

Use of Novel Virtual Reality System for the Assessment and Treatment of Unilateral Spatial Neglect: A Feasibility Study

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Abstract—This paper is a report of the feasibility and outcome of using a novel virtual reality system, SeeMe, for the assessment and treatment of unilateral spatial neglect following stroke in two subjects: a recovered post-stroke subject with residual symptoms of unilateral spatial neglect (USN) and a patient in rehabilitation in the subacute phase, with obvious clinical signs of USN. The recovered post-stroke subject received 8 weekly sessions of treatment and the patient in the subacute phase received 4 daily treatment sessions. Outcome measures included the Short Feedback Questionnaire, standard paper and pencil tests and the assessment procedure of the SeeMe system itself. The tests were done on the first and last treatment days. In both cases, paper and pencil tests were normal even though the patients showed clinical signs of USN. However in both subjects, the SeeMe system showed a clear difference between movement times in the right and left hemispace. Following treatment, both subjects showed improved movement times to the left hemispace and also showed functional gains. Both subjects greatly enjoyed the experience of training with a virtual reality system and were highly motivated to participate in the treatment. Neither subject experienced any discomfort such as nausea or dizziness while using the system. This initial pilot study indicates that the SeeMe virtual reality system has the potential to be used in clinical settings in order to assess and treat USN. A full clinical trial is necessary in order to examine this premise.

Keywords :unilateral spatial neglect; stroke; virtual reality; rehabilitation, SeeMe

I. INTRODUCTION

Unilateral spatial neglect (USN) is a neurological disorder characterized by impairment of the ability to perceive or adequately respond to stimuli in the contralesional space [1]. When asked to search for target stimuli presented in extrapersonal space, patients often ignore contralesional stimuli. Similarly, when asked to copy a shape or form or to draw a figure from memory, patients are likely to omit or distort features of the object located contralateral to the lesion [2] USN affects the ability to perform many of the activities of daily living and is well known to have an adverse effect on the likelihood of successful rehabilitation [3]. Approximately 80% of survivors of right hemisphere stroke and 65% of left hemisphere stroke suffer from unilateral spatial neglect [4].

In the clinic, assessment of USN is usually performed using traditional paper and pencil tests. The widely used Behavioral Inattention Test (BIT) consists of a battery of three cancellation subtests as well as copying, line bisection and drawing tasks [5].

There is a need to develop different methods of assessment for USN for several reasons. First, the current standard paper-and-pencil method is weak at detecting mild or subtle signs of USN [6]. In a study of right hemisphere stroke patients, physical and occupational therapists were asked whether they thought patients demonstrated evidence of neglect in activities such as locomotion, route finding, and activities of daily living. In 13 out of 49 cases, patients were more likely to have been classified as having neglect by the therapists than by paper and pencil tests [7]. Second, paper-and-pencil tests have limited usefulness for measuring the level of recovery over time due to their limited sensitivity and patients' ability to improve just by retaking the test [8, 9]. The lack of theoretical modeling of normal performance further limits the validity of pen and paper tests [10]. Third, the score for these tests does not reflect the difficulty experienced by the patient: a swift, orderly cancellation of targets and a slow, haphazard performance may lead to the same score [11].

In an attempt to better deal with this last problem of timing and relative difficulty, Manly et al [12] suggested videotaping the patient while completing the paper and pencil tests. Observers then watched videos of patients performing cancellation tests and examined a variety of parameters including search organization, time per target and speed variability. They concluded that adding video analysis increased sensitivity over standard paper-and-pencil and allowed analysis of non-spatial aspects of USN.

Alternatives to paper and pencil tests

There is a necessity to have an assessment test that is more relevant to daily activities than paper and pencil tests; the static nature of these tests does not reflect the natural environment [11] However, in order to be useful in a clinical setting, tests for the detection of neglect need to be inexpensive and easy to use, yet readily reflect the patient's

natural and dynamic environment. One approach to solving this problem is to include tests of ADL in the assessment of neglect [13]. Other approaches include the use of computer based tests and virtual reality. These latter methods have been used in treatment as well as in assessment.

Computerized methods provide a dynamic approach to the assessment of USN in a cost and time effective manner, and enable the researcher to measure variables such as reaction time and spatial localization of deficits in an accurate and reproducible form that can be stored and analyzed. Two examples of computerized testing are the Starry Night test that measures reaction time and detection accuracy of visual target stimuli in a dynamic background [11] and the VISSTA test that assesses both feature and conjunction visual search modes [10].

Virtual reality

Virtual reality technologies hold great opportunities for the development of effective assessment techniques for neglect because they can provide “multimodal and highly controllable environments” [14]. In a virtual world, the patient not only reacts to the stimuli, as occurs in the computerized tests, but can actually interact with this computer generated 3D, lifelike environment, providing an entire new realm of possibility for evaluation and treatment. One of the first attempts to use virtual reality in the treatment of USN was a non-immersive virtual environment for training safe street crossing in neglect patients [15]. Some researchers have patients manipulate virtual objects with a haptic pen [16, 17]. Others use a head-mounted display to manipulate the patient’s view of the standard paper-and-pencil tests [18] or track a moving ball [19]. Buxbaum et al [6] have developed a virtual reality wheelchair navigation system. The patient sits in a wheelchair on a wheelchair treadmill, and either controls navigation of the wheelchair or is ‘pushed’ along a winding path through scenery full of a variety of objects. The patient must name the objects on both sides of the path. This assessment technique is highly relevant to everyday life and has the advantage of the option of adjusting difficulty level. However, it requires a wheelchair treadmill and an observer present during the entire test to record the observations of the patient.

The SeeMe System

We present here a novel virtual reality system *SeeMe*. Unlike other virtual reality systems that require a head mounted display (e.g. [18, 19]), or specialized equipment such as haptic devices [16, 17] or a special wheelchair treadmill [6], *SeeMe* does not require any equipment beyond a webcam camera and a computer with a good video card. Unlike other virtual reality systems that have been used for the assessment and treatment of neglect, *SeeMe* is designed to be used while standing and moving about, in addition to sitting. This confers a dimension of immersion and ecological validity lacking in systems that are used only in sitting. This article presents the use of *SeeMe* for the assessment and treatment of USN in two subjects, a recovered post-stroke person with residual symptoms of USN and a patient in rehabilitation in the

subacute phase following a stroke. We show that the *SeeMe* system has the potential of being a useful addition to available techniques for the assessment and treatment of both the chronic and subacute stages of USN following stroke.

II. METHODS

A. Research Design

The research design was a feasibility study of the *SeeMe* virtual reality system as a means for the evaluation and treatment of unilateral spatial neglect with testing of outcome measures before and after the intervention.

B. Subjects

Subject A was a 66 year old woman who had suffered a massive right hemisphere stroke 15 months previously. At the time of the study, she had no obvious disability remaining from the stroke, aside from some functional signs of left USN. The subject was living at home in the community and was not undergoing any rehabilitation treatments. She was independent in activities of daily living, and oriented in place and time.

Subject B was a 70 year old man 6 weeks following right CVA with left hemiparesis. At the time of the study, he had clear signs of left hemiparesis along with clinical signs of left USN. Following hospitalization in an acute care setting, he was admitted to the Beit Rivka Geriatric Rehabilitation Center for rehabilitation. He was assessed and treated with the *SeeMe* system as part of his regular physical therapy treatment.

C. Intervention

Subject A attended 8 weekly treatment sessions using the *SeeMe* system; each treatment was approximately one hour long. Subject B attended 4 daily treatment sessions. Each treatment was approximately 45 minutes long. Both subjects were evaluated on the first and last days of treatment with the *SeeMe* system along with the standard paper and pencil tests of line bisection, and cancellation .

D. The SeeMe System

SeeMe is a projected video capture, virtual reality system that works with a standard PC and a single, standard web camera. No markers, wires or monochromatic background are required. The participant’s image is embedded in the virtual story using novel algorithms for movement and position recognition and analysis. Two of the authors, R.B. and A.B., served as advisors in the development of the system.

Participants stand or sit in a demarcated area viewing a large monitor that displays an environment or functional tasks such as touching virtual balls. A video camera mounted on the television screen directly in front of the user captures the user’s image and projects it onto the screen. The subject sees himself on the screen interacting with the virtual story in real time, in three dimensions, using trunk and limb movements. A single screen-mounted camera and vision-based tracking system capture and convert the user’s movements for processing. The user’s on-screen video image corresponds in

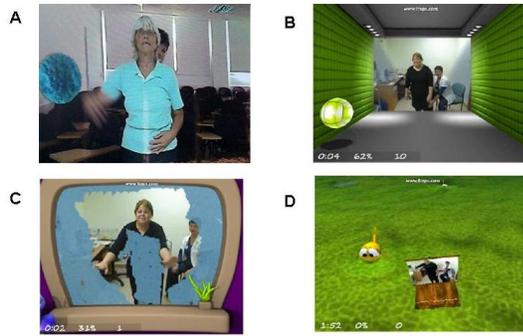


Fig. 1. Screenshots from SeeMe applications. A. SeeMe React, B SeeMe Ball, C. SeeMe Cleaner, D. SeeMe raft

real time to his movements, so that it appears as though the user is part of the virtual environment, leading to engagement in the simulated task.

SeeMe offers excellent graphics and interactivity, and the possibility of training subjects while monitoring movements. The parameters of the virtual games can be modified to suit the individual clients. This can be done even in the middle of a game so that the tasks can be made easier or harder in accordance with the performance of the subject. The data can be saved and presented later in formatted Reports or as Excel files for comparison between populations and patient groups. Subject performance data for each therapy session, including movement time, success rate and the parameters of the virtual game, are stored and can be easily retrieved. The therapeutic programs can be tailored to suit the needs of different clients and adjustments of the level of difficulty can be made even while the client is using the system. Each of the games has several levels of difficulty, with distracters being added at the higher levels.

The following games from the SeeMe console were chosen:

React

In this task, virtual balls appear randomly at fixed distances on both sides of the screen. The task of the subject is to touch the virtual ball within a set amount of time. (Fig 1A) The system records both the number of misses and the movement time necessary in order to reach the target.

SeeMe Ball

In SeeMe Ball, the subject has to hit the virtual balls that come toward him from various directions. In the higher levels, distracters are added in the form of the occasional shoe (which needs to be avoided) being thrown at him (Figures 1B and 5). The therapist has complete control of the frequency, location and velocity of both the balls and the shoes.

SeeMe Cleaner

In the SeeMe Cleaner application, the subject is supposed to clean a series of mirrors as quickly as possible, by wiping off the virtual dirt (Fig. 1C). The aim of the game is to clean as many mirrors as possible within the given time. In the cleaner task, the location of the area to be cleaned can be closely controlled. For example, to make the task easier for a neglect patient, the area to be cleaned can be limited to the right hand side of the screen and gradually moved over towards the left side of the screen.

SeeMe Raft

In this application, the subject navigates a raft down a stream by moving his body (Fig. 1D). The aim of the game is to collect as many fish as possible. In the higher levels of the game, barrels are added as distracters to be avoided. The presence or absence of barrels, the speed of the raft, the number of fish and barrels, as well as their speed of movement can all be controlled by the therapist.

E. Outcome Measures

Outcome measures included standard paper and pencil tests such as line bisection and cancellation tests, movement time measurements using the React task of the SeeMe system, and the Short Feedback Questionnaire (see below). The VR outcome measure tests were carried out on the first and last days of treatment. The Short Feedback Questionnaire was filled out only by Subject A and this was done on the last day of treatment. In addition, an open ended interview was conducted with each subject on the last day of treatment.

Short Feedback Questionnaire (SFQ): This questionnaire in Hebrew, from Rand et al [20] is based in part on a translated version of Witmer and Singer's [21] Presence Questionnaire and was administered on the last day of treatment. The six questions assessed the participant's 1) feeling of enjoyment, 2) sense of being in the environment, 3) feeling of success, 4) sense of being in control, 5) perception of the environment as being realistic and 6) whether the feedback from the computer was understandable. The responses to these questions are on a five-point scale, with 1 indicating low and 5 indicating high for each question. The answers were summed to give a total score for the experience with a maximum score of 30. Following the lead of Rand et al [20], an additional question was added to inquire if the participant felt any discomfort during the experience.

III. RESULTS & DISCUSSION

SUBJECT A

Initial Evaluation

At the time of the study, Subject A had no obvious disability remaining from the stroke. However, she showed functional signs of USN. For example, she complained of bumping into the left side of doorposts when going through a doorway, collided with open closet doors, and did not pay attention to

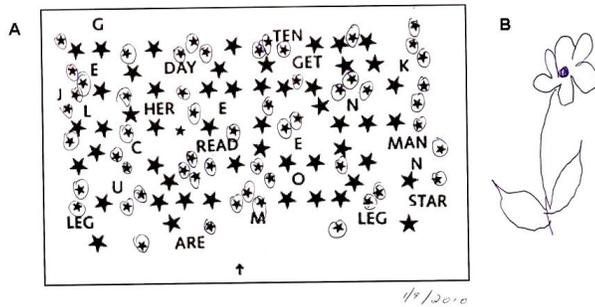


Fig. 2. Paper and Pencil test performed by Subject A on the first day of treatment. A. Star cancellation test, B. Drawing of a flower.

people and objects on the left side of her visual field. In addition, she complained of feeling disoriented and said that she was unable to follow any route that required consecutive turns to right and left and therefore never left her home without a companion.

The subject tested normal on the standard paper and pencil cancellation tasks which she completed quickly and easily (Fig 2).

Virtual Reality Evaluation

The VR evaluation was done using the React task of the SeeMe system. The system records both the number of misses and the movement time necessary in order to reach the target. The results of the initial evaluation of Subject A appear in Fig 3. In this graph, one can see that the average movement time to targets on the left hand side of the screen was 1282 msecs as compared with 1040 msecs for targets on the right hand side of the screen. That is to say, movement time for the left hand targets was 23% greater than for the right hand targets. In the first evaluation, she missed 50% of the balls on the left hand side and none on the right hand side. In the final evaluation, she did not miss any balls on the left hand side.

Course of Treatment

The tasks chosen for treatment were the ball task, the mirror cleaning task, and the raft task. In each of the tasks, the various parameters of the task were constantly adjusted to meet the abilities of the subject. If the therapist saw that the task was too easy – as indicated by 100% success in the task – the task was immediately made more difficult. Conversely, if the task was too difficult as indicated by a high failure rate, the therapist would immediately make it easier. This could be done even in the middle of a game – there was no need to wait for the end of a game before adjusting the level of difficulty. Fig 4 shows the result of a therapist changing the parameters of a game “online”, while the game was still in progress. The figure shows the summary report of two separate sessions of the ball task. In the first session, the balls came only from the upper right hand quadrant of the screen. In the second session, balls now came from all parts of the screen and in addition, there were distracters to be avoided. Because of this added difficulty, the success rate of the subject fell. The treating

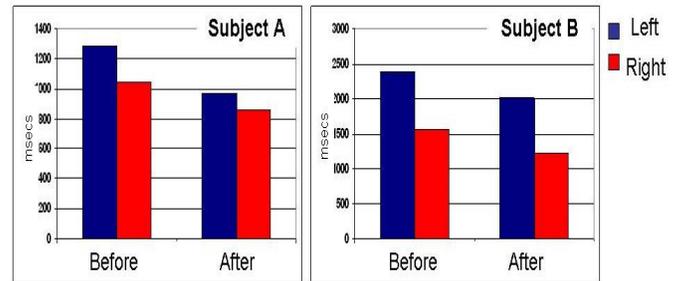


Fig. 3. Movement times to left and right hemispace before and after treatment.

therapist saw that the task was too difficult and therefore slowed the speed of the balls and the success rate immediately increased.

Of the various SeeMe games, it was the mirror cleaning task which most clearly showed her rightward bias. During the initial treatments, she consistently started the cleaning task on the right side of the screen, leaving the left side for last and often neglecting to clean it altogether. She was given oral instructions to start the cleaning task on the left side of the screen. By the end of the treatment sessions, she performed the mirror cleaning task much more efficiently and no longer neglected the left side of the screen

In each treatment session of the mirror cleaning task, the area of the mirror to be cleaned, initially only on the right hand side of the screen was gradually moved towards the left until finally only the left side of the mirror was to be cleaned. Fig. 5 shows how the control panel allowed the therapist to organize the progression of the treatment. In the other games, parameters were changed as needed usually by increasing the speed of the various targets, enlarging the playing area to include the left side of the visual field and adding distracters.

Final Evaluation

The subject very much enjoyed the SeeMe therapy sessions and felt that she was receiving very up-to-date treatment. She especially enjoyed the fast moving games that posed a particular challenge to her attention and alertness. As she put it in her own words “I liked the games that kept me on my toes”

About half way through the treatment sessions, we asked the subject to please keep a diary and record the number of times that she bumped into doorposts and other objects. She replied that there was no need since she hardly bumped into anything anymore. On the last day of treatment, the subject reaffirmed that there was a great improvement in the collision rate with various objects in her environment. When asked if she felt any differences in her condition following treatment, she claimed that she was less disoriented than previously and

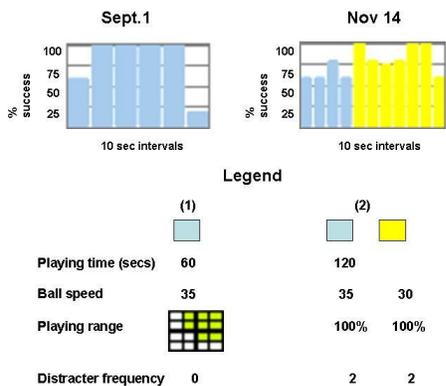


Fig. 4 Summary report of two separate sessions of the ball task. In the first session, the balls came only from the upper right hand quadrant of the screen. In the second session, balls now came from all parts of the screen and in addition, there were distracters to be avoided. Noting that the success rate of the patient had fallen, the therapist decreased the speed of the balls. As a result, the success rate improved.

now could follow simple routes that required consecutive turns and was venturing alone out of her home for short excursions.

Short Feedback Questionnaire (SFQ)

The SFQ was administered on the last treatment day. The subject gave a score of 5 out of 5, for the items of enjoyment, feeling of control and success in the virtual tasks. However, she gave a score of only 2 to the question ‘How real does the environment seem to you?’ This did not interfere with her feeling of immersion in the virtual task. This was most clearly evident in the ball task. Figure 6 shows her ducking to avoid the virtual shoe that was being thrown at her. Clearly she was totally immersed in the task. When asked to rate the level of difficulty of each of the games, she rated the Mirror Cleaning and raft tasks as the most difficult and the React task as the easiest, with the Ball game being rated as the most enjoyable. With the intention of establishing how VR treatment is perceived in the eyes of a patient, the subject was also asked if she felt VR was a “real” treatment. Absolutely not, she replied, it was too much fun; On the other hand, she asked if she could refer other post-stroke subjects suffering from neglect for the VR treatment, thus indicating that she did perceive the VR treatment as valuable.

Final Virtual Reality Evaluation

Movement times decreased for both right and left sides (Fig 3) indicating that there was some learning in the system. However, it is worth noting that the difference between left and right hand movement times decreased from 243 msec to 106 msec. Accordingly, by the last treatment, left hand movement time was only 12% greater than right hand movement time. She did not miss any balls in the final evaluation.

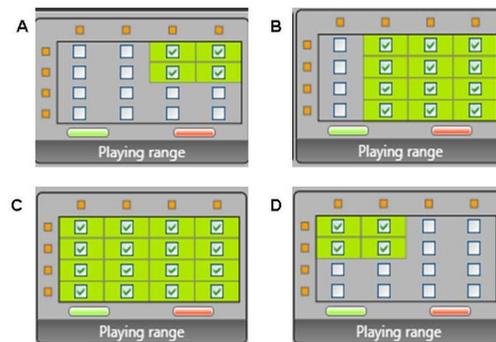


Fig. 5 The control panel allows the therapist to organize the progression of the treatment. Area of the mirror to be cleaned moves from upper right quadrant (A), through increasing area of the mirror (B,C) through to only the upper left hand quadrant (D).

Subject B

Initial Evaluation

When Subject B was admitted to the rehabilitation facility, he was suffering from left hemiparesis and severe signs of left sided neglect. Paper and pencil tests done at the time of his admission showed clear signs of left neglect. However, at the time of treatment by VR (one month after admission), the paper and pencil tests were normal even though the patient continued to show clear clinical signs of left neglect. For example, he ate only from the right side of his plate, and did not relate at all to the left side of his body or to the left hemisphere.

Virtual Reality Evaluation

Subject B was evaluated using the React task of the SeeMe system. Because of his still severe left hemiparesis, the subject was treated sitting down performing all movements with his right hand starting from directly in front of his body on a table. It was found that his average movement time to targets on the left side of the screen was 2388 msec as compared to 1549 msec to targets on the right side of the screen (Fig. 3). The very slow movement time to the right indicates the severity of his general condition. In the first evaluation, subject B succeeded in hitting only 33% of the balls on the left as compared with 87% of the balls on the right.

Course of treatment

Subject B was treated using the React game and also the Mirror Cleaning game. All the other games were too difficult for him. The patient very much enjoyed his VR treatment and was highly motivated to complete the treatment.

Final Virtual Reality Evaluation

In his final evaluation, Subject B's movement time to targets on the left had decreased from 2388 msec to 2023 msec, while movement time to targets on the right had decreased from 1549 msec to 1222 msec. This was still a very slow movement time. The difference in movement times between right and left remained at approximately 800 msec. This difference in movement times indicates that there was still a problem in movement towards the left hemisphere. ..

IV. LIMITATIONS

Limitations of this study include the fact that only two subjects were tested. In addition, only the SeeMe system was tested and no comparisons were made with other computerized evaluation systems such as the Starry Night [11] or the VISSTA [10]. Finally, there is no control group comparing treatment with the SeeMe system with other treatments both computerized and not. A full scale clinical trial with an appropriate control group is necessary in order to evaluate the effectiveness of this system for patients with USN.

V. SUMMARY AND CONCLUSIONS

This paper presents a feasibility study of the use of the SeeMe system for the assessment and treatment of USN following stroke. We have used the SeeMe system to evaluate and treat USN in two post-stroke subjects, one in the subacute phase and the other recovered, but with residual signs of USN. In both cases, the SeeMe system showed a clear difference between movement times in the right and left hemisphere, even though paper and pencil tests were normal. Following treatment, both subjects showed improved movement times to the left hemisphere and also showed functional gains.

Use of the system was found to be feasible in a clinical setting. There were no technical problems in setting up and using the system and the treatment was well received by the subjects who very much enjoyed the experience. Neither subject experienced any discomfort such as nausea or dizziness while using the system.

In conclusion, we have showed the feasibility of using the SeeMe virtual reality system for the assessment and treatment of USN. The system was sensitive enough to detect evidence of USN that was not detected by standard paper and pencil tests. Unlike other virtual reality systems that have been suggested for the assessment and treatment of USN, the SeeMe system does not require a head mounted display or indeed any other equipment beyond a standard webcam camera. The fact that SeeMe is designed to be used while standing and moving about and not only in sitting adds to the feeling of immersion and interaction with the virtual environment, thus providing a more ecologically valid environment than is possible in the seated position.

In conclusion, this initial feasibility study indicates that the SeeMe system has the potential to be used in clinical settings in order to assess and treat USN. Clearly, a full clinical trial is

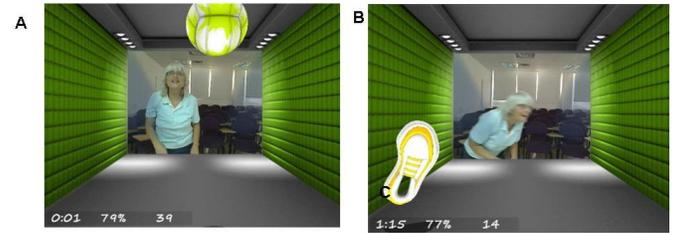


Fig. 6. Immersion in the virtual game. Subject waits to receive ball (A) and ducks to avoid the shoe (B)

necessary in order to examine the accuracy and effectiveness of the SeeMe system.

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