57.5)	4.8 (124.5)
Mesulam Cancellation						
Score – # correct Left	7.4 (9.2)	13.6 (12.2)	-6.3 (6.4)	6.5 (9.3)	12.6 (10.6)	-6.1 (6.4)
Time in seconds	519.0 (559.7)	381.5 (326.3)	137.5 (430.0)	353.9 (199.6)	290.3 (61.9)	52.7 (224.9)
ADL Checklist						
Therapist score	2.2 (0.5)	1.4 (0.6)	0.8 (0.3)	1.4 (0.7)	0.8 (0.5)	0.6 (0.4)
VR measures						
# Look left	10.5 (5.0)	17.3 (7.2)	-6.2 (5.6)	7.8 (6.5)	14.4 (13.9)	-5.2 (10.3)
# of Accidents	7.9 (6.9)	3.8 (4.6)	4.1 (6.8)	3.8 (2.8)	3.4 (2.7)	-0.2 (1.8)
Real Street Crossing measures						
# of times look left	4.0 (2.4)	5.4 (2.9)	-1.4 (2.8)	6.3 (3.7)	5.8 (4.6)	0.5 (6.2)
Decision time per vehicle prior to initiation of street crossing when vehicles come from left	5.6 (7.9)	5.7 (7.6)	-0.2 (9.0)	12.8 (14.1)	10.1 (9.2)	2.7 (6.3)
when vehicles come from right	9.6(12.1)	7.3 (7.7)	2.2(13.7)	8.2(3.9)	6.1(5.6)	2.0(6.8)

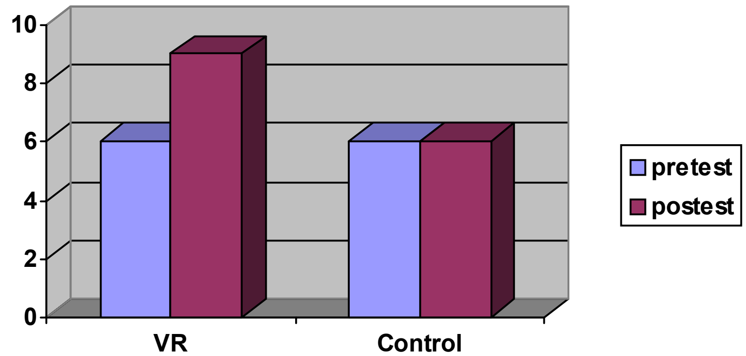

Figure 2. *Histogram showing frequencies of how many patients in each group looked to the left in the real street crossing test.*

4. DISCUSSION

The results of the study show that the VR intervention was effective both in terms of improving visual-spatial performance as measured in this study and for some improvement in the ability to cross a real street. It therefore appears to have potential to become a useful tool in rehabilitation. Although the results of some of the analyses did not reach significance at the 0.05 level (likely due to the small sample size) the direction of improvement was evident. In addition, the fact of the initial pre-test difference on the severity of USN between the groups which occurred despite the random assignment to intervention type was a limitation. We attempted to correct for this difference by comparing pre- and post-test differences rather than absolute scores. Nevertheless, these differences make it more difficult to assess the effect of VR intervention as compared to conventional computer scanning tasks.

It is important to note that treatment based on the computer visual scanning tasks that were provided to the control group in this study are, according to most research evidence for USN therapy, currently the intervention method of choice. As a result of a meta analysis reviewing the effectiveness in the treatment of visual spatial deficits, Cicerone et al. (2000) recommended that training visual scanning be used as a 'practice standard' to improve patients' ability to compensate for visual neglect after right hemisphere stroke. In addition, the evidence demonstrated that training on more complex tasks appears to enhance patients' performance and facilitate generalization to other functional areas as well. Similar recommendations were made by Cappa et al. (2003) in their report.

The results achieved by this VR street crossing intervention equalled, at the very least, those achieved by conventional visual scanning tasks. For some measures, the VR intervention even surpassed the scanning tasks in effectiveness. This is an important finding given the fact that this virtual environment, as well as the simple desktop hardware used to display it, constitutes the lower end of the immersion spectrum. Until recently, there was only a limited capacity to grade the difficulty of the street crossing task and to control the delivery of stimuli in accordance with a given patient's ability. Taking these limitations into account it seems that the use of this VR street environment is encouraging and supports further development of the program.

The above considerations, together with observations of the video-taped records, and discussions with the clinicians involved in the VR training process have led us to revise our environment and experimental paradigm. We are currently carrying out a second phase of the study and are including patients who are at a more advanced stage of rehabilitation. That is, post-acute patients who participate in rehabilitation as out-patients and have the need to cope with real-life street crossing as a routine daily task. This population would likely be even more motivated to use this tool, and stand to obtain greater benefit from it. Thus the second phase of the study includes participants with the same diagnosis at ambulatory and post-hospitalization or day treatment. Participants are able to walk alone or with assistive devices such as a cane, tripod or walker and will thus be able to be tested during independent street crossing.

Moreover, we have added a questionnaire of pedestrian walking behaviours, both prior to the stroke and since the stroke. This will enable us to determine how improvements in USN, as well as virtual and real street crossing skills are correlated with the participants' functional abilities. Finally, the original street crossing program has been revised to include a greater variety of pedestrian situations (e.g., traffic lights), different routes to choose from and places to go to (see Fig. 3). The new version provides opportunities to explore the participants' executive functions, in particular as related to planning and decision making. In addition to the current population of older adult patients with stroke, this new environment is currently being tested to train pedestrian safety for children with autism.

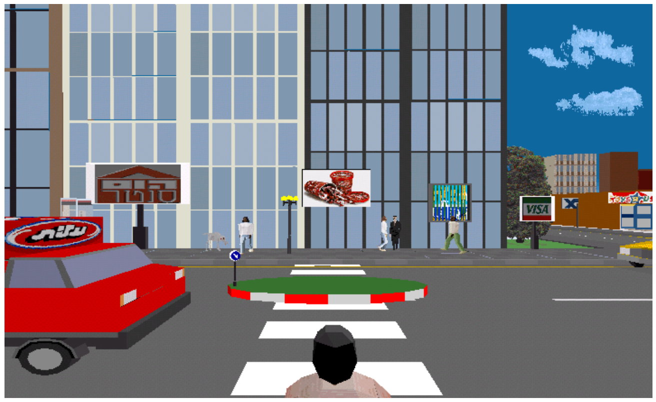

Figure 3. *Screen shot showing revised street crossing environment.*

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