Move-IT: A Virtual Reality Game for Upper Limb Stroke Rehabilitation Patients

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Abstract. Stroke rehabilitation plays an important role in recovering the lifestyle of stroke survivors. Although existing research proved the effectiveness and engagement of Non-immersive Virtual Reality (VR) based rehabilitation systems, however, limited research is available on the applicability of fully immersive VR-based rehabilitation systems. In this paper, we present the development and evaluation of “Move-IT” game designed for domestic upper limb stroke patients. The game incorporates the use of Oculus Rift Head Mounted Display (HMD) and the Leap Motion hand tracker. A user study of five upper limb stroke patients was performed to evaluate the application. The results showed that the participants were pleased with the system, enjoyed the game and found it was exciting and easy to play. Moreover, all the participants agreed that the game was very motivating to perform rehabilitation exercises.

Keywords: Virtual Reality ⋅ Serious game ⋅ Rehabilitation ⋅ Stroke ⋅ Upper limb ⋅ Fully immersive ⋅ Head Mounted Display

1 Introduction

Stroke or brain attack is a disease that occurs when a blood stream or part of the brain is ruptured or blocked by a blood clot [1]. At the point when this happens, brain cells are left without oxygen and will start to die within minutes. Once the cells cannot work, the part of the body they control cannot work either, which can make daily activities difficult to stroke survivors [2]. Technically speaking, the affected side of the brain determines the affected area of the body, for example, when the stroke occurs in the right part of the brain, the left part of the body will be affected and vice versa. Moreover, when the stroke occurs in the lower part of the brain, the damage of the body will be greater [3]. Furthermore, stroke disease is classified as the third cause of death in the world after heart and cancer diseases [4].

According to the World Health Organization, there are 15 million people who suffer from stroke worldwide each year [5]. About 5 million of these people die, while 5 million become permanently disabled. Nation wise, statistics indicate that more than 100 strokes occur daily in the Kingdom of Saudi Arabia [6]. Many experts expect that the
rate of stroke will rapidly grow as a result of the increasing population ages, occurrence of high blood pressure, number of smokers, incidence of diabetes and obesity [7].

There are four types of stroke treatment: prevention therapy, medical treatments, surgical treatment, and physical therapy (Rehabilitation) [4]. Stroke rehabilitation is a post stroke treatment that helps stroke survivors to become as independent as possible and have a better control of their life. According to Gunasekera and Bendall [8] Rehabilitation is defined as “a dynamic process of planned adaptive change in lifestyle in response to unplanned change imposed on the individual by disease or traumatic incident”.

Rehabilitation helps patients to relearn basic skills such as eating, dressing, and walking, which were lost due to the damage of stroke. Rehabilitation is generally performed in hospitals in the early stages after stroke [9]. As the treatment advances, patients often need to go to specialized units for a supervised outpatient therapy. Finally, the last stage consists of home-based programs that may involve the professionals’ visits in order to permit the patient to develop his/her skills in home environment.

The tests of rehabilitation programs proven that the patient’s function recovers by performing a series of repeated exercises identified with a certain goal [10]. There are several typical movements practiced in upper limb rehabilitation following stroke, which are usually relevant to daily life [2] such as: reach towards object, grasp object, manipulate object, release object, and single handed and bimanual tasks. Nonetheless, this treatment approach suffers from the absence of patient motivation for performing several repetitive tasks at regular intervals. Moreover, health care providers need to ensure that this treatment program is completed by outpatients. Therefore, the focus of recent research has been on Virtual Reality (VR) based rehabilitation systems, as they were proven to be much effective and engaging than conventional rehabilitation therapy. However, most of these systems are non-immersive.

A recent Cochrane review [11], looking at using VR in stroke rehabilitation, showed growing evidence on the benefits of VR and interactive video gaming on improving upper limb function and activities of daily living function when used as an adjunct to the usual rehabilitation program. However, the clinical trials that are so far available did not have sufficient power to reach a conclusion on the effectiveness of VR on upper limb performance among people with stroke [9]. The lack of sufficient evidence warrants more research on this area. Therefore, our contribution in this paper contains two parts as an extension of our published work in [12]:

1- Present the development of Move-IT game, which is fully immersive VR game designed for stroke upper limb rehabilitation exercises.
2- Evaluate the game feasibility and usability via interviews and observation during test sessions.

The rest of the paper is organized as follows: Sect. 2 illustrates Move-IT game design and implementation. Section 3 reports the evaluation of Move-IT game, and finally. Section 4 concludes the paper with the game limitations and future work.
2 Move-IT Game Design and Implementation

Move-IT game is a fully immersive VR game, which is especially designed for stroke upper limb rehabilitation exercises. The patient needs to perform several arm rehabilitation movements in order to complete the game. The game incorporates the use of Oculus Rift Head Mounted Display (HMD) and the Leap Motion hand tracker. It was developed using the following tools: Unity game engine, Oculus SDK, and Leap Motion SDK.

The story of the game is very simple. It is about a regular person who needs to move some colored cubes arranged in a certain order on a shelf and place them into their boxes next to him. There will be two different colors of cubes and a box for each color. These boxes are located in the right and left side of the user. The user is required to move the cube to the box of the same color (as shown in Fig. 1). Moreover, the game can be played either seated or standing to allow stroke patients who need support or who are unable to stand to use the game. In addition, Move-IT game includes one option, which allows the user to restrict using one hand to achieve the game tasks or using both. The default option is using both hands.

![Fig. 1. (left): A Player hand grasping a cube; (right) The environment set-up with a patient](image)

The main user interface of our game module is comprised of four main options:

1. Warm up exercise option that enables the patient to warm up before starting the game.
2. Rehabilitation game option that allows the patient to perform the rehabilitation exercise in an engaging form.
3. Training option that enables the user to try and play the game without any constraints such as time or score.
4. Non-immersive game option that enables the patient to play game without the HMD.
To set an appropriate level of challenge, the game provides users with a variety of difficulty levels that are increased gradually as the user proceed in the game. There are several factors that determine the difficulty of the level. These factors are the number of cubes on the shelf, the arrangement of cubes, and the number and height of the shelves.

There are four different levels of difficulty offered in the game to maintain the user’s engagement and to suit a verity of upper limb stroke patients with different severities. The game mainly focuses on the user’s upper extremity movements, and requires the patient to perform numerous arm rehabilitation movements. These movements are shoulder flexion to 90° and 120° to reach the cubes on the shelves, shoulder extension, abduction and adduction to move the cubes into the boxes on the right and left sides, hand extension, grasp and release. Moreover, these shoulder movements include implicitly the elbow flexion and extension. These movements are described by images in Table 1.

| Movement                        | Image |
|---------------------------------|-------|
| Shoulder flexion and extension  | ![Shoulder Flexion and Extension](image1.png) |
| Shoulder abduction and adduction| ![Shoulder Abduction and Adduction](image2.png) |
| Elbow flexion and extension     | ![Elbow Flexion and Extension](image3.png) |
The movements included in the game were provided by the occupational therapists (OTs) and physical therapists (PTs) of Sultan Bin Abdulaziz Humanitarian City (SBAHC) and King Fahad Medical Center (KFMC).

There were multiple visits to both centers. The first visit included conducting a focus group with a number of specialists from both centers where several questions were raised and answered. These questions were about the stroke patient’s characteristics, the processes and approaches of the rehabilitation therapy, the rehabilitation sessions for inpatients and outpatients, the upper limb rehabilitation exercises, the assessment and evaluation outcome measures, and the VR-base rehabilitation game requirements. The focus group lasted for about one hour in each center.

The second visit involved on-site observation of patients, OTs and PTs during the rehabilitation session, which included interviewing the OTs and PTs, as well. This observation lasted for four hours in SBAHC. It was important to gather reliable information, take notes and get a clearer view of what is the actual rehabilitation therapy activities and environment.

Additionally, Move-IT game has a target time duration identified for each level, to assess the suitability of this level to the user. For example, when the user finishes the current game level before the target time, this means that the level is very easy to the user and s/he needs to pass to the next level. While, spending much time to achieve the game’s goal, the game will determine either that this level is suitable to the user and s/he needs to replay it again, or that this level is very hard to the user and s/he needs to be moved to the previous level; depending on the amount of extra time spent. All these decisions are done transparently without the user’s knowledge or disturbance to permit him/her to enjoy the game without frustrations.

The user will earn 50 points for each cube he grasps and placing it in the right box. If the user puts the cube in the wrong box, s/he will not earn any point. These points will be displayed during the game and a total of the points won will be displayed at the end of the game. The user statistics option contains records of the user’s movement data that are presented in a simple way with graphs; hence the patient could easily read and understand.

3 Evaluation

A pilot evaluation was conducted at Sultan Bin Abdulaziz Humanitarian City (SBAHC) in Saudi Arabia; a total of five patients participated in this pilot evaluation. Prior to conducting the evaluation with real stroke patients, several occupational therapists from SBAHC were invited to actually use the game, propose their suggestions and confirm whether the game is ready to be used on real patients. Their main suggestions are summarized in the following points:

- Modifications on the warm-up exercise so that it focuses on the shoulder and elbow exercises only, excluding hand exercises, which are very difficult to stroke patients.
- Adding a training mode to train the patients before trying the game.
- Adding a non-immersive level (using Leap Motion hand tracker only) that is equivalent to the first level of the original game to enable patients to try between immersive and non-immersive game and choose their preference.
Therefore, all these recommendations were implemented and added to the game before conducting our evaluation with the patients.

### 3.1 Environment Set-Up

The evaluation was conducted in a quiet and closed room at SBAHC. The laptop that contains our game is placed at a regular computer desk. The Oculus Rift positional tracker is attached to the top of the laptop’s monitor. The patient sits on a chair facing the laptop while wearing the Oculus Rift HMD with the leap motion attached to it, at a distance of about 80 cm from the positional tracker. Figure 1 (right) shows the environment set-up with a patient. A therapist assistant was present in the room during the evaluation for prompt assistance.

### 3.2 Participants

A sample of five stroke patients was recruited in the study as shown in Table 2. SBAHC Institutional Review Board (IRB) has granted ethical approval and the participants were selected according to the following inclusion criteria, which was determined with the help of SBAHC therapists:

- First episode stroke,
- Need for upper limb rehabilitation,
- Minimum ability to grasp and raise arm to 90° within functional rate,
- Ability to speak and understand,
- Not involved in other study during our study period.

All the five patients were male, 56–61 aged. They were from SBAHC as the evaluation was conducted there. Their muscle power differs from each other; most of them have 3+/5 muscle power, while the other two have 3/5 and 4/5 muscle power. Moreover, none of them has experienced playing video games before except for two patients (P2, P4) who used to be expert gamers in Sony PlayStation. In addition, none of them has tried an HMD, except (P1) who has used it once very shortly, just for watching.

| P# | Gender | Age | Start of stroke | Muscle power | Affected hand | Dominant hand | Gamer | Have used HMD |
|----|--------|-----|-----------------|--------------|---------------|--------------|-------|---------------|
| P1 | Male   | 60  | 2 months        | 3+/5         | Left          | Right        | No    | Once, very shortly |
| P2 | Male   | 58  | 5 years         | 3/5          | Left          | Right        | Yes, daily before stroke (PlayStation) | No |
| P3 | Male   | 56  | 2 months        | 3+/5         | Left          | Right        | No    | No |
| P4 | Male   | 60  | 1 year          | 4/5          | Left          | Right        | Yes, weekly (PlayStation) | No |
| P5 | Male   | 61  | 3 months        | 3+/5         | Right         | Right        | No    | No |
3.3 Method, Results and Discussion

In order to measure the usability of our game, we used quantitative measures to collect performance data such as the time spent on each game level, the number of errors and the number of assistance required to complete the game tasks. In addition, we used qualitative measures to collect preference data such as the participant’s opinion, expectation and experience of the game [14]. On the other hand, the feasibility of the game was measured by the number of patients who was able to complete all the given game sessions without inconvenience or harms.

Once the participant accepts and signs the consent form, a pre-interview was conducted. The goal of this interview is to gather patient’s demographic information such as gender and age, clinical characteristics such as post stroke period and affected side, and his experience with video games and HMDs.

Next, during the test session, we have adopted the observation usability evaluation method to watch the participants while they interact with the game and take notes. The computer screen actions and time spent on each task was recorded.

Participants were asked to complete several tasks in the game. These tasks include:

- Task 1: performing the warm-up exercises,
- Task 2: trying the game in training mode, once the patient is able to grasp one cube and move it to its box successfully he will be moved directly to the real game (task 3).
- Task 3: playing three rounds of the game starting with the first level.
- Task 4: playing one round of our game, which is equivalent to the first level.

All the participants completed the given tasks successfully, except one participant (P1) who could not complete Task 2, which was about trying the game in training mode. From our observation, we found that this patient was not able to achieve any progress in the game because he was not able to control his virtual hands movement correctly. He was only considering his real hands movement and distance from the virtual game objects, which prevented him from reaching and grasping the cubes successfully. Therefore, he was moved directly to Task 4 where it does not require cubes movements. However, this patient declared later that the game is very useful especially for younger ones.

Interestingly, all the patients have earned the maximum score in the completion game levels. However, they varied in the time spent to finish these various levels. Figure 2 shows the time spent on each level for each patient in seconds. It reveals that the best result was achieved by patient (P4) who spent the shortest time in all game levels compared to the other patients. His impressive performance was due to the fact that he was higher functioning and has a video game experience. In addition, we can notice that all patients spent less time on level two than level one. Perhaps, because they learned the game rules from level one and became more skilled in the game. Besides, level two has the same number of cubes and only differs in their placement on the shelf. Moreover, we can notice that all the patients spent more time on the non-immersive level than the other levels, although this level was equivalent to the first and second levels in terms of difficulty. This indicated that the patients struggled in this level more than the other original game levels (the fully-immersive levels).
Figure 3 shows the number of errors and assistance required to complete the game for each patient, which were considerably small. In fact, some patients have not made any error and did not need any assistance. Perhaps, because that the game concept and rules were explained during the tutorial session. Besides, patients were able to try the game first in the training level (Task 2). However, most of the errors were related to grasping the cube correctly. As some patients attempt to grasp the cube while their hand is already closed; they need to open their hand and then grasp it near to the cube, similar to the way objects are grasped in real world.

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After the patients completed the evaluation tasks, we conducted a post-interview to measure the overall impression of Move-IT game. The questions were ranked according to Likert scale, which is based on five scale (5 means strongly agree and 1 indicates strongly disagree) to assess the user experience of Move-IT game, and if they had encountered any difficulties while playing. In the entire evaluation sessions took about 30–45 min for each participant.

Figure 4 illustrates that most patients have enjoyed the game and found it exciting and easy to play. Moreover, all the patients agreed that the game was very motivating to perform the rehabilitation exercises. None felt bored, frustrated or tired except one patient (P1) who felt tired but with joy; because he thinks the more effort the more arm function recovery. In addition, all the patients felt successful after playing the game.

![Figure 4. Questions related to usability of the game](image)

Figure 5 reveals that most patients indicated that the game environment (the living room, game colors, and sound) was comfortable. In fact, some stated that it was encouraging to continue playing and perform the rehabilitation exercises. Additionally,
most of the patients considered using VR technology easy, except one patient (P1) who could not complete the fully immersive levels. All the patients agreed that the warm-up exercises and the game tutorial were clear and well described. Finally, they all indicated that the game could support rehabilitation. Actually, one patient has pointed that it can support any arm exercise in general not only rehabilitation exercises.

Moreover, we asked the patients what they enjoy and prefer more: the fully immersive or the non-immersive version of the game. Remarkably, 80% of them stated that the fully immersive version was more exciting, the game objects are bigger and the virtual hand movements were more reasonable and easier to control. Surprisingly, one of them played the fully immersive levels without wearing his medical glasses and still preferred it over playing the non-immersive level with his glasses on. This could be possibly because the games’ objects were big enough and have colors which standout from the rest of the game environment.

Furthermore, we have also asked them whether they prefer our game or the other conventional rehabilitation games. 60% of them chose the conventional games because they prefer dealing with solid objects that can be touched physically. Besides, these games were easier to set-up. Additionally, 80% of them would like to use the VR game again and recommend it to others. None of the patients have faced any issues during the game sessions expect one patient (P1), who had a slight headache at the beginning of the training level for a short period of time.

Also, patients were asked to give their suggestions and recommendations to improve the game. Most of them gave the same suggestion, which is adding more set of games to increase diversity and prevent getting bored. Finally, our game was found to be feasible for most of stroke patients. As 80% of the patients were able to complete all the given game levels easily and shortly without taking breaks between them.

From the previous results, we can confirm that a well-designed fully immersive VR-based rehabilitation system can provide a higher sense of amusement and inspiration to stroke patients than non-immersive VR-based rehabilitation systems. Moreover, it was proven to be usable and feasible to stroke patients with medium and high arm functional abilities. Nevertheless, most of the stroke patients still prefer the traditional rehabilitation games for the reason that dealing with real physical game objects is more convenient for them. This can be somewhat resolved by incorporating the use of real objects such as game controllers or using haptic gloves.

Furthermore, the system needs to include several set of games in order to maintain the user motivation and enjoyment, cover more rehabilitation exercises, and suit many stroke patients with different severities.

4 Conclusion and Future Work

The lack of patient’s motivation is a serious challenge that faces stroke rehabilitation programs. This project aimed to propose a solution to overcome this issue by introducing a fully immersive VR-based rehabilitation system and assessing its usability and feasibility to determine its applicability to stroke patients and to the stroke rehabilitation process. Our proposed game “Move-IT”, proved to be usable, feasible and safe
rehabilitation tool to enhance arm motor function among patients in various stages of recovery after stroke. It also encouraged and motivated further rehabilitation.

There were some challenges that were related to the VR field such as health side effects of using fully-immersive VR technology, which include dizziness, nausea, headache and eye strain [15]. In our game, we tried to reduce these side effects by implementing the following:

- Reducing the head movements required to achieve the game goals.
- Removing the Head-Up Display (HUD) that was distracting and annoying while using the HMD and placing its elements (game score, timer, and exit button) inside the game world (i.e. on one of the room walls).
- Building a virtual game environment that has correct dimensions and distances that are similar to real world.

Future work will involve adding other set of games to increase diversity and cover all the rehabilitation movements. In addition to recording the patients’ movement data and allowing their therapists to monitor them remotely through developing a portal for the therapists where they can view their patients’ movements data, monitor their progress and receive notifications whenever their patients perform the rehabilitation exercises. Furthermore, clinical pilot study will be conducted to assess the effectiveness of our game.

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