The effect of interactive virtual environment training on independent safe street crossing of right CVA patients with unilateral spatial neglect

Yuval Naveh[1], Noomi Katz[2] and Patrice L (Tamar) Weiss[3]

School of Occupational Therapy, Hadassah-Hebrew University,
POB 24026, Mount Scopus, Jerusalem, ISRAEL

[1]*msyuvaln@mscc.huji.ac.il*, [2]*msnoomi@ mscc.huji.ac.il*, [3] *msweisst@ mscc.huji.ac.il*

ABSTRACT

Unilateral spatial neglect is defined as a disorder in which a patient fails to pay attention to stimuli presented to the contralateral side of the lesion; it is known to be associated with decreased functional independence. Our objective was to determine the suitability and feasibility of using a PC-based, non-immersive VR system for training individuals with unilateral spatial neglect to cross streets in a safe and vigilant manner. A virtual environment, consisting of a typical city street, was programmed via Superscape's™ 3D-Webmaster, a 3D web-authoring tool. Twelve subjects, aged 55 to 75 years, participated. Results demonstrated that this virtual environment was suitable in both its cognitive and motor demands for the targeted population. With very few exceptions, the control subjects were able to complete all levels of the program with success. The performance of the patient subjects was considerably more variable, and they were able to complete fewer levels, and usually took more time to do so. The results indicate that the virtual reality training is likely to prove beneficial to people who have difficulty with street crossing.

1. INTRODUCTION

Unilateral spatial neglect (USN) is a phenomenon seen most often in right cerebrovascular accident (CVA) but is also present in patients following traumatic brain injury (Halligan and Marshall, 1993; Lezak, 1995). Neglect is defined as a behavioural disorder in which the patient fails to respond or pay attention to a stimulus presented to the contralateral side of the lesion (Halligan and Marshall, 1993; Heilman et al., 1997). USN has major rehabilitation implications since it is known to be associated with decreased functional independence.

A number of techniques have been suggested as a means for the treatment of unilateral neglect including scanning tasks, right hemisphere activation tasks, visuomotor imagery tasks, self instruction in wheelchair transfer tasks, sustained attention tasks and training awareness of disability tasks (Golisz, 1998; Tham, 1998). One of the basic approaches involves modification of the individual's environment by enhancing stimuli on the left (neglected) side. For example, a colorful band may be worn on the left wrist, brightly coloured food may be placed on the left side of the plate, and red tape may be placed on the wheelchair break mechanism (Golisz, 1998). Another approach is the use of scanning techniques via the use of contrived tasks such as cancellation tasks or natural tasks such as reading or writing. These activities resulted in improvements in the individual's ability to perform a specific task but did not generalize to the performance of other activities. Recent intervention studies include "Sustained attention training using self-talk procedure" (Robertson et al, 1995), "Computerized visual scanning training" (Bergego et al, 1997), "Visuomotor imagery" (Smania et al, 1997), "Contralesional limb activation with 'Neglect Alert Device'" (Roberstson et al, 1998) and "Awareness training influence on motivation for rehabilitation" (Tham & Borell, 1996), all with few cases only. To date, experimental studies have failed to demonstrate the ability of interventions of these types to influence the individual's ability to function well in real life situations.

The apparent inability of traditional tasks to reduce the functional deficit due to neglect led us to consider the use of virtual environments with this population. Due to its unique combination of attributes, this medium has the potential to become an effective, reliable, safe and relatively inexpensive evaluation and treatment tool for the remediation of certain neurological deficits. In particular, its capacity for providing the individual with a sense of presence in and interaction with a simulated yet realistic environment as well as its capacity for motivating the user, being presented in a consistent and standardized manner and the clinician's ability to readily grade and modify demands made on the user have the potential to make virtual reality (VR) an extremely powerful tool (Riva et al., 2000). In the specific application discussed here, the safety issue is paramount, as training an individual suffering from unilateral spatial neglect in a real street may be dangerous.

The objective of this initial study was to determine the suitability and feasibility of using a PC-based, non-immersive VR system for training individuals with unilateral spatial neglect to cross streets in a safe and vigilant manner. A successful outcome using a "low-end" VR system would mean that the system would be fully affordable and available to all hospital and community based clinicians.

2. METHODS

2.1 Street crossing Virtual Environment

The virtual environment was programmed via Superscape's™ (3D-Webmaster, a 3D web site development authoring tool. This tool has been in use to develop the virtual soup preparation environment by Christiansen et al. (1998) and the virtual coffeemaker by Davies et al. (1998).

As shown in Figure 1, the street crossing environment consisted of a segment of a typical Israeli city street (signage in both English and Hebrew). An avatar pedestrian, representing the subject, was initially located at the center of the scene facing a crosswalk. Vehicles of different types (e.g., cars, trucks) approached the pedestrian crosswalk from different directions and at different speeds. Subjects were able to control the position of the avatar's head by pressing on one of three large arrows keys (designating head movement in the right, left, and forward) located on the overlay of a programmable keyboard (Intellitools, Inc.). Pressing another key signaled that the subject was ready to commence street crossing, and pressing on either of two red hexagon symbols (also located on the programmable keyboard) caused vehicular travel in the specified direction to stop. The environment was run on a desktop Pentium I computer with a stereo 16 bit sound card and displayed on a 15 inch diameter CRT monitor or projected on a screen via a video projector.

Figure 1. *Screen shot of one level of the street-crossing environment*

2.2 Subjects

Twelve subjects, aged 55 to 75 years, participated during the program development phase of the study. Six of the subjects had sustained a right hemispheric stroke at least 6 weeks prior to the study; four of these six subjects showed clinical signs of left neglect on standard tests. All patient subjects were independently mobile but had difficulty crossing actual streets in a safe or confident manner. The remaining seven subjects were healthy age-matched adults who were independently mobile and had no difficulty in crossing streets. In the experimental phase of the study, currently in progress, an additional 16 patients, aged 40 to 70 years, following right hemispheric stroke who have persistent unilateral spatial neglect (USN), 6-8 weeks since onset are participating. These subjects are also independently mobile but have difficulty in crossing streets in a safe or confident manner. In this phase, the subjects are divided into two equal groups, one that receives VR training via the environment described above and the other that spends a comparable amount of training time with computerized visual scanning tasks.

2.3 Protocol

At the outset, an avatar representing the subject, was located in front of a crosswalk, near the centre of the street. The subject was initially presented with the virtual environment in Stage 1, i.e., a completely controlled configuration. For example, subjects had to look to the left, to the right and to the left again or else the program would not permit the initiation of street crossing. Vehicles approached at low speeds, and cars honked when they approached the crosswalk. In Stage 2, the next level of configuration, the program did not require subjects to look in any particular direction; vehicles approached at low speeds but the approaching vehicle honked only if the figure started to cross the street too soon. In the third configuration, vehicular speed increased by a factor of two. Finally, in the fourth configuration, the direction from which vehicles approached was randomised. Within each configuration, the levels of difficulty were graded from one (e.g., a single vehicle, approaching slowly from the right side of the street, with minimal distracters) to seven (e.g., more vehicles of different colours, moving faster and with additional distracters).

The subject's task was to commence crossing the street (by pointing on the avatar with the mouse) when, in his opinion, it was safe to do so. He was instructed in the use of direction keys for turning the avatar's head to the left, right, or forward in order to see whether vehicles were approaching from either direction. He was also shown which keys to press to cause approaching vehicles to stop moving. If the subject succeeded in safely crossing the street, he automatically progressed to the next level of difficulty. If he caused the avatar to start street crossing when it was not safe to do so, he would see it start to cross the street, and then "experience" an accident. That is, one of the on-coming vehicles would hit the avatar, a screeching brake sound would be heard, and a warning sign with the label "Accident! " would appear. In such a case, the subject was guided verbally by the trainer to increase his awareness of what had occurred. For example, the fact that a car approaching from the left direction had been ignored would be brought to the subject's attention. Subjects were able to repeat each level, or, upon success, continue to the next level. The number of training sessions varied from 1 to 4 sessions, and the duration of each session varied from 30 to 60 minutes.

2.4 Outcome Measures

The severity of unilateral neglect was determined via standardized tests including the Behavioral Inattention Test (Wilson et al, 1987), the Mesulam symbol cancellation (Weintraub & Mesulam, 1987), as well as an ADL neglect checklist (Hartman-Meir and Katz, 1995). In the initial program development phase, the outcome measures focused on the subjects' ability to perform in the virtual environment. These included (1) the frequency, order and direction that subjects searched for on-coming vehicles, (2) the number of trials as well as the total time it took to successfully complete each level, and (3) the highest level successfully completed at the end of training. In addition to these variables, during the experimental phase of the study, the ability of subjects to safely cross a real street was evaluated prior to and following virtual reality training.

3. RESULTS

Results from the initial 12 subjects have demonstrated that this virtual environment is eminently suitable in both its cognitive and motor demands for the targeted population; both the patient and older control subjects had no difficulty in learning how to use the program and in responding to its requirements. Anecdotal evidence, obtained via interviews with each subject following the experiment, indicated that the majority of subjects found the task to be an interesting and stimulating one that had functional relevance to their every day lives.

In Table 1 are presented the total time taken (in minutes and seconds) by each of the program development phase subjects to complete the up to nine different levels of the program. Subjects H1 to H6 were the six age-matched controls and subjects P1 to P6 were the six patient subjects. The age of each subject is listed in the second column. Note that not all of the subjects performed at all levels.

The total time taken to complete the different levels varied dramatically both within and between subjects. For example, the time taken by a typical control subject (H1) varied from 4 minutes, 55 seconds at Level 8 to 29 minutes, 30 seconds at Level 3. In contrast, the total time taken by a typical patient subject varied from 15 minutes, 18 seconds to 45 minutes, 48 seconds. Overall, the total time taken by the control subjects was less than that required by the patient subjects (4:55 to 36:4 min for control group as compared to 16.2 to 45.5 min for the patient group).

As indicated above, if the subject caused the avatar to start street crossing when it was not safe to do so, he would see it start to cross the street, and then an accident would occur. That is, one of the on-coming vehicles would hit the avatar, a screeching brake sound would be heard, and a warning sign with the label "Accident! " would appear. succeeded in safely crossing the street, he automatically progressed to the next level of difficulty.

©2000 ICDVRAT/University of Reading, UK; ISBN 0 7049 11 42 6

As shown in Table 2, both the patient and control subjects experienced numerous accidents indicating that the virtual environment presented a significant challenge. In rare cases, for example subject H5 at Level 6, the number of accidents was very great (21), but in most cases, subjects either did not have an accident or they incurred between 1 and 7 accidents before progressing to the next highest level.

It is noteworthy that accident information was used as an indicator of a level's difficulty. Thus, it was immediately evident from our experience with Subjects P1 and P2, that the first two levels were too easy to complete from the point of view of accidents. All subsequent subjects therefore commenced training at Level 3 or higher.

Information concerning the subjects' street-crossing strategies was also documented. For example, the number of times a subject used the arrow keys to look to the left and/or to the right was counted at each level of difficulty. All subjects felt comfortable using these keys, and did no regularly at all levels of difficulty. It would appear that the change in worldview (to the left or to the right) was realistic, and succeeded in providing needed information about the approach of vehicles.

4. DISCUSSION AND CONCLUSIONS

Although the benefits of using virtual reality in training for situations where safety is a factor have been established in defence and industry, there are, to date, relatively few applications in rehabilitation even though its potential for the reduction of distraction for attention disorders and assessment or training of compensatory techniques in the improvement of executive function deficits are acknowledged (Christiansen et al., 1998; Trepagnier, 1999). As demonstrated in the present and other studies, virtual environments provide settings for training and testing that can be controlled by the clinician on one hand and can also simulate realistic field settings on the other (Rushton et al., 1996).

Examples such as an immersive virtual kitchen demonstrate the use of training subjects in meal preparation tasks involving multiple steps (Christiansen et al., 1998)). The study used a prototype computer-simulated virtual environment to assess basic daily living skills (specifically a soup preparing task) in a sample of persons with traumatic brain injury. The study found adequate initial ability to continue development of the environment as an assessment and training prototype for persons with brain injury (Christiansen, et al., 1998).

Another application of immersive VR is a simulated building, represented by a series of rooms of variable shape with entrance and exit doors that are connected by corridors. The objective was to exit the building as quickly as possible. In order to move from one room to the next, subjects had to select a strategy based on given color and shape cues which appeared on the doors. The strategy was changed every seven consecutive right selections. The results encouraged the researchers to continue developing a more advanced prototype (Pugnetti et al., 1995).

In the present study of a street-crossing virtual environment, the results were also indicative of the potential success of simulated settings for various rehabilitation populations. With very few exceptions, given sufficient training time, subjects were able to complete all attempted levels of the program with success. The performance of the patient subjects was considerably more variable than the healthy controls, and they were able to complete fewer levels. On those levels that they did complete, they usually took more time to do so. Overall, the conclusion of the program development phase of the study, based on the time taken to perform at each level, the number of accidents, and the number of times subjects looked to the left and to the right, was that the street-crossing environment provided an appropriately graded setting for training subjects' functional abilities, and one that was perceived as being functionally relevant to an important everyday task.

Based on the performance of subjects during the program development phase, the program has been modified to include an increase in the number of vehicles, randomisation of the spacing between vehicles as well as the direction from which they approach the street crossing, and an increase in the number of distracters (visual and audio). The program is now run with a faster processor (450 MHz) that serves to create a more realistic environment. The preliminary results indicate that the virtual reality training is likely to prove beneficial to people who have difficulty with street crossing including neurological deficits other than stroke and the elderly.

Table 1: *Total time required to complete each level ("-" indicates that subject did not perform at this level).*

Subject	Age (years)	Total Time at each Level (min:sec)								
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
P1	65	22:10	34:38	-	-	-	-	-	-	-
P2	67	22:00	20:33	42:00	25:43	-	-	-	-	-
P3	70	-	-	36:25	29:18	26:16	-	-	-	-
P4	72	-	-	16:13	-	30:03	-	-	-	-
P5	62	-	-	-	-	-	22:10	14:36	-	-
P6	75	-	-	39:00	45:48	15:18	28:21	-	-	-
H1	58	-	-	29:30	25:25	18:56	30:50	7:58	4:55	14:18
H2	60	-	-	32:23	22:31	15:15	10:28	-	-	-
H3	61	-	-	21:18	22:46	18:56	9:35	6:05	7:46	15:03
H4	69	-	-	25:10	21:35	14:30	11:00	6:25	6:25	18:05
H5	71	-	-	36:36	25:01	15:55	19:10	8:28	7:58	9:01
H6	73	-	-	33:38	25:00	16:53	17:40	22:30	10:08	13:53

Table 2. *Number of accidents in each level ("-" indicates that subject did not perform at this level).*

Subject	Age (years)	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
P1	65	0	0	-	-	-	-	-	-	-
P2	67	0	0	3	4	-	-	-	-	-
P3	70	-	-	2	1	7	-	-	-	-
P4	72	-	-	0	-	0	-	-	-	-
P5	62	-	-	-	-	-	7	3	-	-
P6	75	-	-	2	4	5	5	-	-	-
H1	58	-	-	2	0	0	8	3	0	5
H2	60	-	-	0	0	0	0	0	2	0
H3	61	-	-	2	1	0	1	0	0	6
H4	69	-	-	2	1	0	1	0	0	6
H5	71	-	-	5	1	3	21	3	2	0
H6	73	-	-	9	0	1	2	1	0	1

Table 3. *Number of times subject looked to the right (R) or to the left (L) ("-" indicates that subject did not perform at this level).*

Subject	Level 1		Level 2		Level 3		Level 4		Level 5		Level 6		Level 7		Level 8		Level 9	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
P1	7	3	17	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P2	12	9	20	9	44	40	29	28	-	-	-	-	-	-	-	-	-	-
P3	-	-	-	-	15	11	23	12	27	13	-	-	-	-	-	-	-	-
P4	-	-	-	-	15	12	-	-	-	-	-	-	-	-	-	-	-	-
P5	-	-	-	-	-	-	-	-	-	-	23	18	9	9	-	-	-	-
P6	-	-	-	-	28	15	39	24	36	24	31	12	-	-	-	-	-	-
H1	-	-	-	-	11	11	13	16	13	10	15	15	11	10	4	2	13	8
H2	-	-	-	-	16	9	7	5	6	7	5	3	-	-	-	-	-	-
H3	-	-	-	-	13	15	13	10	11	9	7	7	6	7	9	9	11	14
H4	-	-	-	-	22	28	22	13	12	13	6	7	10	7	7	6	17	15
H5	-	-	-	-	28	15	24	9	19	5	13	2	11	3	9	5	11	5
H6	-	-	-	-	32	43	43	42	41	38	39	26	70	34	22	19	37	46

To date, one control and one experimental subject have completed all training and testing. Based on our experience with the program development phase the following changes and additions were made to the experimental protocol:

- The ability of subjects to cross a busy street is explicitly tested (and recorded on videotape) prior to and following virtual reality and control training;
- The number of practice sessions prior to the commencement of actual VR training is set as are the number and order of levels;
- The during and timing of training sessions is rigorously controlled;
- All subjects are tested with a 17-inch monitor and there are two training groups (VR versus other non-interactive computer programs).

5. REFERENCES

C Bergego, P Azouvi, G Deloche, C Samuel, A Louis, R Kaschel, and K Willmes (1997), Rehabilitation of unilateral neglect: A controlled multiple baseline across subject trial using computerized training procedures. Neuropsych Rehab., 7, pp. 279-293.

C Christiansen, B Abreu, K Ottenbacher, K Huffman, B Masel and R Culpepper (1998), Task performance in virtual environments used for cognitive rehabilitation after traumatic brain injury. Arch Phys Med Rehab, 79, pp. 888-892.

R C Davies, G Johansson, K Boschian, A Lind?n, U Min?r and B Sonesson (1998), A practical example using virtual reality in the assessment of brain injury, Proceedings of the 2nd European Conference on Disability, Virtual Reality and Associated Technologies, Sweden.

M Golisz (1998), Dynamic assessment and multicontect treatment of unilateral neglect. Topics in Stroke Rehab., 5, pp. 11-26.

P W Halligan, and J C Marshel (1993), The history and clinical presentation of neglect. In Unilateral neglect: Clinical and experimental studies (I H Roberston & J C Marshel Eds). Lawrence Erlbaum Associates, Hove.

A Hartman-Meir and N Katz (1995), Validity of the Behavioral Inattention Test (BIT): Relationships with functional tasks. Amer. J. Occupat.Ther., 49, pp. 507-516.

K M Heilman, R M Watson, and E Valenstein (1997), Neglect: Clinical and Anatomic Aspects. In Behavioral Neurology and Neuropsychology (T E Feinberg & M J Farah, Eds). MacGraw-Hill.

M D Lezak (1995), Neuropsychological Assessment. Oxford University Press, London.

L Pugnetti, L Mendozzi, A Motta, A Cattaneo, E Barbieri, and A Brancotti (1995), Evaluation and retraining of adults cognitive impairments: Which role for virtual reality technology? Comput. Biol. Med, 25, pp. 213-227.

K Tham and L Borell (1996), Motivation for training: a case study of four persons with unilateral neglect.

Occupat. Ther. Health Care, 10, pp. 65-79.

K Tham (1998), Unilateral Neglect: Aspects of rehabilitation from an occupational therapy perspective. Stockholm.

G Riva, A Rizzo, D Alpini, E Barbieri, L Bertella, R C Davies, L Gamberini, G Johansson, N Katz, S Marchi, L Mendozzi, E Molinari, L Pugnetti and P L Weiss (2000) Virtual Environments in the diagnosis, prevention and intervention of age-related diseases. Cyberpsych Behav, In press.

I H Robertson, R Tegner, K Tham and I Nimmo.-Smith (1995), Sustained attention training for unilateral neglect: Theoretical and rehabilitation implications. J. Clin. Exper. Neuropsych., 17, pp. 416-430.

I H Robertson, K Hogg, and T M McMillan (1998), Rehabilitation of unilateral neglect: improving function by contralesional limb activation. Neuropsych. Rehab. 8, pp. 19-29.

N Smania, F Bazoli, D, Piva, and G Guidetti, (1997), Visuomotor imagery and rehabilitation of neglect. Arch. Phys. Med Rehab, 78, pp. 430-436.

C G Trepagnier (1999), Virtual environments for the investigation and rehabilitation of cognitive and perceptual impairments. Rehab, 12, pp. 63-72.

S Weintraub and M M Mesulam (1987),. Right cerebral dominance in spatial attention: Further evidence based on ipsilateral neglect. Arch Neurol, 44, pp. 621-625.

B Wilson, J Cockburn and P Halligan (1987), Behavioral Inattention Test Manual. England: Thames Valley Test Co.