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Virtual Reality Mirror Therapy (VRMT) to Improve Finger Dexterity in Post-stroke Survivors: A Preliminary Feasibility Study of a Home-based Intervention

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There are 1.2 million stroke survivors living in the UK, of which approximately 77% have lost some upper limb function. Traditional mirror therapy (MT) uses repetition, motor priming, and action observation to promote motor recovery in stroke patients. Although a range of intense repetitive exposure to therapeutic interventions, such as exercises and mirror therapy, appear key in motor recovery, it can be difficult to keep patients motivated as change can be slow and therapy appears monotonous. Virtual reality (VR) systems offer the ability of tracking hand function, which could benefit MT as it may provide realistic feedback, in a game like environment to increase motivation. In addition, VR may increase the variety of therapeutic exercises needed for patients as it is not restricted by the physical barrier of the mirror box. This study aimed to develop and evaluate the feasibility and effectiveness of a Virtual Reality Mirror Therapy (VRMT) system, intended to improve finger dexterity in post-stroke patients. Ten post stroke participants with upper limb hemiparesis were recruited for this study, which was run virtually at the participants' home. Participants were randomly allocated into three groups: Group 1 used the VRMT intervention; Group 2 used the Nine-hole peg (9HPT) test and Group 3 received no intervention (Control group). The results show that Groups 1 and 2 increased their 9HPT scores more than Group 3. Feedback from participants highlighted functional issues with the VR controller, which may have impacted on usability and motivation. The results of this study indicate that VRMT has the potential to improve finger function, can be used by post-stroke individuals and could increase engagement with therapeutic exercises post-conventional treatment.

virtual reality, stroke, motor rehabilitation, mirror therapy

1. INTRODUCTION

A stroke is a life-changing disease and the lead cause of adult disability worldwide. Between 55% and 75% of survivors continue to experience motor deficits associated with diminished quality of life [1]. Although, home-based rehabilitation is a growing trend that has been proved to be useful solution in complex contexts (e.g., patients living in rural communities, or during a pandemic; [2], there is a lack of high-quality research in home-based tele-rehabilitation for hand therapy [3]. In addition, motivating patients to adhere to home-based therapy appears to be difficult as motor rehabilitation requires intense training [3, 4].

Virtual Reality (VR) may offer a solution to remote intervention and motivation. VR was originally created for entertainment and gaming and may benefit therapies such as Mirror therapy. Traditional Mirror Therapy (TMT) creates an illusion of a patients affected hand moving by reflecting the movement of the non-affected hand. It uses repetition, motor priming, and action observation to promote motor recovery [5]. However, there are limitations to this therapy; for example, training only one part of the body can lead to asymmetric posture [6]. In addition, it can be difficult to motivate patients to persist with the therapy, which in turn, can slow or stop recovery [7].

Instead of a mirror, VRMT uses realistic 3D hand objects and tracking to create the illusion. VR may increase the variety of therapeutic exercises needed for patients as it is not restricted by the physical barrier of a mirror box [8-12]. New technologies offer the ability of fine finger tracking and provide realistic feedback that is required for hand therapies such as MT. Initial findings shows that technologies such as leap motion and cyber gloves can be beneficial to motor recovery in the stroke population [13-15].

One key element in motor recovery is motivation. As motor recovery requires intense and repetitive exercises, it can often discourage patients and therefore may impact participation [16, 17]. Cheng et al. showed that goal setting, control of task difficulty and feedback are important factors in motivation [18]. These motivational constructs can be implemented in a VR system to provide effective motor rehabilitation. However, research is needed into the effects of traditional methods of motivating a patient compared to motivating methods within VR.

VR systems may also benefit unsupervised home-based therapies by increasing motivation and adherence to maintain dosage at home in chronic stage of stroke. Bollen et al. [4] argued that it is difficult to monitor how much patients are adhering to unsupervised home-based rehabilitation. VR may offer a solution, as it can use the internet to transfer data, allowing a therapist to remotely monitor progress accurately and to modify the patients therapy program e.g., dosage, intensity and & frequency to achieve optimal functional recovery [19]. Therefore, two questions form the basis of the work presented in this study. 1) Are VRMT systems feasible to use in the post-stroke population? 2) Can Virtual reality Mirror Therapy improve finger function in the post-stroke population?

2. METHOD

2.1 Participants

Potential Participants were recruited by contacting the main stroke survivors support agency in Wales who kindly circulated an information sheet indicating the requirements of the study. Eleven people who met the inclusion criteria were accepted on to the study. Inclusion criteria: 1) over 18 years old; 2) able to give informed consent; 3)3 months or more following a stroke; 4) has reduced motor control in one hand;5) has access to the internet and a Windows laptop/computer, and 6) must be able to understand and read English. Ethical approval was granted from the University of South Wales Ethics Committee.

One participant withdrew from the study (for personal reasons), a total of 10 participants (6 males and 4 females with a mean age of 50.8) completed the study. Participants were randomly allocated into 2 groups at the point of consent (written and verbal), group 1 was the test group (VR, age Mean= 46.0, F1:M3, Mean time since stroke 4.2 years) whereas Group 2 (age mean=53.7, F2:M1, Mean time since stroke 7.6 years) was considered the control and told to continue to perform the exercises as outlined by their therapist with the 9HPT. All were tested at the start and conclusion of the experimental period using the Nine-Hole Peg Test (9HPT).

2.2 Design

Participants in Group 1 and 2 were asked to use their intervention for 45 minutes a day, 4 days a week for 4 weeks. Intervention dosage was decided based on that reported in previous literature [8, 9, 20]. Effectiveness was assessed using the 9HPT. The 9HPT is an effective tool for assessing finger dexterity [21], with good inter-observer and test-retest reliability [22]. Feasibility was measured with the Intrinsic Motivation Inventory (IMI) and the System Usability Scale (SUS).

2.3 Materials and Development

This study was a collaborative project with ‘Tg0’ a company that provided the VR controller ‘etee’ and designed the hardware system for the VRMT (see figure 1). Participants calibrated their hands with ‘etee’ and then played a VR game called ‘Intune Therapy’ which was designed by the research team and Tg0 (see figure 2). All the data and progress of the patients was collected and uploaded in the backend to the cloud. In accordance with the Data Protection Act (1998), all the information we received was treated strictly confidentially, and everyone who worked on the study respected the privacy of the participants. A code was assigned to each participant and was assigned to the data from that participant for storage.

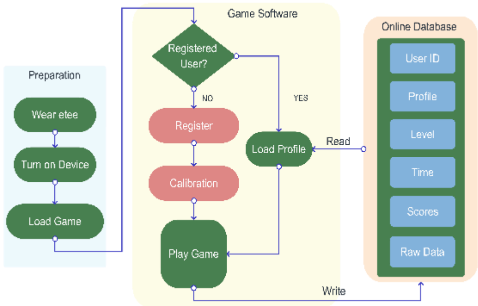

Figure 1: *Process of using etee in VRMT and data collection.*

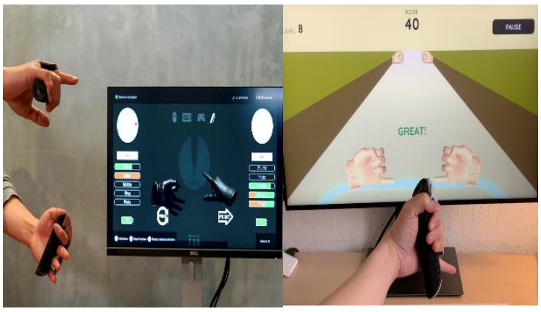

Figure 2: *(a) Holding etee for calibration; (b) using etee to match gestures*

‘etee’ is a new VR hand controller with the capability of tracking fine finger movements through AI-based capacitive sensing technology (See Figure 2), which can detect the status of each finger within ~10cm distance. Each finger has a 'distance’ score from 0-

100 matching the status of the finger from straightening out on-air to bending to the surface of etee. Fully opening a hand would have a score of 0 and creating a fist around the controller (full pressure) would have a score of 100. To make the system work for all hands, a calibration program (see figure 2 (a)) was designed to enable each participant to easily match their hand and fingers to the 3D hand on the screen. Participants placed etee on their non-affected hand and were asked to open their hand out to calculate zero score and then to make a fist to calculate the upper limit, then this range was normalised to fixed range of [0, 100]. This calibration process makes sure the system can cover all sizes of hands.

As shown in Figure 1, every participant had a unique ID, and the calibrated profile for them will be loaded into a VR game called Intune Therapy Game. The game guided users to match their hands with the virtual hands appearing on the screen (See Figure 2(b)). When playing the game, etee was placed only on the participant's non-affected hand but both hands appear on screen moving symmetrically. Participants were told to concentrate on their affected hand on screen. The participants scored higher when they match their fingers accurately. To unlock the next level, participants needed to achieve a certain score. Each level increased with difficulty which created a challenging environment that was customizable for patients in different recovery stages.

More specifically, as shown in Figure 2 (b), the participants would receive a score and feedback (None, OK, Good, or Great) based on their performance. The game has 14 hand poses and 10 levels, while each level increases in difficulty such as speed, accuracy, hand poses and stamina. For example, the first level starts with simple hand poses such as making a fist, having the hand fully open, pointing index finger and pinch pose. Participants would need to get a certain score to unlock the next level. Turning the therapy process into a multiple-level game has made the participants relaxed in the process and encouraged them to practice. All the behaviours are recorded and uploaded to an online database. By accessing the database, researchers can check the participants' status and recovery progress. The data include user ID, score, the total played time, and raw values, which are useful for future analysis and process customisation.

2.4 Procedure

A two phased screening procedure was used to ensure the safety of the individual and the validity of the study. In the first screening the researcher and participant discussed their suitability for the study. In the second screening meeting participants were asked to complete the Star Cancellation Test (Wilson, Cockburn, & Halligan, 1987) and pick up a wooden peg from a flat surface. If the participant passed both tests, they were asked to sign two consent forms and return one form to the researcher. The researcher then took a baseline measurement of their finger function (pinch grip and fine motor control) in both their dominant and non-dominant hands using the 9HPT. In addition to the 9HPT tutorial and baseline measurements, Group 1 also received a tutorial on how to use the VR equipment. This involved showing participants how to download files, charge etee, calibrate and navigate the Intune therapy game. The researcher asked participants whilst they were playing Intune therapy to place their hands on their lap, under a desk or table if it is possible. The researcher checked that the etee was comfortable to use, and they can put it on themselves, if they are unable to do this, the researcher asked if they live with someone able to assist. We asked participants if they were experiencing any nausea, dizziness, or disorientation from using VR. No adverse effects were reported.

3. RESULTS

3.1 Effectiveness results

Three Wilcoxon tests were used to analyse the pre and post intervention 9HPT scores of each of the groups. Effect size r is calculated as ($r = z/\sqrt{N}$). For Group 1, all four participants had a positive rank, mean rank 2.5, the Wilcoxon test shown no significant differences between the pre- and post-test ($Z=-1.841$, $p=0.066$), ($r=-0.7$). However, Group 1 shows a positive trend from pre- to post-intervention 9HPT scores and it appears to be larger improvement than Group 2 and Group 3. In Group 2, 2 participants showed positive ranks, and 1 negative rank with a mean rank of 2.5. The Wilcoxon test showed no significant difference ($Z=-1.069$, $p=0.29$), effect size ($r=-0.4$). Group 2 data shows a positive trend from pre to post intervention 9HPT scores and appears to have a bigger improvement than group 3 but not group 1. Group 3 showed that 1 participant had a positive rank, 1 a negative rank and 1 a tie. Mean rank of 2. The Wilcoxon test showed no significant differences between the pre- and post- affected had scores ($Z=-0.447$, $p=0.67$),

effect size ($r=-0.2$). Group 3 shows a small positive trend from pre to post 9HPT scores, this improvement is much smaller than that of groups 1 and 2. In addition it appears the medium 9HPT score is smaller post-intervention.
It was unlikely that any statistical significance could be found or trusted due to the limited number of participants included in the study, therefore, although Group 1 and 2 may have appeared to have shown significant improvement, a larger sample would be required to test the system appropriately.

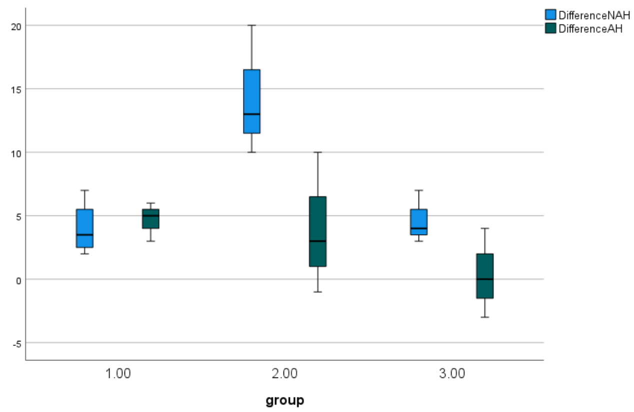

Figure 3. *Improvements of the Nine Hole Peg test (9HPT) scores in both affected (DifferenceAH) and non-affected hand (DifferenceNAH) amongst the VRMT group, (Group 1), the 9HPT group (Group 2) and the Usual care group (Group 3).*

Figure 3 presents the 9HPT score change between the pre and post measure for each group for both the non-affected hand (blue) and affected hand (green). The pattern of data suggests that group 2 increased their 9HPT scores the in both their affected hand and non-affected hand. Group 1 shows a larger increase in affected hand scores. Group 3 has the smallest increase of 9PHT scores in their affected hand. Interestingly the data shows a larger increase in Group 3 compared to Group 1 for the non-affected hand scores.

The data presented here can only be used to guide sample sizes required for future studies. Using the calculated effect size, a power analysis was conducted by G-power to estimate the sample size based on a power of 0.8 (80% chance that the null hypotheses will be rejected). Group 1's effective size of -0.7 would need 15 participants to achieve a power of 0.8.

3.2 Feasibility results

Figure 4 illustrates the mean average score for each of the subscales of the IMI between Groups 1 and 2. All subscales are a positive indicator of motivation except for the subscale pressure and tension, this is a negative predictor. The pattern of data shows that group 1 scores slightly higher in the following subscales: interest/ enjoyment, perceived competence, effort and importance and value and usefulness. Group 2 scored higher in the pressure and tension subscale and perceived choice.

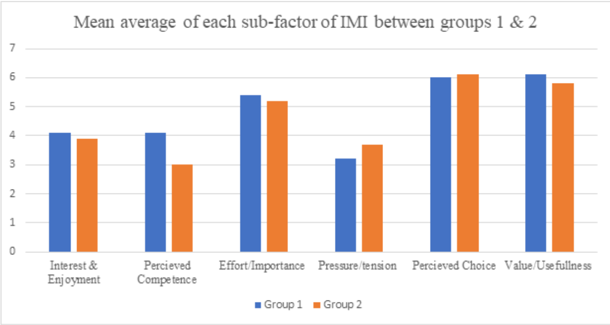

Figure 4: *Mean average Intrinsic Motivation Inventory (IMI) scores of each sub-factor between the VRMT group (Group 1) and the 9HPT group (Group 2).*

Table 1 presents adherence data collected from the login data from the etee system for group one (VRMT). Two out of four participants adhered to the total of 16 days, whilst the other two only adhered for 10 and 12 days during the 4-week intervention phase. In addition, the table includes the mean differences between the 9HPT scores for each of the participants. Participants 3 and 4 appear to show a larger increase their 9HPT scores in both their affected hand (AH) and non-affected hand (NAH) than participants 1 and 2. This may be due to participants 3 and 4 adherence being greater than participants 1 and 2. This corresponds well with existing literature [23].

Table 1: *Group 1 adherence data of using VRMT over 4-week intervention phase and corresponding 9HPT improvements from pre to post intervention in affected hand (AH) and non-affected hand (NAH)*

Participant	Days using VRMT system	Total time (Min)	Difference between (DB) pre and post 9HPT AH	DB pre and post 9HPT NAH
1	*12*	*370*	*5*	*3*
2	*10*	*286*	*3*	*2*
3	*16*	*545*	*5*	*4*
4	*16*	*615*	*6*	*7*

Table 2 presents the SUS scores for group 1. Table 2 indicates that the mean average SUS score is below the usability average (68) [24]. Two out of four participants scored 50 or below and therefore received grade F, while the other two participants scored highly (grades A, B). Participants that scored higher on the SUS, scored higher on all subscales of the IMI (excluding the pressure and tension subscale). However there does not appear to be a link with adherence (Table 1), and SUS scores.

Table 2. *SUS scores and corresponding grade and IMI score for the VRMT group (group 1).*

Participant	SUS score	Grade	Mean average IMI
1	*50*	*F*	*4.3*
2	*75*	*B*	*5.7*
3	*42.5*	*F*	*4.7*
4	*82.5*	*A*	*5.8*
Mean Grade	*62.5*	*C-*	-

4. DISCUSSION

There are several findings to report. First, the VRMT system was found to give promising results in the affected hand data. Second, post-stroke participants were able to use etee, no adverse events were reported. Third, the VRMT intervention appears to be motivating; in particular, participants scored highly on the value/useful subscale of the IMI. However, adherence, IMI, and SUS data appears to show that some participants found the VRMT system easier and more enjoyable to use than others. The results from this study correspond well with the existing literature in that the VRMT system appeared to show an improvement compared to those who underwent no intervention [23].

Our usability results from the SUS, adherence data and recording of adverse effects, found that etee was safe to use in this population and no adverse effects were recorded. These findings correspond well with other feasibility and proof of concept studies [3, 11] in that that VR systems appear to be safe to use, despite the variation of VR equipment used, including Leap Motion, Oculus Rift and Virtual Piano Trainer.

Most VRMT studies have been conducted face to face, with participants attending the VR sessions with the researcher, therefore, adherence was tracked via patient attendance [6,8,9]. By contrast, this study was novel in that it was conducted virtually, with the participants using the equipment by themselves at home. Therefore, an advantage of this study is that the environment provides high ecological validity. Our findings found that two out of four participants adhered fully to the 16 days and two completed 10 and 12 days. Collecting this adherence data is a marked improvement on previous VRMT studies, which have not stated adherence, only dropout rates of participants [6, 9]. The final feasibility measure we used was intrinsic motivation, using the IMI. Literature has highlighted the importance of motivation and its effect on patient adherence [7, 19]. Specifically, as adherence leads to better functional outcomes, it is key to research and implement motivation factors in any rehabilitation program. The novel VRMT system we have created, including the "Intune Therapy" game and online database, attempts to incorporate some of these motivational factors, as well as providing a challenging task hand game where participants match their hands to hand poses appearing on the screen. The VRMT system uses virtual feedback of "OK, Good, and Great" and scores based on the accuracy of the performed task. In addition, the VRMT system has a gradual increase in difficulty in terms of speed, type of hand pose, score needed to unlock the next level and the length of level. This created an environment where individuals could find a level that was challenging for them. Participants were also able to track their progress via the high score page, and researchers also could monitor and analyse all the data by accessing to the online database.

While this study was novel in its use of a new VRMT system to assist the improvement of finger dexterity at home with stroke patients, we must also acknowledge the limitations. First, the sample size is small and therefore findings cannot be generalised to the stroke population. Furthermore, the small numbers of participants reduced the ability of detecting any change or reliably comparing the populations statistically.

In addition, the heterogeneity between the groups in terms of baseline 9HPT scores and the time since their stroke, may have had an impact on the data, as those with lower baseline scores or those who had their stroke longer ago may not be expected to improve as much as those who had better motor function to begin with, were younger, and those who had their stroke more recently.

Moreover, despite including motivational factors in our VRMT design, our results found that the VR group only had a minute increase in IMI scores over the 9HPT group. This may be caused by unfamiliarity with the devices and prototypical nature of the hardware. The hardware and software system can be improved in the future work to increase the performance.

To conclude, the results from this study indicate that VRMT has potential to improve finger function, can be used by post-stroke individuals and could increase engagement with therapeutic exercises post formal treatment by the NHS.

5. FUTURE DIRECTIONS

The findings from this study indicate that there could be benefits to developing and utilising VRMT systems in the stroke population. However, based on our findings, it is difficult to conclude which elements of the system would be most effective and which stroke patients would benefit most. It is recommended that a large scale, appropriately powered, study is performed to accurately measure the effectiveness of this approach, and to investigate the different factors of VRMT systems, such as exploring appropriate dosage, the feasibility of using haptics at home, the impact of the level of realism of avatar limbs, and post- stroke user needs.

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