The Virtual Mall: A Functional Virtual Environment for Stroke Rehabilitation

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Abstract: *Patients who have had a stroke constitute a large population with significant needs for rehabilitation. Even after long, intensive and costly rehabilitation, these patients still suffer from many impairments leading to severe restrictions in participation in every day life. This is a result of limited functional recovery of the upper extremity in addition to cognitive and meta-cognitive deficits. It is also due to insufficient training of IADL functioning during rehabilitation, primarily since such training is both time consuming and technically difficult to implement. The use of VR for rehabilitation of individuals with neurological impairments appears to be promising and its feasibility and effectiveness have been demonstrated in a number of different studies. However, the VR-based interventions that have been developed and reported in the literature used mainly desktop platforms, and the majority of them did not include the stroke population. The aim of this paper is to present the development of a virtual environment using a video capture VR system, which provides an opportunity to carry out therapeutic intervention in a functional, natural and a motivating way. The results of a pilot study on patients with stroke highlighted its many potential advantages. These results as well as future directions will be discussed.*

INTRODUCTION

Stroke is considered to be the third leading cause of death and the most important cause of severe disability in old age.[1,2] Almost half of the patients suffering from stroke retain substantial disability[3] affecting their performance of activities of daily living. The main symptom following stroke is paresis or paralysis to half of the body, contra lateral to the side of brain lesion. Additional symptoms include sensory, perceptual, cognitive and meta-cognitive deficits, which result in a decreased ability to perform activities of daily living.[4] Patients, who demonstrate difficulties functioning in activities of daily living often suffer from deficits in executive functions despite being cognitively intact.[5,6] These patients present problems such as starting and stopping activities, an inability to shift mental processes and behavioral tasks, planning and monitoring deficits as well as keeping a goal in mind throughout a task.[5] The assessment and rehabilitation of executive functions under non-natural conditions such as a research laboratory or clinical facility is still very unsatisfactory, and the evaluation of real life tasks, which has the advantage of giving a more accurate appreciation of the patient's deficits, appears to be time consuming and not suitable for the typical clinical setting.[7]

The functional recovery of the upper extremity after stroke is considered to be exceptional in most cases; the arm does not usually become functional even after intensive and long-standing therapy.[8] Most of patients quickly learn to cope by using only the unaffected arm, and, indeed, prefer to avoid failure by not using the affected arm at all. This phenomenon is known as "learned non-use."[9] Recent research, using "Constraint Induced Movement Therapy" (CIMT) has been shown to be very effective[10] due to the fact that patients use their hands in a functional manner (and not as routine exercises) many times a day (high repetition) which endeavors to stimulate healing process associated with plasticity of the brain.[11]

The objective of rehabilitation is to decrease the various motor, cognitive and meta-cognitive deficits described above, in order to promote the functional ability of basic and instrumental activities daily living (BADL and IADL). To date, most clinical settings rely on the use of non-functional, routine exercises aimed at decreasing impairment, despite the fact that it would appear to be much more relevant and motivating for patients to exercise while engaged in meaningful, purposeful tasks that are related to real life interests and activities.[12-13] Unfortunately there are limited opportunities for implementing purposeful activities within traditional clinical settings via conventional occupational therapy. Therefore many stroke patients do not return to their premorbid functional level, especially in the more complex instrumental activities of daily living.[14]

Virtual Reality (VR) has the potential to be used as a novel modality in rehabilitation assessment and intervention due to its well known attributes.[15-16] To date, a few studies have examined the use of VR with a stroke population, and in most of these studies very small numbers of patients participated. Kizony et al. assessed the sense of presence and whole body performance in virtual games of patients with stroke.[17] Piron et al used VR to train upper limb reaching movements[18] and Broeren et al. developed a VR haptic device for the assessment and training of motor coordination[19] and Merians et al. used a force feedback glove to improve range of motion, speed and strength of hand movement.[20] Safe street crossing which is a major concern was trained with stroke patients who suffer unilateral neglect using a desktop VR system and found to be useful.[21]

In order to encourage activation of a specific limb, the GX system may be operated while users wear a red glove on one or both hands. If the aim is to improve a user's weak upper extremity, the red glove will be worn only on the impaired hand thereby restricting responses within the virtual environment to that specific body part.[10]

To summarize, VR generally, and the GX VR system especially, appear to have considerable potential for assessing and treating executive functions and the upper extremity motor function of patients with stroke. The importance in developing additional intervention tools that are motivating and challenging for patients with stroke and other neurological disorders who are in need of lengthy rehabilitation and, in particular, opportunities to practice instrumental activities of daily living led us to develop the Virtual Mall using the GX-VR system. The Virtual Mall (VMall) was developed and designed to facilitate assessment and treatment whilst the patient is engaged in a complex, everyday task of shopping. The aims of this paper are (1) to describe the development of a functional virtual environment and it's usability for stroke patients (2) to present the results of a pilot study with eight stroke patients.

DEVELOPMENT OF THE VIRTUAL MALL (VMALL)

The VMall aims to simulate a real shopping mall consisting of different stores in order to provide patients a functional and ecological valid environment which can be used to train motor, cognitive, and metacognitive skills as well as a shopping task itself.

The VMall was developed primarily for use with neurological patients who suffer from motor, cognitive and/or metacognitive deficits. The first population tested was adults and elderly patients who suffer from stroke and whose barriers for independence in daily living were described above. Thus it was important for the VMall to facilitate active movement and executive functions while engaged in the shopping task. In addition, the consideration of rehabilitation principles including flexibility of the environment and the ability to adapt the task to suit the patient's level of ability was also important.

To date, the VMall is a large supermarket consisting of many different aisles. Photographs of real grocery items were taken with a digital camera and rendered via 3-D graphic software. These graphic files were then integrated into the VMall virtual environment. Each aisle is composed of a maximum of 60 products located on shelves, and sorted into different categories such as baking goods, cleaning items, and stationary products. The names of the aisles appear on a sign which also has an image of the type of products located in that aisle (see figure 1, right panel).

The products may be selected and sorted by a therapist thereby providing flexibility with regard

Figure 1: Screen shots of the VMall showing a user selecting a shopping aisle (left panel), a food item (middle panel) and verifying the contents of the shopping cart (right panel).

to the number, type and location of items within each aisle. Four copies of each product, one behind the other, are located on the shelves such that following the purchase of one item, another three may be seen (and purchased). Once all four items are bought, the shelf is bare in that location (see figure 1, middle panel).

The names of each product have been recorded. Thus, in addition to the visual display of the grocery items, the name of the product is heard whenever it is touched. The item is also enlarged when it is touched. This augmented visual and auditory feedback has been added to ensure that the user has correctly identified the desired product.

Several additional features have been included to enhance the user's sense of being present within a supermarket environment. Background "shopping mall" type music is played throughout the shopping experience. Typical announcements of special sales are also heard occasionally during the shopping task. Such announcements may be recorded easily by a therapist and suited to a particular patient or shopping task.

ACTIVATION AND OPERATION OF THE VMALL

The user sees himself within the VMall and the navigation is done virtually touching arrows, which scrolls the screen to the left or right side. Entering the desired aisles is done by touching the sign of the aisle and selecting an item is done by touching it.

At first, the users has to select the desired aisle in accordance with the agreed upon shopping list. Once an aisle is entered, the user faces shelves stocked with different products. The products may be "purchased" by touching them with either hand (provided that a red glove is worn). The selected product then appears in a shopping cart (which may be viewed at any time by linking to a second display screen) (see figure, right panel). Items, acquired by mistake or not needed, may be removed from the cart, by touching them. The user can return from the shopping cart screen to the aisle screen to continue shopping, and from each aisle the user can return to the main screen to choose another aisle. Patients may be given different tasks to do, including, for example, the selection of a specific recipe, compilation of the requisite shopping list (in order to obtain the products needed for that recipe), and the purchase of products from this list.

Output measures include data indicating how well the user accomplished the task (e.g., how many correct items were selected, time to accomplish the task, sequence of items selected, the number of times the user checked his shopping cart) which are recorded and saved automatically thereby providing a record of improvement over time. We are currently investigating the possibility of recording the patient's limb and trunk kinematics while using the VMall.

USABILITY STUDY

Following the initial development of the VMall, six community dwelling individuals with stroke at a chronic stage were invited to experience the environment. The aim was to test its suitability for the use with stroke patients and to receive user-centered feedback prior to completion of the environment.

Three males and three females, mean age 60.3 ± 9.5 (range 50-74 years), who sustained a right hemispheric stroke 1.5 to 5 years prior to testing, experienced the VMall. They all suffered from varying degrees of weakness in their affected upper extremity but had no cognitive deficits. Five patients were able to walk and one was independently mobile in a wheel chair. Four of them go shopping on a regular basis.

They experienced the VMall for approximately ten minutes while receiving an explanation about how to operate it. They then were given a six item shopping list and were asked to shop for the items. When the task was completed they filled in a feedback questionnaire (the Scenario Feedback Questionnaire (SFQ)[22] with several additional questions related to VMall usability (e.g., To what extent were the products clear?). They were also asked to rate their level of perceived exertion (Borg's scale)[26]. A short interview was done at the end.

Overall the patients all enjoyed their virtual shopping experience very much and said they would very much like to use it again. They all found the task to be challenging and interesting, and commented that it had potential to use in rehabilitation. The mean SFQ scores was 25.6 ± 3.4 points (maximum 30 points) and the mean rated exertion was 13 ± 1.2 points which indicates an easy level. It was interesting to observe that several patients decided to buy items that were not on the list because they needed them at home! Others bought products that were on sale. From these responses we learn that the task appeared to be relevant and realistic for the participants, and that they felt a high level of presence. After using the VMall, one male user remarked: "During the experience ones uses all of his senses, also his imagination and brain." A female user stated "It forced me to straighten my fingers which I never do spontaneously." A second female user commented "It made me feel as I was capable."

During the usability study we encountered a few technical difficulties with the system which have now been resolved. The requisite red glove was difficult to put on the weak hand on some individuals, and it was therefore replaced with a red mitten. One 72 year old patient complained that the products were difficult to identify, and the resolution of the 3D images has now been improved. One female participant said the task was not relevant for her since she never went shopping prior to her stroke, and was not planning to do so in the future. This point is crucial since relevance is a key objective in using the VMall as a therapeutic task. We therefore now include an initial relevancy question prior to usage: "Did you go shopping prior to your stroke?"

PILOT STUDY

Following these improvements, eight additional patients with stroke experienced the VMall. They were all males and their ages ranged from 38-73 years (mean 58.7± 13.3 years). Most of them were during their sub-acute rehabilitation (3-7 months post stroke) whilst one patient was four years post stroke. Five patients had sustained a right hemispheric stroke which caused weakness to their left side of the body and the other two sustained a left hemispheric stroke. All patients used to shop alone or with a spouse prior to the stroke. One patient (44 years old) was a butcher in a supermarket prior to his stroke. They did not have cognitive deficits (the mean Mini Mental State Examination (MMSE) scores ranged from 26-30 points) but all suffered from a different degree of motor impairment of their upper extremity (upper extremity subtest of the Fugl-Meyer Motor assessment (FMA) scores ranged from 7-58 points, mean 35.6 ± 17.5 points).

The protocol was identical except for the interview which was not conducted and extra details of the patient's impairments were collected. This included the MMSE which was used as a cognitive screening test (maximum score 30 points) and FMA (maximum score 60 points) to assess the affected arm's motor impairment.

RESULTS

The SFQ scores ranged from 19-28 points with a mean of 22.6± 3.2 points. For the first question "To what extent did you enjoy yourself?" the mean score was 4.1 ± 0.99 points (maximum 5 points). The perceived exertion level was 13.2 ± 3.8 points (which ranged from 8-17 points on Borg's scale) and no side effects were reported. From these results it can be seen that overall these stroke patients who were relatively a short time post stroke with different degrees of motor impairments were able to virtually shop for products using one or both of their hands. They too enjoyed the task and thought it to be relevant for their rehabilitation.

CONCLUSIONS AND FUTURE DIRECTIONS

The VMall seems to have great potential for the use with stroke patients during different rehabilitation stages since it provides an interesting and motivating task which encourages active movement especially of the weak upper extremity and facilitates the use of executive functions. Recently a protocol for intervention of stroke patients who suffer from motor and/or executive functions deficits was developed and a study assessing the treatment efficacy has started. We also plan to use the VMall with different patient's population such as adolescents post stroke and patients suffering from traumatic brain injury.

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