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Supara Grudpan[1,2], Sirprapa Wattanakul[1], Noppon Choosri[1], Patison Palee[1], Noppon Wongta[1], Rainer Malaka[2], and Jakkrit Klaphajone[3]

[1] College of Arts, Media and Technology, Chiang Mai University, Thailand
{sgrudpan,sipraprapa.wk,noppon.c, patison.p,noppon.w}@cmu.ac.th
[2] Digital Media Lab, TZI, University of Bremen, Germany
{sgrudpan,malaka}@tzi.com
[3] Department of Rehabilitation, Faculty of Medicine, Chiang Mai University, Thailand {jakkrit.k}@cmu.ac.th

Abstract. The success of stroke rehabilitation therapy is highly associated with patient cooperation. However, the repetitive nature of conventional therapies can frustrate patients and decrease their discipline in working out the physical therapy program. Serious games have shown promising outcomes when applied to tasks that require human engagement. This research focuses on sharing experiences and lessons learned from designing serious games using VR technology in cooperation with medical experts including rehab physicians, occupational therapists and physiotherapists to identify requirements and to evaluate the game before applying with stroke patients. The game has the objective to create an immersive environment that encourages the patient to exercise for recovery from stroke-induced disabilities. It is delicately designed to fit the stroke sufferers in Thailand, meanwhile, to integrate proper clinical physio therapeutic patterns based on the conventional therapy. Game design challenges for stroke patients and our solutions applied in the games were described. Our results of the preliminary field test revealed positive feedback on enjoyment and game features from physicians and physiotherapists. Finally, technical issues and suggestions for improvement were collected to adjust the game for the clinical trial with stroke patients in the next phase.

Keywords: Serious Games · Virtual Reality · Rehabilitation · Stroke· Participatory Design

1 Introduction

Stroke rehabilitation therapies require patients to train muscles for which the control chain downwards from the brain has been damaged. The therapy is challenged by improper and irregular training from poor patients' engagement [7]. An effective recovery process necessitates patients to cooperate in a training

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program designed by a medical rehabilitation team [9]. The conventional practices of training are often monotonous and can be discouraging resulting in an ineffective outcome. Serious games and gamification have shown promising motivational effects when applied to such tasks that require human engagement [15, 3] especially for personal fitness or exercise applications [10, 11].

In order to develop more effective therapeutic tools in clinical settings, we co-investigated the practical requirements with a clinician team. In this way, we avoid falling into the same pitfalls of impracticality that many existing digital solutions suffer from that lack proper integration of medical expertise [13]. We applied several user research approaches and conducted a number of formative tests throughout this feasibility study to answer substantial questions. The questions that were in the focus include: What are the characteristics of successful serious game platforms that are suitable for the target users? How to transform conventional practice of physical therapy to Natural User Interface (NUI)? And: what are the non- functional requirements and limitations to consider?

2 Related Work

Game-based rehabilitation systems have been used to bring motivation to the patient [2, 10]. The rehabilitation process for stroke patients requires regular practice of exercising the muscles carefully guided by physiotherapists and/or occupational therapists. Moreover, a key factor of stroke recovery is the cooperation of the patient. Frequently, patients lose motivation and discipline to effectively continue the intervention. Game-base rehabilitation systems are tools that motivate patients with more appealing environments and a diversity of fun game elements [7, 10].

Virtual Reality (VR) has been researched to treat patients in neurorehabilitation. The creation of virtual environments for interaction of the patient with an asset similar to real world objects can immerse the patient's attention to virtual activities. Furthermore, the interactive response to their activities via both visual and auditory feedbacks can raise their motivation to achieve the training objectives with additional scores and rewards showing and provoking their progression [20].

VR exergames are a distinct type of games for rehabilitation. Commercial exergame systems such as Nintendo Wii and Xbox Kinect-based systems were studied with stroke patients especially in upper extremity motor training. Saposnik [14] compared the effectiveness of mild-to-moderate upper extremity motor impairment patients performing activities using Wii games and recreational activities such as playing cards, bingo or ball game. The result of motor function improvement measured by Wolf Motor Function Test (WMFT) revealed no significant difference. However, Prachpayont and Teeranet [12] assessed effects of Wii-hab in Hemiplegic stroke patients. They found that the subject should have adequate hand muscle strength to hold the Wii controller. Additionally, the distance between the patient and the monitor screen distracted patient attention from the training.

With Kinect technology (e.g. the Xbox VR system), the tool allows patients to interact and control the game play without holding a controller. An infrared sensor is embedded in the device reflecting limb and the body motion of players' body. The game extends rehabilitation training doses in both duration time and repetitions within a session [1]. Trombetta [19] developed 3D VR-based games in 3rd person perspective using the Kinect for stroke rehabilitation. They were designed to engage players with elements such as movement guiding, score, play status, and stimulating sounds. The display on television and on head-mounted display (HMD) affects the subjects differently. HMDs gained better sensation of immersion with more attentiveness through the game When player wears HMD, he/she can see as if he/she is a 1st person in a closed virtual world. However, this game was visualized in the 3rd person perspective which players needed to adjust the sense of movement when he/she wears the HMD to interact with objects in the game. Moreover, the Kinect sensor cannot well detect the motion of fingers. Hand and finger movements are significant motor functions for human to perform daily activity tasks reflecting recovery in stroke patients.

We considered HMD as an interesting device for user immersion. The user wears it as a goggle displaying VR as if the player was in that virtual world.The technology of Oculus Rift provides both the HMD and Oculus Touch Controller. The Oculus Touch is a hand controller with wristband support, so it is possible to be used by stroke patients who have little grip strength. The hand controller provides haptic sensation which is useful for stroke patients to practice their hand and finger muscles in grabbing, holding and touching an object. The haptic technology in the Oculus Touch stimulates the sense of touching by creating vibration that makes user feel interacted with the game as a direct feedback. The controller can be implemented on both hands which can control and record the information of each hand separately [4]. According to our knowledge, a a comprehensive study of a VR game using commercial haptic controller designed for training the upper limb stroke patients is still lacking.

We applied the aforementioned approach as a framework to develop a system to mimic and enhance the conventional stroke rehabilitation program with for the upper limb motor system for stroke patients. The intervention requires an adjustment on the intensity and specific task under the supervision of a therapist. Both instructors (therapists) and patients were considered as users of the system which was aimed to be user-friendly leading to more engagement.

3 Virtual Reality Based System for Stroke Rehabilitation

3.1 Development Method

We developed a set of tailored games particularly for stroke patients following a participatory design approach. We established a collaboration with a rehabilitation team consisting from the Department of Rehabilitation medicine, Faculty of Medicine, Chiang Mai University who provided the core knowledge of stroke rehabilitation, and contacts to patients, physiotherapists, occupational therapists, physicians and nurses. In the first step, the rehabilitation team demonstrated sessions of stroke rehabilitation intervention in which the development team gained insights into patients' movement in various disability levels and training requirements through the contextual observation.

The main aim of the game was to encourage patients to exercise their muscles in the similar way but with more motivation during the conventional therapy. Concerned with game design and technology, we first chose a gaming platform that is suitable for an exergame employing the control of a character using physical interaction with full body motion game control (Physical User Interface, PUI) rather than standard controllers such as joystick, mouse, or keyboard. The potential platforms were Wii and Kinect. We conducted a field study to generate a Customer Journey Map to visualize the pain point of patients when they are in the cycle of therapy. It was found that the patients typically lose their interest after a short practice and suffering from boresome. To improve the patient experience, we decided to choose the PUI that can integrate the Virtual Reality technology to create the immersive environment. Therefore, we decide to adopt the Oculus Rift and Oculus touch.

The development of our games was initiated by creating throw-away prototypes for testing basic game mechanics and input devices. The games were implemented in an iterative process over a period of 16 months. A number of formative tests were conducted with a rehabilitation team to fine-tune pace and levels of difficulty of the games that matched patients' capability. The summative evaluation was conducted after the first release. Then we recruited rehabilitation residents and staffs as well as physical therapists and other healthcare practitioners (in total 37 participants) to test the game. During the test session, they were asked to think aloud and give feedback after finishing the session.

We finished the development phase by testing the game with volunteer patients. Our first patient that we recruited to test the game was a spinal cord injury patient, not a stroke patient, who had no problem with mobility impairment of the upper limbs at all. We conducted this preliminary test with the aim to see if it was practical to set up and apply the game as an intervention in conjunction with conventional therapy at In-patient Department (IPD). We finally employed a short session test with the stroke patients under the supervision and assistance of the medical rehabilitation team.

3.2 Design Principles

Through the participatory research and experience during the development of our VR Games, the following principles were identified. These principles should be taken into account when designing games for stroke rehabilitation focusing on the upper limb.

Instruction and support system: Abilities and motor skills of stroke patients vary depending on the patient's specific symptoms, state of disease and daily living activities. The level of the game should be suitable for the individual patient's abilities and motor skills. It is important to have instructors who schedule the training program for the patients and to monitor them during play sessions. Thus, the important parameters, which relate to the patient's movement and intensity level of the exercises should be adjustable by the instructor. Examples of adjustable parameters are movement speed, interval and number of obstacles (game level). Additionally, in conventional training, when players feel weary or hardship during the training session, instructors (therapists) persuade patients by giving encouragement. They use cheer up words or compliments such as "good", "a bit more" or "nearly finish" to keep patients performing the tasks through the session. The game should also provide features or support system that allows instructors to conduct the training in a similar approach for encouraging patients.

Appropriate setting of VR device and movements: Using VR devices for exergames for stroke patients requires consideration on the patients' conditions. Thus, designing a game should consider the setting of distance in the simulation and in the real-world to avoid injury to patients while playing games. Feedback of early prototypes showed that the game required players to move their whole body in order to reach the object in the game. This circumstance can impose an injury risk to the patient. Additionally, the way of holding game controller should mimic the gestures in the virtual scenario of the game. Initially, our game prototype was designed to be controlled with one hand, but there were suggestions to use and train both hands of the patients in parallel. Besides, the movement of fingers should be detectable via the control device in order to collect data and evaluate their movements.

Familiarity to the game content: In order to make patients feel immersive in the game, the game should have a theme which the patients are familiar with. Most stroke patients are elderly people which leads to a challenge in designing video game for this target group [17]. The game content should be related to their experiences or daily life. For example, physiotherapists mentioned that "Most Thai elderly patients could not get accustomed to table tennis game (Wii Sport) because they have never played this kind of sports before". Because the game content and game scenario are the elements that are key for motivation and for game selection, we designed our game based on the theme of Thai temple fair atmosphere game. Three games which are well-known activities that can be found in any Thai temple fair are used as scenarios in our mini games.

Encouragement through rewards and positive feedback: A major challenge of conventional physical and occupational therapies is that patients are likely to give up the training when they feel frustrated from a failure to achieve the goal straight away [2, 7]. Rewards and positive feedback are effective game mechanics that are used to motivate players [15]. These elements show the progress of players which can increase their engagement to the games. The game elements such as scoring, showing reward item (e.g. stars) are used to increase motivation and engagement of players. Additionally, the juicy mechanics as effect and sound also help to increase aesthetic and fun of the game [8, 6].

3.3 Implementation

The virtual reality-based system was aimed to be deployed for physicians and physiotherapist at Maharaj Nakorn Chiang Mai Hospital. The games were supposed to be an adjunctive tool to improve effectiveness of upper limb rehabilitation via immersive experience. It was also our goal to develop a software to reduce purchases of expensive software or devices such as Armeo Therapy. The games were implemented using the Unity 3D game engine and could be executed on a PC. The user interacted with a HMD (Oculus Rift) and Touch controller (Oculus Touch controller) that supported touch sensitivity and feedback when grabbing game objects. This seemed to be particularly suitable for movements that required stroke patients to practice using their upper limb muscles.

3.4 Games

According to the design principle mentioned above, we developed three mini-games which are shown in Fig. 2. The games contained features to encourage the patient by immersing the patient in the Thai temple fair atmosphere where they had to make movements to complete the virtual reality game. The games helped patients to train in three patterns of movement identified by rehabilitation team. The first pattern reinforced practicing a reaching-out gesture, which involved movements by the following muscles: Deltoid, Triceps, Biceps, Pectoralis and Serratus anterior muscles through "Ice-cream selling" game (Fig. 1.). The second pattern was arm-sweeping from left and right, which involved the action of the following muscles: Deltoid, Pectoralis, Infraspinatus, Latissimus, Rhomboid and Trapezius through a "Gun shooting" game. The third pattern training is to practice vertical arm movements with the following muscles: Deltoid, Triceps, Trapezius and Serratus anterior through the "Star picking" game. Moreover, in every game, players or patients needed to use their small muscles to trigger picking up virtual objects.

The games were designed to support two types of users which are Player (participants or stroke patients) and Instructor (physiotherapists, occupational therapists or physicians). In the main pages of game, participants were able to select to play one of the three games. Every game allowed instructors to adjust difficulties of the games by going to Game setting menu. The information that instructors needed to give in the setting menu was player's name, time period of game play, number of obstacle items, number of input controller (controlled by one or two hands), and grasping patterns (to hold game controller by middle finger, index finger, and to use both thumb and index finger).

Additionally, the games allowed instructors to encourage and support players during play sessions. The instructor had a keyboard used as separate input from player's game controller. He/ she could send stickers to encourage and use help features for helping players when they were in a difficult situation (Fig.3).

Fig. 1. Examples of player's movement, Left: vertical movement; Right: horizontal movement

Moreover, the instructor had the authority to pause and quit the game anytime in order to avoid injuring or over training patients.

The "Ice-cream selling game" is the first-person game that participants play a role as ice-cream seller.This game encourage reaching out gesture (straighten and pulling movements)in both horizontal and vertical. The player has to make ice-creams by shaking hand ice-cream maker (horizontal) and give the ice-creams to customer(vertical) within the limited time in order to get the score. The sequence of movements that player need to do in play session in order to get the score are as following: 1). To grasp ice-bucket/ holding controller, 2). To shake ice-cream maker until ice-cream ready/ rotating their arm in horizontal ,and 3). To grasp ice-cream from the ice-cream maker to customer/ To press button on hand controller and give to customers who show different color of ice-cream on their face (Fig.2.). The instructor able to adjust the difficulties of the games which depend on frequency of customers and period of time for rotating ice-cream maker.

"Gun shooting game" was a first-person shooting game where players joined shooting booths of a Thai temple festival scenario. This game motivated players to perform arm-sweeping movements from the left and right and vice versa in order to shoot random targets in the game. The movement in this game required players to sweep the arm horizontally to point the gun with the help of a laser beam (Fig.2.). Different scoring with different target characteristics was another game element. To trigger the gun, a player needed to push the button on the hand controller. The difficulties of the game could be adjusted by changing the frequency of target popup, moving speed of the target and the time for reloading bullets.

"Star picking game" was a first-person game where players attended a booth to draw lots and play a customer's role to pick ruffled papers that were made in a star shape. This game encouraged arm-lifting movements involving both upward and downward hand motions mainly in the vertical direction. Players had to move their hand to reach the position of one of selected stars which were hung on the tree (with random appearance). After getting the star, players had to hold pressing the button until the halo surrounding that star disappeared and then could release the button (Fig.2.). The instructor could adjust the level of difficulty in this game by changing three parameters including a force that was used for picking stars, number of stars, and time for holding stars.

Fig. 2. Top left: Selling ice-cream; Top right: Shooting; Bottom left: Picking stars game; Bottom right: Game menu

Fig. 3. Left:Screenshot of help feature in Selling ice-cream game, Right: Controller for instructor

4 Field Study

Once we completed the development of game prototypes, we managed to verify the feasibility of the games for clinical practice with the assessment by stroke rehabilitation experts. We conducted a 2-day workshop with 14 physiotherapists, 7 occupational therapists, 13 rehab physicians and 2 nurses. The participants gained knowledge and experience in the intervention for stroke patients with activity and movement enhancement. During the field study, data were collected using observation and interview methods to acquire feedback for improving the VR game system.

4.1 Setup and Procedure

On the first day, the participants were trained and had a chance to experience the VR technology for stroke therapy. The study of VR technology in medicine was new in Thailand. Some therapists had experienced commercial game systems such as Nintendo Wii and the Xbox 360 Kinect. However, commercial software and tailored software were different in functional and non-functional properties for user experiences. Therefore, an introduction session comprised Virtual Reality in therapeutic aspects, the principles of Gamification, stroke recovery and the tailored program for stroke patients. This session conveyed the understanding of how VR game systems linked to stroke patients' muscle movement and neurological recovery factors. The game mechanics such as scoring, sound and feedback in real time had potential to induce patient's motivation and concentration. In addition, the collected data on duration, repetition, difficulty, movement shape and etc. could be beneficial for therapeutic analysis. In the last session of the day, there was a workshop demonstrating the use of the developed VR game system: VR devices and VR game application which the participants tried out.

On the second day, the participants used the developed VR games and we collected evaluation data by way of observation and participant interviews. We provided the devices including Oculus headset and Oculus touch controller connected to a computer. The game visuals are displayed on both the Oculus headset and a computer screen. Within the interval of 5 minutes, each participant equipped his/her body with the interaction devices and played one game in 3 levels (easy, medium, hard). During the game, an observer monitored the activities of the participant and the play on the computer screen. After the game play, the participant was asked to evaluate the game play. Each participant played all three games (Ice-cream selling, Gun shooting and Star picking games).

4.2 Results and Discussion

Based on the observations and interviews, we collected and analyzed significant points with the medical rehabilitation team. Overall, the game features worked well, and we gained further comments on functional and non-functional issues.

Game functional: The participants confirmed that the main functions of the game suitable for training upper limb muscle for stork patients. We listed the significant suggestions and limitations of the game according to the feedback as follows.

The game setting scale for instructor – in order to adjust the game level to be proper for particular patient's condition, the game provided a user interface such a scale for instructor to adjust game parameters such as the game pace and number of targeted object element, play time, arm reaching distance and the controlling of Oculus Touch con-troller. However, the setting scale range of the prototype was rather limited. Even though some parameters were adjusted to the lowest bound, the game seemed to be too fast for playing by stroke patients. The scale should be finer and wider.

The scoring system – it should be in a proper balance between the plus and minus scores to engage players. Minus score could be discouraging while too high score could be ignored by players. The minus score was used as a mechanic to give immediate feedback how well they were achieving the goal. For example, for the "Ice-cream selling" game, the player did not only make and picked the ice-cream but also needed to consider the ice-cream color matched with the color shown on the customer face. While the plus score was used to give reward for challenging activity that required the skill level which the player had never reached before. This rewarding score was applied to improve the player's skill [5]. The examples of such rewards were shown in the "Star picking" game, where a player who could pick more stars hung with greater distance got higher score than the one who picked mostly closer stars.

Game non-functional: Overall, the participants liked graphics and theme especially the visualization and effect. We listed the feedbacks which were related to those elements as follows:

- Sound: Sound: Background music and stimulating sound effect were interesting and made the game fun.
- Visual: Adding visual particle as feedback effect on an achievement was suggested.
- Touch: Adding vibration on the controller to notify the achievement or to stimulate player during the game would be useful.

We also received feedbacks focusing specifically on the features of particular games which were shown below.

Ice-cream selling: This game seemed to fit well with stroke patients, especially one with isolated joint movements (Brunnstrom motor recovery stage 6). The player used the index finger or the thumb finger to control the grabbing of ice-cream stick. However, the majority of patients who had an acute stroke attack usually had distal muscle paralysis and an additional game level for the patient who could not control their fingers was suggested.

Gun shooting game: The participants acknowledged the game design that they could choose the combination of the left and/or the right-hand control which was available for the hemiplegia patients. However, the scoring of each hand should be separated. The game mechanic also was intended to stimulate the use of both hands and configurable of task assigned on each hand.

Star picking game: The game required the arm to reach out mainly in vertical direction, but oftentimes extreme reaching-out motions could cause a risk of falling from the chair. Body strapping or seat adjustment during the play was suggested. Besides, motion sensitivity of sensor should be adjusted to reduce body movement.

5 Conclusion and Future Work

The objective of our work was to study how to develop games specifically for training stroke patients. The working process required knowledge in multidisciplinary fields including medicine, physiotherapy, and game design, and needed an interdisciplinary team to fabricate a prototype regarding direct feedbacks from medical experts and the users (patients). Thus, we employed a participatory design approach and worked closely with rehab physicians, physiotherapists, and volunteer patients in order to receive iterative feedback.

The field study confirmed the design principles that we identified during the development process. Specifically, the role of the Instruction and Support system, and Rewarding and Positive Feedback were highlighted. Even though the games provided features for instructor to adjust difficulties of the games, the games required a finer scale for tuning some parameters which should be adjustable for individual patients. This issue gives potential for a future work such as adaptability of game for people with disability, not abled people. Regarding the game content, most of the participants enjoyed the game content, vitality, and sound. Concerning difficulty adjustment, another issue to be looked at in the future would be balancing game and exercise difficulty in separate models as proposed in the dual flow model for Exergames [16].

Our field study was only a limited and preliminary study to evaluate the game features by medical experts. In the next step we want to evaluate the game with real patients and to evaluate the instructor interface in more depths with therapists and physicians. Moreover, the system needs to be tested for a long-term to evaluate long-term effect with patients and the usefulness for therapy. So far only a few studies of exergames have shown evidence for long term effects [18].

Our user tests during the development process and the field study revealed that participants in general enjoyed this new way of training. Moreover, the physicians who were involved in this project confirmed that these games reached the basic requirements needed for training stroke patients who have dysfunction in the upper limb. However, these games still need further evaluation with more extensive clinical trial with stroke patients in order to investigate long term effects and potential negative effects. Additionally, the game should record and analyze player data in a privacy-preserving way. This recording should be done in a non-intrusive manner so that it will not affect the player's clinical rehabilitation. In the future, we will further work on analyzing and modeling all physiological data on horizontal and vertical movements. The next phase of this project will focus the relationship between the game scoring and the results of clinical rehabilitation measurement. Some clinical measurement would employ (1) Fugl-Meyer assessment on upper extremity motor score or FMA, (2) Wolf motor function test (WMFT) which evaluates the hand and arm movements, (3) Barthel index (BI) which evaluates the rehabilitation process, and (4) Arma-TH which evaluates the use of hands and arms in doing activities. This evaluation will be implemented in the second phase of our project.

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