Interactive virtual environment training for safe street crossing of right hemisphere stroke patients with Unilateral Spatial Neglect

N. KATZ1, H. RING2, Y. NAVEH3, R. KIZONY1,4, U. FEINTUCH1,5 & P.L. WEISS4

1 School of Occupational Therapy, Hebrew University and Hadassah, 2Loewenstein Rehabilitation Center, and Dept. of Rehabilitation Medicine, Sackler Faculty of Medicine, Tel Aviv University, 3Meonot Macabbi-Migdal Hazahav, 4Department of Occupational Therapy, University of Haifa, 5The Caesarea Rothschild Foundation Institute for Interdisciplinary Applications of Computer Science, University of Haifa

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Abstract

Purpose. 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, and to compare it to a standard computer visual scanning training.

Method. Participants included 19 patients with right hemisphere stroke in two groups, 11 in an experimental group were given computer based Virtual Reality (VR) street crossing training and 8 in a control group who were given computer based visual scanning tasks, both for a total of twelve sessions, 9 hours total, over four weeks. Measures included: 1. Standard USN assessments, paper and pencil and ADL checklist; 2. Test on the VR street program; and 3. Actual street crossing videotaped. Testing was performed pre and post intervention.

Results. The VR group achieved on the USN measures results that equaled those achieved by the control group treated with conventional visual scanning tasks. They improved more on the VR test and they did better on some measures of the real street crossing.

Conclusions. Despite several limitations in this study the present results support the effectiveness of the VR street program in the treatment of participants with USN, and further development of the program.

Keywords: Virtual Reality, treatment effectiveness, visual scanning, visual spatial neglect.

Introduction

The overall goal of this study was to determine whether a non-immersive, computer desktop-based interactive virtual environment (VE) wherein the user is represented by an avatar, is an effective medium for training individuals who suffer from Unilateral Spatial Neglect (USN) as a result of a right hemisphere stroke.

USN is a disorder of orienting characterized by impairment in the ability to perceive or respond to stimuli presented to the contralesional space, and which is not attributable to significant sensory or motor deficits [1,2]. Behaviorally USN patients ignore objects or people located in the contralesional side, can miss food that is located on the contralesional side of the plate, ‘bump’ into objects on that side, etc. In neurobehavioral testing, upon request to search targets or draw pictures, these patients tend to locate or draw details mostly in the ipsilateral side. Typically, patients with USN are not aware of their deficit, however, they are not “blind” in the contralesional hemi-visual field and when they are cued to search objects in that visual field they are able to locate them [1,3]. USN has serious consequences for rehabilitation, and long term disabilities that are more severe than in patients without USN [4,5].

Although there are various treatment methods that aim to remediate this deficit and to teach compensatory strategies, only some, most notably visual...
scanning 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 or participation level [6,7].

Virtual reality (VR) is a new technology based on computerized simulation and real-time visual, auditory and, in some cases, haptic (relating to the sense of touch) feedback [8,9]. VR technology may provide a promising method to treat patients who suffer from USN due to its well-known attributes. First and foremost, VR has inherent ecological validity, enabling a therapist to present intervention within contexts that are both realistic and more meaningful to the client [10,11]. VR also provides opportunities for experiential, active learning which encourage and motivate the participant [12]. Performance within virtual environments can be measured objectively and the level of difficulty can be graded to provide stimuli that are achievable yet challenging [13,14]. Furthermore, activity within the environment is safe and strict experimental control may be maintained over stimulus delivery and measurement [15]. VR also offers the capacity to individualize treatment needs, while providing increased standardization of assessment and re-training protocols, provides the opportunity for repeated learning trials and offers the capacity to gradually increase the complexity of tasks while decreasing the support and feedback provided by the therapist [11].

In recent years, virtual reality technologies have begun to be used as an assessment and treatment tool in rehabilitation [11,16–21]. The growing interest in VR has been highlighted in two special issues of “Disability and Rehabilitation”, one in 1998 and one in 2002. In his editorial for the 2002 special issue, Rizzo [22] stated that many advances have already been made in VR technology and accessibility in recent years. As recently reviewed by Weiss, Kizony, Feintuch and Katz [23] virtual environments may now be run on platforms of greater complexity and expense including Head-Mounted Displays and video-capture systems. Nevertheless, a considerable number of desktop applications are also being used for a variety of populations. Although such applications are considered to be less immersive and generate a decreased sense of “presence” within the virtual environment, their low cost, ease of use as well as the low chance for experiencing cybersickness-type side effects make them good candidates for clinical use especially in neurological populations.

Street crossing is one example of a training environment that has been implemented on a desktop computer. Effectiveness of VR for teaching pedestrian safety and transfer to real world behavior was studied by McComas, MacKay and Pivik [24] for children. Results showed that children in the VR group learned safe street crossing skills as demonstrated by their scores on pre and follow up trials whereas the control did not. More recently, Lam, Tam, Man and Weiss [25] have developed a 2D non-immersive virtual environment for training street survival skills and use of underground transportation by people with cognitive deficits. To date, the results of the pilot study of 11 subjects with stroke have demonstrated this program to be feasible for use.

PC platforms were used also by Harrison, Derwent, Enticknap, Rose and Attree [26] in the assessment and training of inexperienced powered wheelchairs users. The first virtual environment involved a maneuvering task within a hospital room, while the second VE required route-finding in one floor of one wing of the hospital. Based on the first 6 patients, the authors concluded that although this VE has potential for rehabilitation further research is needed. Subsequently, 4 additional patients were trained within the same VE using four different routes. Results showed that for all patients virtual training was as successful as real training [27]. Support for the ecological value of VR “route finding training” can be found also in a case study by Brooks et al. [28].

Improving wheelchair mobility for patients with USN was studied by Webster et al. [29] using a computer program with different modules for scanning and detection as well as a VR wheelchair simulation which gradually became more complex requiring the avoidance of obstacles in various locations. In addition, a real life wheelchair obstacle course was used. The trained subjects (n = 19) performed significantly better on the real life obstacle course than did the control group (n = 19), and had fewer incidents of falls and accidents during hospitalization.

The specific objectives of this study were 1) to use the virtual street environment to train patients 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 on USN measures of patients with USN who received the VR training to a control group who received computer visual scanning training, 3) to compare patients’ ability to carry out a functional task (crossing a street) prior to and following training in the virtual environment and in computer visual scanning.

Method

Participants

Participants included 19 patients in two groups: 1) 11 experimental: 7 men and 4 women, mean age in
years = 62.4 ± 14.0 (standard deviation (SD)), years of education = 11.4 ± 2.3(SD); and 2) 8 in the control group: 5 men and 3 women, mean age in years = 63.3 ± 10.8, years of education = 11.5 ± 4.9(SD). All participants had a first right hemispheric stroke (RCVA), confirmed by neuro-imaging (brain CT or MRI), with persistent USN. The mean time since stroke onset until beginning of the intervention was 47.9 (21.3) and 35.6 (10.0) days respectively (see Table I) and all were right handed. 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.

As shown in Table I, the mean Functional Independence Measure (FIM) total scores for the VR group were 53.0 ± 19.3 at pretest and 73.7 ± 14.0 at posttest. The mean difference was significant (p = .002). For the control group, the mean FIM scores were 54.1 ± 24.8 at pretest and 73.6 ± 22.8 at posttest. The mean difference was significant (p = .001). There were no significant differences between the groups in the pre-post difference scores, and it is evident that the groups were very similar in their general function both prior to and following the intervention; both showed significant improvement but were still impaired at posttest.

**Instruments**

**Virtual environment program.** A street crossing virtual environment was programmed via Superscape’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. The level of difficulty was graded by the number and velocity of the cars that approach the pedestrian crosswalk as well as the side (right or left) from which they approach, thus increasing attentional demands on the user. In addition other destructors were included such as commercial signs, blinking lights etc [30,31]. A screen shot of the initial view of the virtual street is shown in Figure 1.

**USN measures.** Severity of USN was measured with conventional paper and pencil measures:

| Table I Participants’ demographic data, days since onset and functional status. |
|---------------------------------|-------------------------------|-------------------------------|
| VR Group                       | Control Group                 |
| (n = 11)                       | (n = 8)                       |
| mean (SD)                      | mean (SD)                     |
| Age in years                   | 62.4 (14.0)                   | 63.3 (10.8)                   |
| Years of education             | 11.4 (2.3)                    | 11.5 (4.9)                    |
| Gender                         | M 7                           | M 5                           |
|                                | F 4                           | F 3                           |
| Time since onset till treatment began (days) | 47.9 (21.3) | 35.6 (10.0) |
| Pre total:                     | range                         | range                         |
| Post                            | range                         | range                         |
| Difference post-pre            | −20.7 (12.8) ***v             | −19.5 (9.9) ***c              |

**v p = 002; **c p = .001;

![Figure 1 Initial view of street crossing environment.](image)
1. Star cancellation from the Behavioral Inattention Test (BIT) [32].
2. Mesulam Symbol Cancellation test [33]. Symbols or letters are randomly organized on a page. The person is asked to cross out a given symbol from among such symbols that exist on each side of the midline. The test has pages, with symbols and with letters, for each there are two conditions, one that is random and one that is organized in rows. The random symbol page, which is the more difficult one, is used in many studies by itself.

3. For each of these two tests the number of items cancelled correctly on the left side was calculated and the time it took to complete the test was measured.

4. ADL checklist was used to measure the effect of the USN on daily activities. Ten tasks were observed and scored on a three point scale; total score range is 0–30 with lower scores representing no or mild USN [34].

VR street crossing test. A standard street crossing test was performed before starting any training and after completion of training. Variables measured included number of times the participant looked to the left and to the right, the total time it took to complete each level and the number of accidents.

Real street crossing performance. Functional evaluation of the ability to cross an actual street was assessed from video-taped records. Since the participants were in wheelchairs, an occupational therapist wheeled their chair to the curb but commenced street crossing 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. At any given point in time the number of vehicles passing on a road varied. Performance scores were therefore 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.

Procedure

The study took place at Loewenstein Rehabilitation Hospital, with additional participants recruited from Hadassah Medical Center Department of Rehabilitation and Beit Rivka Medical and Geriatric Center. The study was approved by the Institutional Review Boards of the respective hospitals. For the first 8 subjects, participants were randomly assigned to either the VR training group (experimental) or the computer visual scanning tasks group (control); the remaining 3 subjects were all assigned to the VR group in order to increase the number of subjects who experienced the experimental condition.

The virtual reality training protocol continued for four weeks, with three sessions per week, each of 45 minutes duration, for a total of nine hours. The timing of the control group computer scanning training protocol was identical. Prior to commencement of training and subsequent to it within a week after completion of the training, all participants were assessed with the USN measures, a virtual street crossing test and a real street crossing task performance.

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.

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 program. The pre- and post-test results for both patient groups are shown in Table II and include scores for the USN measurements, the VR measurements, and the real street crossing measurements.

USN results

We first noted that the VR group performed lower than the control group at pre-test on most measures which is indicative of a more severe USN. 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. 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 (see Figure 2). The difference score for the Mesulam was significant at \( p < 0.01 \) as indicated in Table II by the two interconnected arrows. Both groups took less time to complete the test following intervention (see Figure 2) but the mean difference was not significant. However, the percent improvement was about twice as large for the VR group in comparison to the control group (mean difference 137.5 out of 519 s (26.5%) compared to 52.7 out of 354 s (14.9%) respectively).

Performance on the ADL checklist, i.e., a patient’s ability to cope with daily living skills (which reflects the functional implications of USN) showed significant improvement for both groups from pre- to post-test (see Figure 2). The difference score for the Mesulam was significant at \( p < 0.01 \) as indicated in Table II by the two interconnected arrows. Both groups took less time to complete the test following intervention (see Figure 2) but the mean difference was not significant. However, the percent improvement was about twice as large for the VR group in comparison to the control group (mean difference 137.5 out of 519 s (26.5%) compared to 52.7 out of 354 s (14.9%) respectively).

Performance on the ADL checklist, i.e., a patient’s ability to cope with daily living skills (which reflects the functional implications of USN) showed significant improvement for both groups from pre- to post-test (see Table II). The VR group showed significant improvement at \( p < 0.01 \), as shown in Table II. More importantly, the VR group, most patients made fewer accidents (about 50%) during the virtual street crossing at post-test which was significant at \( p < 0.035 \). 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 7.0) between groups was also significant at \( p < 0.035 \) (see Table II).

### VR Street crossing results

The VR street crossing performance of both groups showed improvement regarding the number of times they looked left, although only the results for the VR group were significant at \( p < 0.05 \), as shown in Table II. 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 \( p < 0.035 \). 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 also significant at \( p < 0.035 \) (see Table II).

### Real Street crossing results

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 Figure 3 which shows that a greater number of participants in the VR group looked to the left at post-test (6 versus 9) as compared to the control group who demonstrated no change (same 6 patients). 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 (see Table II).

In addition, moderate correlations were found between decision time in real street crossing at post test with the number of times looking left in the VR post test \( r = -0.47 \), NS) and ADL checklist score post test \( r = -0.49 \), \( p < 0.05 \). Thus, improvement in the VR street test and ADL performance show moderate relationships with real street crossing.

**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 in achieving some improvement in the ability to cross a real street immediately after the intervention. It therefore appears to have potential to become a useful tool in rehabilitation, although the timing of post testing in this study (shortly after completion of the intervention) prevents any conclusions about long-term effect. The results of some of the analyses did not reach significance at the 0.05 level, perhaps due to the small sample size, nevertheless, the direction of improvement was evident. In addition, the fact of the initial pre-test difference on the severity of USN between the groups was a limitation. We attempted to correct for this difference by comparing pre- and post-test differences rather than absolute scores.

In general, our results together with those of other studies reviewed aiming to improve neurological deficits, USN and disabilities in real life activities point to the potential effectiveness of desktop VR functional environments. However, the relatively small number of participants and difficulty in measuring objective functional outcomes in real environments mean that caution must still be exercised with regard to recommending VR as the definitive intervention for USN. Such a conclusion must await the gathering of further intervention data with larger sample sizes.

It is important to note that the intervention given to the control group in this study, computer visual scanning tasks, is currently one of the treatment methods of choice, according to most research evidence for USN therapy [7]. The results of a meta
analysis reviewing the effectiveness of treatment of visual spatial deficits, led Cicerone et al. [7] to recommend that visuospatial rehabilitation and scanning training be used as a ‘practice standard and guidelines’ to improve patients’ ability to compensate for visual neglect after right hemisphere stroke. Of seven Class I or Ia studies that assessed the effectiveness of intervention for visual neglect [35–41] all but one [38] found visual scanning treatment to significantly improve USN. However, almost all of these studies recommended that visual scanning should not be the only treatment method, and that a more comprehensive intervention should include sensory awareness and spatial organization [36], limb activation [38], trunk rotation [39], or size estimation and complex visual perceptual organization [41]. In general, the evidence demonstrated that training with 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. [42] in their report which also incorporates the findings by Cicerone et al. [7].

The results achieved by this VR street crossing intervention equaled, at the very least, those achieved by conventional visual scanning tasks. For some measures, the VR intervention even surpassed the scanning tasks in effectiveness, supporting also the contention that effectiveness of visual perceptual tasks increases with task complexity. This is also 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. It will thus be interesting to note the results of a more immersive video projected environment in which a motorized treadmill is synchronized with a street crossing environment delivered via the Motek’s CAREN software to provide locomotor training following stroke (McFadyen et al. [43]. Thus far, this system has been shown to be feasible for use with the stroke population; further studies will continue to explore its effectiveness as a rehabilitation intervention.

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, i.e., post-acute patients who participate in rehabilitation as out-patients and have the

Figure 3 Histogram showing frequencies of how many patients in each group looked to the left in the real street crossing test at pre and post test.

Figure 4 Screen shot showing revised street crossing environment.
Defense.

This study was funded by a grant from the for children with autism. Currently being tested to train pedestrian safety addition to the current population of older adult as related to planning and decision making. In the participants’ executive functions, in particular The new version provides opportunities to explore more signs, stores and avatars), and feedback for (e.g., traffic lights), more dynamic scenery (e.g., revised to include additional pedestrian situations (e.g., traffic lights), more dynamic scenery (e.g., more signs, stores and avatars), and feedback for successful completion of the route (see Figure 4). 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.

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References


