Virtual reality system for upper extremity rehabilitation of chronic stroke patients living in the community

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ABSTRACT

For stroke patients with residual motor impairment, access to sufficient rehabilitation after discharge is often difficult to achieve due to cost, distance and availability of rehabilitative services. Virtual Reality (VR) rehabilitation is a promising method for maximizing the intensity and convenience of task specific rehabilitation training. However, many of the systems that have been developed are expensive, heavy and require frequent technical support. This feasibility study was the first phase in the evaluation of a commercially available game controller for leisure-based therapy at home. Eight people at least six months post stroke took part in a two group randomised control trial. Participants completed a range of measures of upper limb functioning before half spent three sessions a week playing computer games using the game controller while the other half spent the same amount of time in a progressive muscle relaxation program. The study is still underway so data are presented on the performance of the participants in the games group. Their results so far suggest that participants have the potential to improve their performance on the games available using this device.

1. INTRODUCTION

Stroke is the third most common cause of mortality and the leading cause of long-term disability worldwide (Mackay and Mensah, 2004). The literature suggests that 75% of survivors regain their ability to walk again, however a considerable proportion ranging from 55% to 75% fail to regain functional use of their impaired upper limb (Feys et al., 1998). Upper limb motor impairment limits the individual's functional autonomy and activities of daily living. In the UK the National Clinical Guidelines for Stroke recommend rehabilitation which focuses on "participation" and includes planned withdrawal of medical and rehabilitation services and substitution with leisure and social activities that encourage independence and reintegration to normal life (RCP, 2004). However, access to further rehabilitation is often difficult to achieve after hospital discharge, due to cost, distance and availability of rehabilitative services (Reinkensmeyer et al., 2002).

To address the need for augmented rehabilitation, several research groups have explored the use of emerging technologies. Within this context Virtual Reality (VR) rehabilitation has been heralded as one of the most promising methods for maximizing the intensity and convenience of task specific rehabilitation training (Dobkin, 2004). Indeed scientific evidence suggests that early intensive (Kwakkel et al., 2004) task specific (van Peppen et al., 2004) practice for a prolonged period of time (van der Lee et al., 2001) facilitates motor recovery. Additionally, various forms of augmented feedback are considered to be a potent variable affecting motor skill acquisition following stroke (Van Dijk et al., 2005).

Preliminary research in the area of VR stroke rehabilitation focused primarily on examining the feasibility of complex VR systems that provide the participants with different types of augmented feedback and different VR rehabilitation protocols for acute, sub-acute and chronic stroke patients (eg Merians et al., 2002). Although this work mainly involved small sample sizes it suggested promising trends, triggered the active exploration of telerehabilitation applications (eg Broeren et al., 2004) and finally lead to further studies involving bigger sample sizes (Holden et al., 2007) and small controlled clinical trials (eg Piron et al., 2006). This later work established the feasibility, health and safety of VR stroke rehabilitation systems and indicated that previously obtained positive outcomes were not attributed to spontaneous recovery (Holden et al., 2007). Neuroimaging studies also demonstrated that VR training can induce cortical reorganization following stroke (Takahashi et al., 2008).

Given the fact that most of the above systems employ relatively sophisticated or expensive hardware and software, one question of paramount clinical importance is whether the benefits obtained from these systems can outweigh their cost or if similar results can be obtain with less sophisticated affordable systems. What now needs to be explored is the rehabilitation potential of commonly available VR platforms and games. Although commercially available platforms lack specificity in terms of software, hardware and performance metrics they often provide other equally important advantages such as mass acceptability, easily perceived feedback and most importantly affordability for unrestricted home use. In addition some of these platforms and games share similar characteristics to their higher cost predecessors. For example, they take an egocentric perspective combined with a virtual representation of the hand and this further enhances the potential to facilitate improvement through activation of relevant motor areas of the brain (August et al., 2006).

We set out to evaluate a highly acceptable, usable and accessible VR rehabilitation system for leisure-based therapy at home. Feedback from focus groups conducted with the local Stroke Research Consumer Group suggested that VR rehabilitation is very acceptable and clinically relevant to chronic stroke survivors and that a device to play appropriate computer games would motivate users to continue with the activities at the recommended frequency. Following a review of existing technology, we decided to use a commercially available game controller, the Novint Falcon (http://home.novint.com/products/novint_falcon.php). This has several advantages for home use including low cost, size and weight; 3 degrees of freedom to allow the development of motor schemata that underlie everyday tasks; safe force feedback for building strength, speed, endurance and precision of multijoint movements and easy calibration for non experienced users. The software available with the device includes a variety of VR mini-games that motivate users to perform sufficient repetition of tasks aligning with established neurorehabilitation principles such as task variability and contextual interference (Krakauer, 2006).

Before embarking on an evaluation of the intervention in patients' own homes, a hospital based feasibility study was required to determine the design; sample size; suitable outcome measures that assess improvements in functional ability; the procedure for the home based study and any changes to the prototype to enhance its usability in a home based setting. As this study is still in progress, results from the performance of the intervention group only are presented in this paper.

2. METHODS

2.1 Design

A small two group randomised control trial with 4 participants in each condition.

2.2 Recruitment of Participants

Potential participants were recruited from two stroke clubs. Invitation leaflets were handed to members who were aged between 18 and 85 years, had experienced their stroke more than 6 months previously, were still experiencing problems with their upper limb for which they were receiving no formal arm therapy and who lived in the community. Volunteers first had to complete a screening questionnaire which included a set of questions about their arm function, general mobility and health and safety designed to exclude those whose current condition would prevent them from using the system for the required period of time. If their answers indicated that they were suitable for the study, one of the research team (AC) visited them at home to further assess their suitability using a set of standardized outcome measures of cognitive, perceptual and motor function corresponding to the VR tasks that the participants needed to perform. These measures were the arm section of the Motricity Index (MI) (Demeurisse et al., 1980); Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987); Mini-Mental State Examination (MMSE) (Hodgkinson, 1972): Star Cancellation Test (STAR) (Wilson et al., 1987) and the Sheffield Screening Test for Acquired Language Disorders (STALD) (Syder et al., 1993). The MI and MAS were also used as secondary outcome measures. Potential participants were also excluded if they also suffered from other serious conditions.

8 people were recruited to the study who met the above criteria. There were 4 men and 4 women aged between 36 and 74 years. On recruitment, participants were randomly assigned to either the VR Leisure or VR Relaxation group. Table 1 shows the characteristics of the six participants who have already started the study.

Table 1. *Baseline characteristics of the participants.*

	VR leisure	VR relaxation
Sex (Male/ Female)	2M/2F	1M/1F
Age (Mean/Range)	62.75/36 - 74	57/56 - 58
Months since stroke (Mean/Range)	58.25/12 - 116	121/36 - 206
Hand dominance (R/L)	3R/1L	2R
Side of weakness	3R/1L	2R
STAR (Mean/Range)	52.5/51 - 54	54/54 - 54
STALD (Mean/Range)	16.5/8 - 20	18/16 - 20
MMSE (Mean/Range)	27.25/22 - 30	26.5/25 - 28

2.3 Measures

A variety of outcome measures corresponding to different aspects of upper extremity activity were included in this feasibility study to ascertain suitable outcome measures for the home based study; to ensure that the participant's upper limb status did not prevent them from effectively using the system and to assist with power calculations for the home based study. All measures have been demonstrated to be valid, reliable and relevant to the upper extremity while also being convenient to administer as the whole battery can be performed in about 30 to 35 minutes.

2.3.1 Primary Clinical Outcome Measure. The Action Research Arm Test (ARART) (Lyle, 1981). This is a staff-scored, patient-completed 19-item test divided into 4 domains: grasping, gripping, pinching and gross movement. Each item is graded on a 4-point ordinal scale for a total possible score of 57 indicating normal arm functioning. The test is hierarchical in that if the patient is able to perform the most difficult skill in each category, they are assumed to be able to perform the other items within the category.

2.3.2 Secondary Clinical Outcome Measures.

The 10-Hole Peg Test (PEGS) (Annet, 1970) was used to assess manual dexterity. This is a staff-scored, patient-completed measure of manual dexterity consisting of two parallel rows of ten holes and ten pegs. The participant has to move the pegs one by one from the further to the nearer row, when the board is placed horizontally across their midline. The time taken is recorded from touching the first peg to releasing the last, to an accuracy of 1/10 seconds. There are 10 trials each trial alternating between the right and the left hand. The mean completion time for the five trials with the left hand is subtracted from that for the right hand so the larger the resulting figure, the larger the difference between the affected and unaffected side.

The Motricity Index (MI) (Demeurisse et al., 1980) was used for assessing motor impairment. The MI is a staff-completed index measuring general motor impairment on three basic upper limb subtests (pinch grip, elbow flexion and shoulder abduction). The maximum score that can obtained is 100 indicating normal functioning.

The Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987) is a measure of spasticity. It is a staff-completed manual test that staff use to grade the resistance encountered during the passive stretching of different spastic muscle groups. It involves applying rapid manual movement of the limb through the range of motion to passively stretch specific muscle groups. Each joint is scored between zero and five with zero indicating no increase in muscle tone.

The Nottingham Extended Activities of Daily Living (NEADL) (Nouri and Lincoln, 1987) was used to asses the participant's ability to carry out activities of daily living. The NEADL is a patient or carer-completed measure of Instrumental ADL ability comprising 22 items grouped into 4 categories: mobility; kitchen tasks; domestic tasks; leisure activities. The maximum score is 60 indicating full independence of daily living activities.

2.3.2 User Experience Outcome Measure. The Short Feedback Questionnaire (SFQ) (Kizony et al., 2006) and the Borg Scale of Perceived Exertion (Borg, 1990) were used to assess the participant's experience of using the system and physical effort respectively.

2.4 Virtual Environments

2.4.1 VR Leisure Group. From the games that were provided with the Novint Falcon, five were chosen that would motivate the participants to use their arm in order to perform sufficient repetition of upper limb movements/ tasks (i.e. pull, push, reach, grasp) to help them produce improvements in their upper limb motor control and function.

The five games differed in terms of the motor activity that was required to play them so that a combination of the games provides the opportunity a) to focus on different aims based on the users abilities, needs and preferences; b) progressively increase difficulty and complexity by moving to more complex games and c) provide a combination of games (i.e. task variability). Details of the games and skills required are summarised in Table 2.

Table 2. *Summary of the details of the games available for the VR leisure group.*

Game	Description	St	Sp	E	P	C	RT
Penguin Push	Push forward to shove the penguin along the ice and slide it onto the target at the end of the ice				✓		
Hook & Weight Fishing	Swing the fish over to the bucket to collect the fish	✓	✓		✓	✓	✓
Cucaracha	Hit the approaching cockroaches with a hammer before they reach any of the food or beverages on the table		✓		✓		✓
3-Point Shootout	Grab a ball and shoot it from five different locations	✓	✓	✓	✓	✓	
Top Pin Bowling	Grab a bowling ball, throw the ball and knock over as many pins as possible	✓		✓	✓	✓	
Duck Launch	Grab the nearest duck, strap it into a giant slingshot, and fling it into one of the ponds	✓		✓	✓	✓	

St = Strength; Sp = Speed; E = Endurance; P = Precision; C = Coordination; RT = Reaction time

2.4.2 VR Relaxation Group. This involved listening to a recording of an instructor's voice describing a progressive muscle relaxation program. The program encouraged participants to imagine themselves in a relaxing environment similar to the virtual reality environment (VRE) presented on the monitor and to actively perform a contraction-relaxation program involving the same upper limb muscles as the experimental condition, however in the absence of functional upper limb movement. This condition (i.e. attention control) was carefully chosen in order to keep contact time consistent across participants as opposed to providing conventional therapy or providing a no treatment condition and was based on studies which suggest that similar control conditions keep participants interested, compliant, and blinded (Page et al., 2007).

2.5 Procedure

The intervention took place in the research laboratory. Participants had sessions scheduled for three times a week for four weeks which lasted 30-45 minutes but could be terminated earlier if they wished. When they attended for their first session they completed the ARAT and ten hole peg test before starting either the VR leisure or relaxation condition. For both conditions they sat in an ergonomic chair facing a 21″ widescreen computer monitor computer with one of the researchers (AC) sitting alongside them to give assistance and encouragement if required. The participants in the VR relaxation group wore a pair of wireless headphones to isolate them from the environment to allow them to focus on the instructions without external influences.

Participants in the VR leisure group started on the game that, in discussion with the researcher (AC) seemed to be the most appropriate to their current level of arm function. They then spent several sessions playing this game before moving on to play a second game and then a third. The games were quite short so that in each session the participant could attempt the game several times. Each session was recorded on videotape, with the camera positioned to view both the participant and the researcher sitting next to them. The videotapes were analysed using a method established in an earlier study (Standen et al, 2002) which yielded measures of help given by the researcher. This was described as physical (giving assistance) or verbal (giving information). The researcher also recorded the scores obtained for each attempt at each game and also the number of errors. A diary was kept to record any other information that might be useful but that would not be picked up by video analysis.

Video collected data were expressed as a percentage of session duration; scores and errors were averaged for each session. The purpose of collecting these performance data was to confirm that the games were set at a level suitable to the abilities of the participants and that with continued practice they had the potential to show some improvement.

3. RESULTS

3.1 Outcome Measures

As the study has not been completed, currently available results for six participants are presented. Baseline scores on the outcome measures are shown in Table 3.

3.2 Performance Measures

Figures 1 and 2 show the mean scores and errors over the sessions for which data are available for two participants on two of the games, Penguin Push and Top Pin Bowling. For all participants there was an increase in score obtained from the first to the last session (see Tables 4 and 5). However, these increases were accompanied by a decrease in errors for only three of the four participants: participant 5 playing Penguin Push had a higher mean number of errors in session six than they did in their first session. This suggests that whatever strategy they adopted to increase their scores was at the expense of accuracy.

Table 3. *Mean and range for each group at baseline on the outcome measures.*

	VR leisure	**VR relaxation**
Action research arm test	43.25/2 - 57	23/1 - 44
10 hole peg test	7.21/0.46 – 12.03	17.13/11.84 – 22.43
Motricity index right hand	74.5/40 - 100	62/40 - 84
Motricity index left hand	85/40 - 100	100/100 - 100
Nottingham extended activities of daily living	47.5/33 - 57	56/54 - 58

Table 4. *Comparison of scores and errors from first to sixth session for Penguin Push.*

	First session		Sixth session	
	scores	errors	scores	errors
Participant 4	1.40	0.73	3.00	0.42
Participant 5	0.78	0.44	1.97	1.02

Table 5. *Comparison of scores and errors from first to sixth session for Top Pin Bowling.*

	First session		Sixth session	
	scores	errors	scores	errors
Participant 1	1.77	0.87	3.06	0.89
Participant 2	3.39	0.36	4.79	0.05

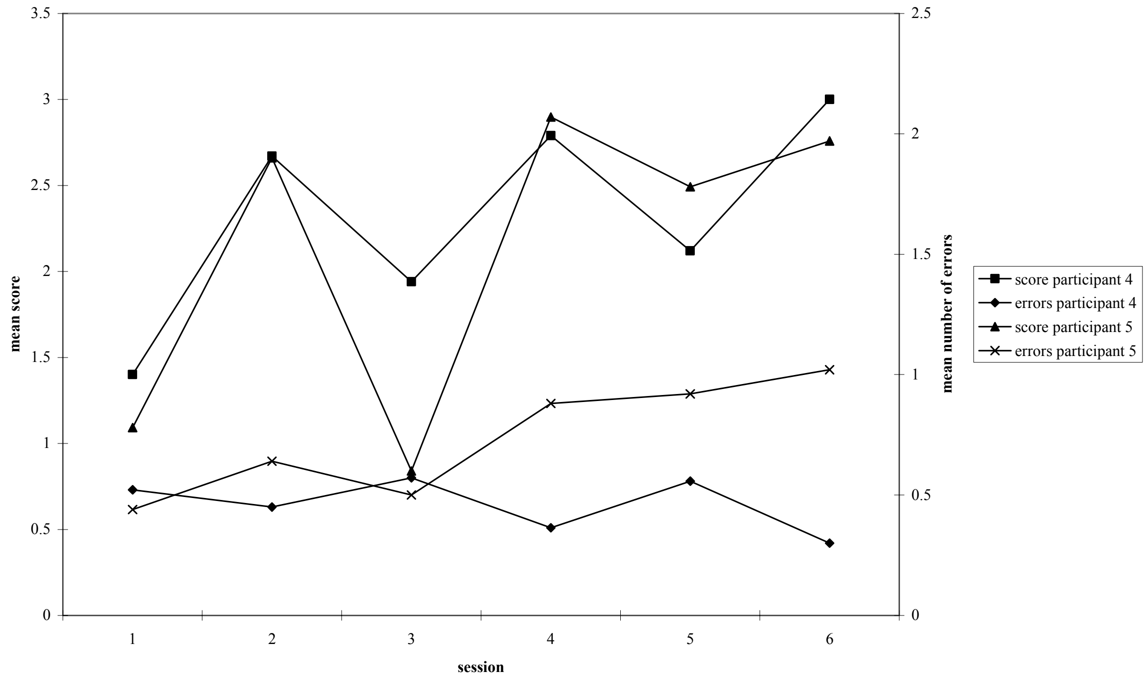

Figure 1. *Mean scores and mean number of errors by session for one game: Penguin Push.*

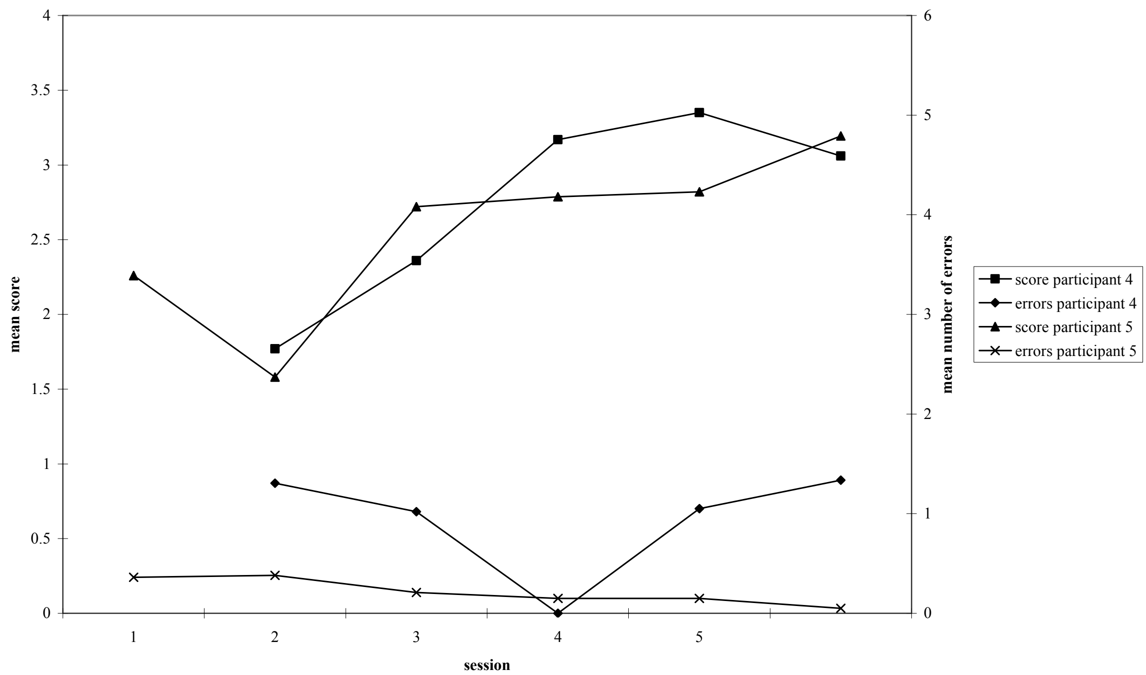

Figure 2. *Mean scores and mean number of errors by session for one game: Top pin bowling.*

4. DISCUSSION

As the study is still in progress it is not possible to compare changes from baseline in any of the outcome measures. However, an examination of the performance on the games suggests that some improvement is taking place even after only six of the total 12 sessions have been completed. The amount of help participants receive from the researcher has also been recorded to determine how much of the improvement may be due to external help. The tapes have not yet been analysed but informal observations indicate that after the first session, help diminished to almost zero indicating that the games are easy to learn and would thus be suitable for a home base intervention where the researcher was not continually present. Performance measures were collected to indicate whether the games were set at a level suitable to the abilities of the participants and that with continued practice they had the potential to show some improvement. It is possible that the improvement shown so far is purely down to increasing familiarity with the games but continued improvement over the remaining scheduled sessions would suggest that there was also an improvement in motor ability which would hopefully be indicated in the final administration of the outcome measures.

This is a small sample and the generous inclusion criteria ensured a wide variation in ability. However, useful findings for the planning of the home based study have already emerged. First of all, it is important to have a variety of games that would ensure that the activity matches participants' ability, needs and preferences and sustains their motivation for improving manual ability. Games that might require fine manual dexterity for example pressing the fire button, can be frustrating and demotivating for those pinch and grip capability is low. Secondly, in spite of having to make the journey to the hospital three times a week, no participants have dropped out of the study. Although other pressures will exist in a home based study that will affect compliance, playing the games or taking part in the relaxation condition appear to be sufficiently motivating to maintain continued participation. Finally it was interesting to hear from one of the participants in the VR leisure group that between sessions he had been encouraged to attempt more manual activities at home for example opening screw top jars. This suggests that the future study should try to incorporate an extra measure of daily activity outside of the gaming sessions.

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