Development and Validation of Virtual Reality Combined with Shoulder Wheel Device for Active Rehabilitation Training

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Research Article

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Abstract

Objective: To develop and validate the rehabilitation system based on virtual reality to increase patients' time of active rehabilitation during exercises.

Methods: Thirty stroke patients admitted to rehabilitation clinics, who met the inclusion criteria, were selected after the initial evaluation performed by a physiotherapist. All patients were randomly divided into two groups. The first group was treated with common shoulder wheel therapy combined with virtual reality, and the control group was treated only with shoulder wheel therapy. Both groups received routine shoulder rehabilitation exercises for four weeks. Clinical assessments (action research arm test and Fugl-Meyer assessment) and functional testing (torque) were performed three times in a 15-day interval, and also a reaction rate-test for one time, at the end of rehabilitation.

Results: Results showed that parameters of reaction rate and functional torque tests, clinical evaluations of action research arm test, and Fugl-Meyer assessment increased in both virtual reality and control groups during the treatment. Torque and reaction rate, as well as the Fugl-Meyer assessment functional test were significantly (p <0.05) higher in the intervention group than the control group. Although this difference indicated the relative superiority of virtual reality-based rehabilitation, there was no significant difference in action research arm test assessments (p >0.05).

Dissuasion and Conclusion: A rehabilitation system based on virtual reality was designed and developed for stroke patients' shoulders and was evaluated clinically. Results indicate the influential role of virtual reality in improving shoulder functions and increasing active rehabilitation time in stroke patients.

1. Introduction

According to the World Health Organization (WHO) report, stroke is caused by the interruption of blood flow, which carries oxygen and nutrients to the brain tissue. This can cause brain cell death and thus loss of part of nervous system function [1]. The increase of life expectancy and population growth around the world in recent years means that more people are now reaching the age at which neurological disorders are prevalent, which is the main cause of disability and the second leading cause of death in the world. Stroke is the major factor affecting this group worldwide [2], while 60% of stroke survivors often develop long-lasting disabilities that affect their social and economic lives. Depending on the severity of the stroke, patients experience various disabilities such as motor, sensory, and cognitive disability. Most of the patients' impairment of the upper limb motor function extends gradually [3–7]. In addition to stroke patients, those patients with dislocation or fractures also develop impaired upper limb motor function. Studies conducted by the US Emergency Department in 2009 indicated that the incidence of upper limb injuries is about 1130 cases of upper limb Injury per 100,000 persons per year [8]. Most of these patients experience a decrease in the range of motion or a reduction in muscle strength in shoulder joints (Hemiplegia).
The shoulder is one of the upper limbs that biomechanically affects the movement of the hand as the main upper limb; therefore, impaired shoulder movement makes daily activities difficult for the injured person, and it may cause depression in these patients [8, 9]. One of the challenges in the rehabilitation of patients with movement restriction is upper extremity interventions. Exercises that are voluntary task-oriented and high intensity, as well as functional and repetitive exercises, have been shown to play an effective role in improving upper extremity function, even in the chronic stages of stroke [10]. In doing daily activities, many movements coincide by engaging different senses; therefore, exercises that simultaneously target all these senses are closer to the reality of life and have a more significant impact on improving patient performance and saving time [10, 11].

Many patients complain about being tired of doing long-term traditional rehabilitation exercises, and their motivation to continue rehabilitation work is reduced due to uniformity of training; as a result, they leave the training after a short time [12, 13]. One of the best solutions to overcome this problem in rehabilitation is to use Virtual Reality (VR) to increase the patient’s motivation to practice and repeat it over the long term [12–14]. VR is a simulated environment that simulates reality using two-dimensional or three-dimensional visual effects, but it lacks physical materiality. In fact, the individuals interact with the simulated environment derived from the real world [15]. VR and video games are relatively new therapies in rehabilitation. The benefits of this approach include offering targeted, repetitive assignments as well as providing the opportunity to perform exercises that clinical environments lack [14–16]. Also, VR programs are often designed to be more fun and enjoyable than traditional rehabilitation exercises. As a result, the patient is encouraged to repeat the exercise, and on the other hand, the feedback from the VR exercise is much higher than the routine exercise. In the VR method, changing different training factors such as speed, accuracy, pattern, and other factors can be done precisely at a small cost [14, 17, 18]. Patients, who have reduced joint range motion or decreased muscle strength in shoulder and elbow joints, can use a Mechanotherapy device called Shoulder Wheel System (SWS) to establish the range of motion or improve strength. However, the problem of rehabilitation with the shoulder wheel device is a decrease in motivation to perform rehabilitation exercises. Subsequently, the effects of exercise on the patients are decreased due to the mentioned problems [19].

This study aimed to provide a rehabilitation system based on VR to increase patient’s time of active rehabilitation (motivated rehabilitation) at each rehabilitation session and clinical parameters such as range of motion and functional reaction rate.

2. Material And Methods

In this study, a VR environment is designed and implemented to rehabilitate people with limited shoulder and elbow movements. It is expected that this designed environment motivates motivated patients to improve the quality of rehabilitation. Accordingly, it has been tried in this rehabilitation system to give visual and auditory patient feedbacks on changing various situations to perform a more natural pattern of training and to develop more proper neuroplasticity in the brain. The block diagram of the research steps is shown in Fig. 1.
2.1. Participants

In this study, 30 stroke patients were selected from occupational therapy clinics and rehabilitation centers of Tehran province, provided that they had FMA criteria and upper limb evaluation tests in the same range with at least six months have passed from their stroke (two groups of 15 subjects including a control group with a mean age of 49 ± 10 and an intervention group with a mean age of 48 ± 11). Patients could sit independently on the chair for at least 60 minutes to ensure adequate body stability as well as the cognitive ability (score above 22 on the Mini-Mental Status Examination test) [20]. It is important to note that during the research design, all patients followed their routine treatment plans. The study protocol was approved by the Ethics Committee of Kermanshah University of Medical Sciences (IR.KUMS.REC.1398.497). Consents were obtained from patients, and they were free to withdraw from the study at any time. Patients had no neurological disorders other than the stroke disease. In addition to examinations performed by neurology and rehabilitation specialists, patients were physically and psychologically examined by a physician before each rehabilitation appointment at the treatment center. After being approved by a physician, the procedure started.

2.2. SWS Combined with VR

The SWS is one of the most important tools for shoulder rehabilitation, and it can be used to stretch the vertebral column, lower limb stretching, inward and outward arm rotation to lift the arm (such as eating), and flexion and extension of the elbow. This device has one degree of freedom that can rotate in clockwise and counterclockwise directions. However, the problem with these rehabilitation devices is the frustrating environment and lack of patient's functional parameters monitoring. One solution to address these problems is to combine the devices with VR. For this reason, VR can be used to motivate and encourage the patient to perform shoulder and elbow joint movements during rehabilitation exercises; hence, integrated Hardware and software was implemented and designed.

2.2.1. Hardware

VR-game based system was implemented in PC-based for clinic use and phone-based for home rehabilitation. Details of the apparatus used in the PC version are shown in Fig. 2. The SWS is made of a 70-centimeter diameter steel wheel that rotates easily around an axis to provide a wide range of circular motions from 0 to 360 degrees. The SWS height is adjustable up to 30 centimeters and can be used by different users. The SWS shaft is connected to a holder box where the optical encoder (Autonics Rotary Encoder EP50S8-1024-2F-N-5) 70-centimeter diameter mounted [21]. The encoder can transfer SWS rotational angles with high resolution to the Arduino Mega 2560 microprocessor. The microprocessor operating voltage (5 v) is provided by a Universal Serial Bus (USB) cable connected to a PC [22]. Angle, angular velocity, and acceleration are digitized and transferred to the PC as game inputs for boat trajectory. Finally, the game is displayed on a head-mounted display (HMD) (Oculus Rift Development Kit 2 (DK2)) that connects to a computer and creates a high-quality immersive VR experience for users. The therapist can also monitor the rehabilitation process and the game that is displayed simultaneously[23].
Using SWS is essential at home for patients who need more practice. Hence, a low-cost system (phone version) was developed (Fig. 3). In this system, processed data are transferred from the microprocessor to the smartphone by a USB connector (through a USB On-The-Go). The smartphone attaches to Gear VR (Samsung) and creates suitable VR [24]. For immersive VR, the head was tracked by the phone magnetometer and gyroscope. It should be noted that the experimental setup and test protocol were carried out according to a PC-based version, and the phone-based version was only implemented for home-based rehabilitation feasibility and future studies.

2.2.2. Software

The VR-based game is used in this study as a navigation system that creates an immersive game for patients. Game space was designed by Unity3D (Unity Technologies) under expert rehabilitation opinion with the shoulder recovery goal. Since the shoulder wheel is similar to the boat wheel, the game engages patients to imagine that they are boat captains and should steer the boat. Playing with 360-degree view experience helps the patients to interact with an immersive virtual-game environment, so they incline to respond realistically to virtual sailing. To navigate and direct the boat, a C# program was written as an interface between the SWS and game engine by input data obtained from the microprocessor. In addition, the game engine has the Unity Core Assets that includes the scripts, plugins, and prefabs.

In this study, the main simulated virtual objects include the boat, boat wheel, river, shore, and gems. The player acts as a boat captain and should direct his boat precisely in the winding river by the shoulder wheel. The boat should be conducted to the gem target (Fig. 4a) and also should not collide with the shore (Fig. 4b). The boat moves to the left (counterclockwise) or right (clockwise) based on the hand position, quantified by the setting in the scripts. For more correspondence between virtual scene and reality, the boat steering wheel rotates to correspond to the same angle that the user rotates the shoulder wheel device.

The game score is the primary metric that shows the patient’s performance. The overall score is dependent on positive and negative scores, while gem obtaining increases the score and the boat collision decreases its proportion. Smiley face, scores, the number of archived gems, and the number of collisions corresponding to the patient's performance are displayed as visual feedback. When the patient obtains gems, the desired sound is played as positive auditory feedback. But, when the boat collides with the shore, the undesired sound is played as negative auditory feedback.

A secondary metric, which is obtained for aiding performance interpretation, is movement efficiency. This is the ratio of the perfect boat movement distance (the distance that the boat will be moved if the same number of gems is obtained using ideal straight lines) over the actual boat movement distance (the actual distance traveled by each patient obtaining the respective number of gems).

The level of the game gradually becomes more difficult. If the user completes the path and reaches the appropriate score, he can go to the next level in the next session. On a new level, the player tackles a more winding road, and the speed of the game increases.
The graphical result-performance metrics-displays the patients' actual performance at the end of the game. In the next session, the performance meter is compared to the previous sessions to notify the patients how they have improved exactly. Furthermore, the patients’ database includes all exercise data stored on the computer for later examination and analysis. Also, patients can easily work with the game software after several times of pragmatical training.

2.3. Test Protocol

In this single-blind clinical trial, the effect of the combination of two methods of VR technology and motion therapy techniques for improving upper extremity functionality in stroke patients was investigated. After screening and obtaining patient consent, two initial evaluation appointments were conducted within one week. After the second appointment, patients were randomly divided into two groups: motor rehabilitation combined with VR and traditional motor training rehabilitation. Patients were randomized by SPSS software.

The first group (control group) received conventional upper extremity rehabilitation for stroke patients who needed shoulder and elbow rehabilitation. Conventional rehabilitation means hybrid upper limb functional patterns, scapular, elbow, forearm, wrist, and finger mobility, and slow muscle stretching. The purpose of these exercises is to strengthen weak muscles of the shoulder and elbow in balanced or unbalanced weights to increase joint mobility, relieve muscle power imbalance, gain control of a transverse limb, reduce muscle stiffness, and gain a complete range of motion. Shoulder exercises with SWS without VR were performed for maximally 60 minutes by these patients in that way. To test and evaluate the true effect of using VR-based shoulder and elbow rehabilitation exercises, patients in the first group practiced SWS therapy without using an HMD for maximally 60 minutes, three times a week, and 12 appointments, and functional physiotherapy was performed.

Patients in the second group (VR group) were treated with SWS exercises combined with VR with the purpose of internal neural stimulation performed by the patients after control of the internal nervous system. The main focus was on the shoulder and elbow joints to improve the function of the arms. Rehabilitation exercises were performed for a maximum of 60 minutes, three times a week, and 12 appointments.

The patient’s data were recorded to use in analyses and evaluations. Patients were given 3–5 minutes to learn how to operate the machine at the beginning of the session, and exercises were carried out to ensure that they learned it. Patients were seated in front of the SWS while the game was displayed on HMD (Fig. 5).

2.4. Evaluation

In addition to recording the time of training, both groups were given questionnaires for rating patients' satisfaction with the exercises at the end of rehabilitation sessions. In this study, we used the Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT) to evaluate the motor function of the shoulder and elbow of stroke patients. The mean value of two repeated measurements was adopted for data
analysis. All evaluations were made three times with an interval of 15 days during one month by the same evaluator therapist, who was blinded to the treatment groups. This study was intervened by one evaluator therapist to enhance objectivity. The occupational therapist had 8 years of clinical experience, and he had completed rehabilitation education at Tehran University of Sciences, Iran.

2.4.1. Clinical Evaluation

Based on the Brunnstrom approach and stages of motor recovery, the FMA is used by many researchers and therapists to assess changes in post-stroke motor injury, even when not using the Brunnstrom approach for treatment [25–27]. Test items consist of 50 moves in 6 levels of improvement that include 33 upper extremity items in the shoulder, elbow, forearm, wrist, and hand. Each item is scored in a 0–2 range (0: if a patient cannot do the movements, 1: if a patient does the movements incompletely, 2: if a patient does the movements completely). The total score for the upper limb is 66 [28]. In this study, FMA clinical evaluations of patients were performed three times with an interval of 15 days during one month by the same evaluator therapist, who was blinded to the treatment groups. Finally, FMA results were compared between the two groups.

ARAT: An observation that is used to evaluate upper extremity function following cortical injury and consists of 4 subgroups; 1. grasp, 2. grip, 3. pinch, and 4. gross movement. It contains 19 items sorted by difficulty. Each item is scored in the range of 0–3 with a total score of 57 [29]. In this study, the patients’ clinical evaluations ARAT were performed three times during 15 days. Finally, the results of clinical evaluation ARAT were compared between the two groups [28–32] (Fig. 6)

To measure torque, the patient extended his arm from the end of hyperadduction (0°) and swiftly rotated 180° to maximal shoulder hyperabduction (Fig. 7) while grasping the shoulder wheel holder. At the same time, upper limb torque was measured against the shoulder and elbow fast movements by the sensor connected to SWS. In this study, the patients’ evaluation of the functional torque was performed three times with intervals of 15 days. Finally, the results of torque were evaluated between the two groups.

To evaluate patients’ reaction rate after completing rehabilitation exercises in both groups, the response rate test was presented to each patient in 20 randomized motion pictures with two rest times (each time two seconds rest) (Fig. 8). The time difference between the beginning and the end of the test session was measured by the patient's total movement time. Finally, this time difference for exercise was evaluated and compared between the two groups. This time was inversely related to the individual’s reaction rate.

2.4.2. Questionnaire

The Specific stroke patient satisfaction assessment questionnaire from the game has 30 questions in five separate dimensions, including 1. Usability (8 questions), 2. Game validity (8 questions), 3. Positive sense (6 questions), 4. Game graphics (4 questions), 5. The motivation for the exercises (4 questions). The test-retest method was used to determine awareness and quality of life data gathering tool reliability. Thus, tools were completed in two stages, with a 15-day interval, for 10 independent individuals of the
units under study. The reliability of the knowledge assessment tools with an emphasis on internal consistency resulted in the Cronbach's alpha coefficient of 88%. To evaluate game satisfaction tool reliability using Pearson's correlation coefficient, reliability was calculated in the usability dimension of 95%, game realism dimension of 98%, game positive-sense of 85%, overall game graphic of 91%, and motivation for the computation exercises of 92%. The validity and reliability of the questionnaire were evaluated and approved by medical and computer engineers, rehabilitation specialist, and physiotherapists from Kermanshah University of Medical Sciences and Tehran University of Medical Sciences.

2.5. Statistical Analysis

Statistical analysis was performed using SPSS-16 by a statistician unaware of the study. Data analysis by the Shapiro-Wilk test indicated the normal distribution of information, and therefore parametric tests were used to analyze the data [33]. One-way analysis of variance was used to determine the difference between two baseline assessment sessions before the start of training in both groups and to examine the similarity of groups according to age and baseline assessment results. An independent t-test was used to evaluate the difference between the two groups. To determine the effect of the intervention, analysis of variance with the repeated measurement with 2 groups and 3 evaluation sessions was used at the end of each treatment session. All results were analyzed at a 5% significance level.

3. Results

This study aimed to determine the effect of rehabilitation exercises with SWS on virtual environments on shoulder and elbow in stroke patients. ARTA and FMA upper limb evaluation test values were 39 ± 11 and 50 ± 5, respectively. After data analysis, it was found that there was no statistically significant difference between the two initial evaluation sessions. Also, there was no statistically significant difference between the two groups in the initial evaluation session. This was indicative of the suitability of the randomization of samples (p = 0.380).

At the end of the rehabilitation exercise, a comparison of results showed that the difference between the FMA after exercise in control and intervention groups was statistically significant (p = 0.037). Also, changes in this parameter between control and VR intervention groups during the post-rehabilitation exercise session were significant compared to the rehabilitation exercise pre-session (p = 0.041) (Fig. 9).

At the end of the rehabilitation exercise, a comparison of findings showed that there was not a statistically significant difference between the results of the ARAT post-exercise test of the control and intervention groups (p = 0.073). But changes in this parameter between control and VR intervention groups during post-rehabilitation exercise were significant compared to the rehabilitation exercise pre-session (p = 0.026) (Fig. 10).

At the end of the rehabilitation exercise, a comparison of results showed that shoulder and elbow torque was significantly higher in control and intervention groups (p = 0.032). Also, changes in this parameter
between control and VR intervention groups during post-rehabilitation exercise were significant compared to the rehabilitation exercise pre-session (p = 0.045) (Fig. 11).

At the end of the rehabilitation exercise, a comparison of results showed that the reaction rate test after exercise in control and intervention groups in the last assessment was statistically significant (p = 0.049) (Fig. 12).

In this study, a quasi-experimental group study was performed to evaluate patients' satisfaction with the rehabilitation system. The study population consisted of 15 patients with stroke who participated in rehabilitation exercises based on VR. Data collection tools included the stroke patient satisfaction questionnaire and system performance questionnaire, and results indicated that participants were more satisfied with the rehabilitation system based on VR (scale mean > 73).

### 4. Discussion

VR technology has shown high efficacy as a novel strategy for training and evaluation of motor rehabilitation exercises in patients with a motor disability such as stroke [16, 20]. Results showed improvement in rehabilitation performance and more effective rehabilitation exercises using VR in shoulder and elbow rehabilitation. The quality of exercises in the VR group combined with results of patients' reaction rate test, torque, and FMA was significantly higher compared to usual rehabilitation.

Given that one of the most important factors in rehabilitation exercises and daily routine of life is the individual's reaction rate [30, 31, 34], the effects of VR on this factor were investigated in this study. People who used VR for rehabilitation had a higher response rate than the group without VR (Fig. 12). This significant difference was due to elements designed in the game so that patients were able to increase the speed of decision making and reaction during rehabilitation exercises to complete the steps, which is in line with the results of previous studies [35]. Torque was evaluated using the designed tests in both groups and was improved in both groups, but in the VR group, this increase was significantly different from the traditional rehabilitation group (Fig. 11). This difference could be attributed to the VR system used in this study, a comprehensive computer assessment and training system with electronic software and Hardware for active shoulder and elbow range of motion exercises. This system enhances motivation, acceptance, and endurance of tough, tiring, and repetitive exercises via fun and interesting games. Therefore, it increases torque values for the upper limb. This result is in line with the results of previous studies [36]. The FMA after rehabilitation showed a significant improvement in both groups, but improvement in the VR group was significantly (p < 0.05) higher compared to the normal group (Fig. 9). This is due to motor learning and retraining combined with repetitive functional activity training in both environmental and physical conditions. The FMA parameter increases with appropriate feedback. The present system causes motor learning and retraining by integrating the positive effects of repetitive practice, observation movement, mental imagery, and imitation. The findings of this study were in line with previous studies [37]. It is suggested to use evaluation devices such as functional Magnetic Resonance Imaging (fMRI) to examine brain function enhancement in stroke patients who use wrist or
shoulder rehabilitation tools [38]. In addition to further assessment, a greater understanding of active brain mechanism in learning rehabilitation exercises associated with a virtual environment and central nervous system plasticity improvements will be evaluated.

ARAT results showed a relative improvement in both groups but no significant difference (p > 0.05) between the two groups (Fig. 10). One of the reasons for not being significant was probably insufficient exercise intensity and repeated exercises. This is a limitation of the present plan according to participants' conditions, which requires the duration of more than 3 months for rehabilitation and evaluation of patients. If rehabilitation training was performed in the early stages of stroke, the SWS combined with the virtual environment would have a greater impact on performance evaluation testing because of early brain regeneration. However, implementation of this sort of study was not possible due to ethical considerations and the rehabilitation golden period. Other reasons for this result may be related to the nature of the SWS as it involves the shoulder, elbow, and partially wrist joints, while most of the effective parameters in clinical evaluation tests assess wrist and finger functionality.

Results of this study can be improved by performing repetitive and voluntary exercises with SWS combined with a virtual environment that can lead to changes in motor patterns in the neuromotor system and decreased spastic activity (cramps and pain) through receiving visual feedback on correct movements, imitation learning, observational learning, trial and error, in-brain self-organization improvement, and ultimately reinforced learning. It seems that practicing SWS combined with a virtual environment and following the effects of these stimulations with voluntary training can support the hypothesis of strengthening and prolonging the immediate effects of the SWS together with the virtual environment with therapeutic practice help. Learning occurs after frequent repetitions and can lead to neuronal changes, including increased nerve branching in the muscle, functional synaptic and anatomic changes such as increased number of synapses and altered synaptic connections such as increased neurotransmitters in nerve and muscle connective joints, neurotransmitter relay, and neurotransmitter receptors in muscle membrane enhancement [39]. Increased skill and learning can be due to increased frequency of motor units, increased firing rate synchronization, increased motor firing rates, and decreased central nervous system (CNS) inhibitory effects. The result of these changes is the development of neuromuscular plasticity to increase muscle function. In fact, enhancing the received messages from shoulder joints receptors can improve deafferentation, inverse nerve improvement, and enhancement of the Renshaw cells function. Also, muscle spindle activity adjustment, reciprocal inhibition mechanism enhancement, and Gamma Bias (GABA) (γ-Aminobutyric acid) improvement lead to abnormal coordination, tone control, and regulation of muscle rigidity [39]. Increased synaptic transmission and Renshaw cell inhibition can lead to the elimination of inappropriate time and place misconceptions during repetitive SWS exercises combined with the virtual environment and motor learning in the cerebellum, leading to asynchronous muscle synergies activation and reduced muscle contraction. It is possible that the facilitation of motor pathways by stimulating the limbic system to do voluntary movement while working with the SWS combined with the virtual environment and exercise training improves joint stiffness [40–43]. Visual feedback and excitement for voluntary movement after a period of training with SWS combined with the virtual environment results in greater electrical activity in
the brain cortex and, as a result, greater motor units mobilization, nerve impulse transmission facilitation, neurotransmitter relay enhancement, improved neuromuscular synapses functionality, all of which consequently improve muscle utilization [39, 40]. Reducing the time required for achieving ability, which is a crucial factor in reducing the cost of treating patients after a stroke, is one of the reasons that reduce the duration of rehabilitation. Patient's motivation to perform quality rehabilitation, utilizing the attractions of VR, and visual feedback of patient's actions reduce the duration of rehabilitation compared to normal rehabilitation. In designing and building a rehabilitation system enabling a person to perform home rehabilitation exercises, the ability to install and practice with this system at home and simultaneously observe individual exercises by the clinic and therapist was taken into consideration, to the extent of the financial and rehabilitation costs and time. One of the limitations of this study was doing these in-house rehabilitation exercises with this designed system by patients, which is not possible for all patients due to not having high-speed internet access in Iran. If this problem is solved, further research can be done to accelerate decision making and patient response. Targeted VR games can also be designed for in-home rehabilitation and remote control by a physiotherapist depending on the severity of the complication.

5. Conclusion

A VR-based rehabilitation system for elbow and shoulder organs was designed and developed under clinical guidelines for the application of motor rehabilitation and cognitive science in this study. The present system was developed from SWS and VR combination in order to let patients in need of rehabilitation be treated in a safe environment, and perform repetitive and boring exercises with greater motivation compared with traditional methods. This system can provide accurate feedback to a physiotherapist on the performance of patients, and the therapist can prescribe and apply treatment based on the feedback. Results recorded by the system can be used in future clinical rehabilitation research. The existing system can provide visual feedback commensurate for the patient with their performance, and this neurofeedback improves patient rehabilitation performance in accordance with the principle of self-regulation.

The effect of the designed system in the present study on improving patient function as well as its feasibility in stroke patients was studied. Results indicate that VR-based rehabilitation systems are useful for patients in need of rehabilitation, although further research is needed. It is suggested that the procedure applied in this study be used to integrate conventional rehabilitation devices for other organs such as hands, feet, and neck with VR in future studies. The authors hope that the proposed system will become popular as a rehabilitation tool in clinical settings.

Declarations

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**Conflicts of interest**

The authors declare no conflict of interest.

**Authors' contributions**

All authors participated in the acquisition of data and revision of the manuscript. All authors determined the design, interpreted the data, and drafted the manuscript. All authors read and gave final approval for the version submitted for publication. Data available on request from the authors.

**References**


Figures

Figure 1

The block diagram of the proposed method for active rehabilitation training in stroke patients.
Figure 2

HCI; a) schematic of a human-computer collaborative of the SWS. b) Modules and components of the experimental setup (PC-based version). 1) HMD, 2) shoulder wheel device, 3) microprocessor, 4) PC, 5) LCD monitor, 6) rotary encoder.
Schematic of phone-based version for home-based shoulder rehabilitation. 1) Samsung gear VR headset, 2) shoulder wheel device, 3) microprocessor, 4) phone, 5) rotary encoder

Figure 3
Figure 4

Screenshot of the game environment. a) the boat seen in the middle of the screen is piloted on the winding river, which is constrained. Rotation of the SWS leads to rotating the boat steering wheel in the game. For steering the boat to move toward the target (gem), the right and left direction corresponds to the clockwise and counterclockwise movement of the wheel. The score (obtained gems), the number of collisions (colliding with obstacles), and smiley face feedback, which reflected captain action, are displayed as feedback. b) boat collision with an obstacle; exercise time, boat steering wheel, and setting are presented.
Figure 5

Displaying setup of VR games for stroke patients; The participants performed rehabilitation exercises with the SWS in the form of VR game, and the therapist could control the game and the rehabilitation process concurrently.
Figure 6

The materials include wooden blocks in various sizes, cricket ball, sharpening stone, alloy tubes, washer and bolt, 2 glasses, sharpening stone, marbles, and bearing balls is used for FMA and ARAT.
Figure 7

Torque assessment, The patient should move the shoulder while grasping the shoulder wheel holder from the maximum hyperadduction position (1) to the maximum hyperabduction position (2), and the torque sensor recorded the torque value ($\tau$) simultaneously.
Figure 8

A schematic illustration of the upper limb movement tasks for reaction speed test. a) Schematic of the orientation of shoulder wheel device corresponds to angles (0, 90, 180, and 270 degrees) which are requested from the patient how the upper limb moves in different directions: b) motion sequence (blue, green, yellow, and red denote shoulder wheel device position in 0, 90, 180, and 270 degrees, respectively; white denotes rest) includes 20 randomized movements with two rest times c) Schematic of what is displayed on the screen to be accomplished by the patient. After time start, the patient should rapidly rotate the shoulder wheel device according to what is displayed on the screen (right (0), left (180), upper (90), and lower (270) directions). After achieving the angle displayed, the next requested motion is shown on the screen till the twentieth motion.
Figure 9

Change in FMA at two post-treatment assessments from baseline for the control and VR groups (p<0.05).
Figure 10

Change in ARAT at two post-treatment assessments from baseline for the control and VR groups (p>0.05).
Figure 11

Change in torque at two post-treatment assessments from baseline for the control and VR groups (p<0.05).
Figure 12

Reaction rate test after exercise for the control and VR groups (without considering rest times) (p<0.05).