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Development of Virtual Reality Game for the Rehabilitation of Upper Limb Control in the Elderly Patients with Stroke

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Abstract: Developments in gaming and entertainment technology seem to flourish with the increasing of thousand applications and software in the market. At the same time, world scenario shows drastically increasing number of older people in majority countries around the world including Malaysia. Elderly as going through ageing process, will face some deterioration effects; for instance physical incapability or stroke. It is therefore, virtual reality game exercise has recently been proposed as having the potential to increase exercise behavior in elderly and to assist in motor rehabilitation especialy with stroke issue. However, most of the VR games in current market are not designed specifically for the ageing population. Therefore, this research aims to propose a virtual reality game that could assist upper limb motor rehabilitation VR game exercise among elderly patient's with stroke. This study involves qualitative methods in collecting data for the verification phase. An interview session with geriatric specialist and physiotherapist were done in order to identify appropriate rehabilitation exercises for stroke elderly patients. Next, ADDIE Model was adopted as development methodology for iVRRehab game which involves five phases; analysis, design, development, implementation and evaluation. It is strongly recommended that VR game could appears as a promising therapeutic technology for upper limb motor rehabilitation in elderly patient's with stroke. Besides, VR game be able to enhance mood, increasing enjoyment and healthy among elderly.

Keywords: Virtual reality, Virtual reality game, 3D, Exergames, Elderly, Rehabilitation, Theraphy, Physiotheraphy

1. Introduction

Nowadays, many countries are aging, including several European states, the USA and Japan due to the changes in the age structure resulting from fertility decline and increased longevity (United Nations, 2010). Ageing population is a universal phenomenon experienced by all countries worldwide, including Malaysia where statistics shows that in 2019 there is about 10.3% of older populations in Malaysia (DOS Malaysia, 2019) and this number will keep increasing to 15% in 2030 (Ahmad, Zainal, Kahar, Hassan, & Setik, 2016). Ageing, in general, come with some inevitable changes in several areas such as human perceptual and cognitive functions, motor functions and physical mobility. Technology is predicted to have a potential positive impact in terms of enhancing the older people's quality of life, stay healthy and helping them to adapt well to the new life situation. However many current technologies have great difficulties to reach this particular age group.

The expansion of aging population has brought wide public concerns on older adults' well-being, particularly on psychosocial well-being. As a new and popular form of exercise, virtual reality game exercise, is an emerging technology that can help to promote physical activity and combine the strengths of indoor and outdoor exercise, has recently been proposed as having the potential to increase exercise behavior in older adults. Virtual reality game are interactive video games that use motion sensors to allow players to control on-screen activities through body movements or gestures (Harrington, Hare, & Rogers, 2017). This virtual reality game exercise also are increasingly been used in the primary healthcare domain for older adults who are 60 years and above (Li et al., 2017). Based on previous literatures indicates that virtual reality and games help older adult's to achieve higher motivation and enjoyment during exercise performance (Graafland et al., 2018; Li et al., 2017), reduce psychological conditions and stress related to treatment, improving older adults health behavior (Graafland et al., 2018) and also provide an option for leisure and rehabilitative user engagement (Harrington et al., 2017). In addition, these games present a method of engaging in physical activity in the home and alleviating barriers of facility access and transportation that often inhibit an older adult's ability to exercise. Even though virtual reality game exercise is apparently good method for older adults especially in physical motor rehabilitation, however, previous studies have shown that commercially available virtual reality games on the market are not suitable for older adults (Li et al., 2017). Thus, limited research has been done to show the effectiveness of using VR for older adults in terms of isolation, depression and overall well-being (Lin, Lee, Lally, & Coughlin, 2018). Therefore, this study aims to answer these questions:

1) What are the game design principles for developing virtual reality game for elderly stroke patients?
2) How to develop virtual reality game for elderly stroke patient's rehabilitation?

2. Related Studies

2.1 Virtual Reality Theraphy Game

Virtual reality (VR) is known as an advanced form of computer-simulated environment that gives permission to user in interacting with objects and environments within a rendered virtual scenario (Mekbib et al., 2020). In VR, patients are allowed to receive visual feedback (virtual environments and objects) through the use of head-mounted device, a flat screen and can also receive auditory and haptic feedback through hearing and touching. Necessary devices in VR is such as the sensors that will allow users to interact with the virtual environments, hand controllers, keyboard, mouse and camera. VR game exercise, is an emerging technology that can help to promote physical activity among elderly whereas there are an increasing trend of using VR game exercise especially in healthcare domain for elderly who are 60 years and above. The history of VR game start since 1980s where it has been used in research and entertainment, and later in 1990s began to be developed and studied as a potential tools for rehabilitation (De Bruin, Schoene, Pichierri, & Smith, 2010). Moreover, several studies are promoting the potential of VR as a successful treatment and assessment tool in a wide variety of applications especially in the fields of motor and cognitive rehabilitation. Nowadays, this advance technology is now becoming an emerging treatment option for motor function rehabilitation post-stroke (Donath, Rössler, & Faude, 2016; Laver, George, Thomas, E.Deutsch, & Crotty, 2010). VR game exercise fall in a wide range of purpose. They are also applied to promote physical fitness, for cognitive training

(brain games), to promote knowledge and self-management in chronic diseases and conditions (including asthma, diabetes, and obesity), and to reduce psychological conditions and stress related to treatment (e.g., low self-esteem, anxiety, and pain) (Graafland et al., 2018). This research is focusing on the virtual reality game exercise that focusing on promoting physical fitness among the older adults. For that reason, it is important for the researchers to investigate and identify key design guidelines for designing appropriate VR game exercise for elderly before the development is implemented.

2.2 Principles of Game Design

Existing research in this area have shown that commercially available rehabilitation games on the market are not suitable for elderly audience (Li et al., 2017). Results from previous studies suggested several guidelines and recommendation for developing appropriate rehabilitation games for elderly. It is important to have scientific basis for a successful game framework to obtain full engagement and motivation in gameplay (Barrett, Swain, Gatzidis, & Mecheraoui, 2016). Furthermore, it is even more important for the elderly stroke patients rehabilitation to be engaged in gameplay since it could increase compliance or distract the user from fatigue or pain (Barrett et al., 2016). Review of several research studies have suggested some important guidelines for designing appropriate rehabilitation game for elderly patients.

First principle that is importance to be embedded in rehabilitation game is meaningful play. Meaningful play is a feedback gathered from game that is based on the relationship between player action and system outcome (Barrett et al., 2016). The player must be able to perceive not only the immediate result of each action, but also how the outcome of the action was integrated into the larger context of the game to ensure the game is meaningful and for the continued encouragement to keep playing. Second game design principle is sense of presence. The use of virtual reality game can create highly realistic and immersive environment to facilitate a sense of presence and yet impact on task performance by the player (Barrett et al., 2016; Mekbib et al., 2020). In virtual environments, the elderly patients have the opportunity to explore independently within the pace, and independence in directing their own therapeutic experience (De Bruin et al., 2010). Third important principle in rehabilitation game is motivation. Each game should provide feedback in each level either by using grade, marks or status such as correct or incorrect while this feedback could also enhance motor learning and rehabilitation game effect. Game designers should place concern also on the physical conditions of elderly patients and set suitable difficulty for them. It is known that elderly normally have impairments in balance and motor skills, visual and hearing senses, as well as reduction in short-term memory and attention (Li et al., 2017). With this in mind, it is advisable that game for elderly patients short take short duration, simple enough and acquire only single direction control. According to de Vries, van Dieën, van den Abeele, & Verschueren, (2018) VR training can lead to strong intrinsic motivation since elderly patients showed high enjoyment of VR based training games.

2.3 Evidence of VR Theraphy in Stroke Rehabilitation

Virtual reality (VR) immerses a user into an alternate environment to enhance on physical and mental health, decreasing loneliness, and fostering social interactions (Lin et al., 2018). A lot of studies have investigated the efficacy and mechanisms of VR therapy over Conventional therapy (CT), for instance, a study by Merians, Poizner, Boian, Burdea, & Adamovich, (2006) which reported that exercise using virtual reality interface improves function of fingers, thumb, and overall range of motion for post stroke patients. These researchers also found that VR games is an effective tool to significantly increase level of physical activity intensity or exercise attendance. The uniqueness and effective element of VR training is due to it's attractive visual, live sound effect and information provided during training which resulted in immersive environment for the elderly patients. In addition, the findings of previous scholars also suggest that VR training could lead to strong intrinsic motivation where elderly patients showed high enjoyment of VR based training games (de Vries et al., 2018). Perhaps, we can conclude that based on previous study by scholars in this area, VR games are accepted well by elderly (Skjæret, Vereijken, & Boulton, 2015).

3. Methods

This VR game development was conducted according to ADDIE methodology which consist of analysis, design, development, implementation and evaluation phases as depicted in Fig. 1. The elaboration of each phases is as following:

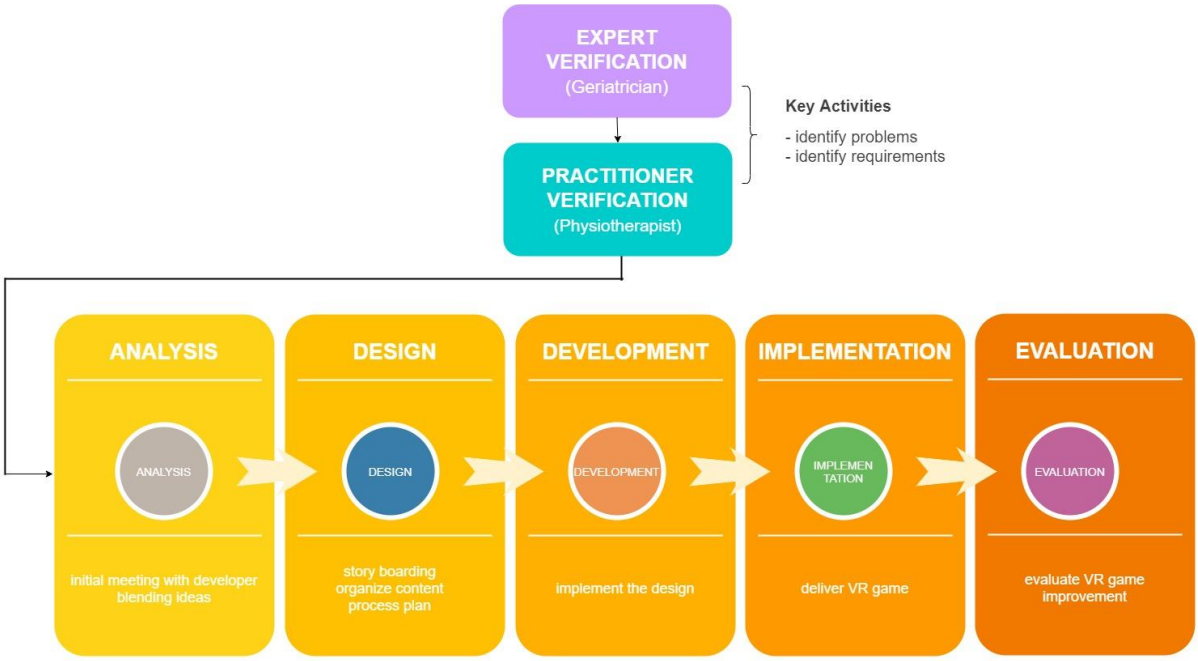

Fig. 1. iVRRehab Game Development Phases

3.1 Expert & Practitioner Verification

The development of an effective VR game for rehabilitation has to be based on inputs from clinicians and game developer. Several meetings have been organized to elicit such

specifications. The key issue is that rehabilitation game cannot work as stand-alone applications but must be included into a broader structure involving therapists, clinicians and hospitals. In this study, two semi-structured interview have been done with the clinicians. The first semi-structured interview has been done with the geriatric specialist from one of establish government hospital in Kuala Lumpur and the second semi-structured interview has been done with one physiotherapist that have wide experience dealing with elderly theraphy sessions in Klang Valley area.

Geriatrician Verification

An interview session with geriatric specialist has been done in February 2019 to gather further information regarding elderly health problem from the clicical perspectives. General information were obtained, for instance, types of impairment among elderly patients, rehabilitation processes focusing on elderly with stroke problems and treatment for specific types of rehabilitation. From the interview session, researchers were explained about 5 geriatric giants occurs among elderly. Geriatric giants are the impairment that appear in older people which comprises of impaired cognition, urinary incontinence, instability, fall and immobility (Hami, Hassan, Kadir, Ismail, & Bachok, 2019). Researchers were advised to focus on on hand coordination or hand function rehabilitation and the assessment can be done based on existing test and rubrics in medical field.

Physiotherapist Verification

Generally, rehabilitation exercises are designed by therapists with specific goals. In each theraphy session, the therapist will usually choose type of exercise activities and define the the correct movement to peform the activities. Theraphy session will be executed in one-on-one basis, while the therapist will check either elderly patients perform the correct movements and maintain correct postures to ensure the exercise activities are effectively done and improve the patients progress (Wüest, Pirovano, Lanzi, Borghese, & de Bruin, 2013). In this study, the physiotherapist was interviewed to identify suitable exercise activity for stroke elderly patients which focusing on the upper limb. The idea later is to map the therapists' rehabilitation exercises, their goals, and the mandatory posture/movement constraints for the implementation in VR game.

3.2 Analysis

The output from the geriatician and physiotherapist verification has been analyzed to get the foundation to build the whole VR game. Careful attention and consideration is important for this game is designed for elderly patients with stroke problem. Series of consultation with the team of developers involves the stating of all the tasks, actions and story that drives the virtual world. Among the key activities in this phase are discussions and blending ideas about end-user characteristics, defining scope and project timeline and also budgeting. Interactive, Oculus Rift device is used to have best quality experience with natural hand controllers, which let's the elderly patient's interact with the virtual spaces.

3.3 Design

This VR game have been design through a concept of a simple game to suits with the elderly patients, each designed according to the goals and the requirements of the underlying exercises. Meaningful play, sense of presence and motivational principles have been all incorporated into the design. Meaningful play states that each game action must have a direct

and clearly instructions. This helps the elderly patient in understanding what he or she must do. It was achieved through a clear guided text and images showing the flavor and type of topping needed for each ice-cream order. The sense of presence is another strong consideration in this game design. As the elderly patient's standing in front of the order counter and feel it's presence when each customer comes in and order for desired ice-cream. In addition, elderly patient's can make movement to the right side about 15 degree to throw into bin the wrong ice-cream preparation and move to the left side to touch the 'Quit' button. This is associated with sense of presence principle where the elderly patient can feel that himself is inside the virtual environment. The third basic principle is the motivational aspect for elderly patients to keep playing the game. The elderly patient's motivation to play the game is achieved when a mark was given for each correct ice-cream preparation.

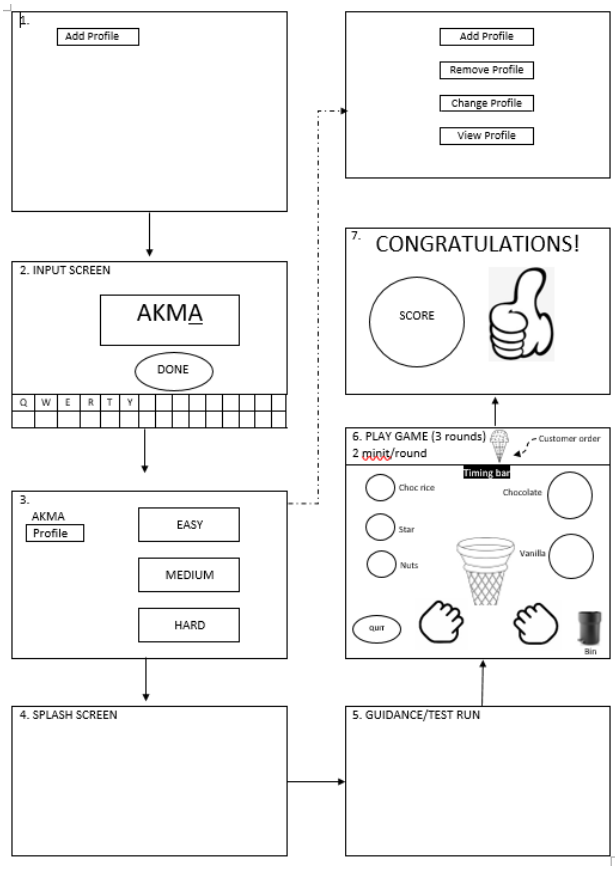

Fig. 2. iVRRehab Game Storyboard

Another important process in pre-production of a VR game is the storyboard because it will clearly conveys how the game will flow. It is from the storyboard that we can also see potential problems that would not go unnoticed, ultimately saving the development time later. The above Fig. 2 depicted the flow of VR game which consists of 4 main modules. The game will start with profile registration, selecting game level, playing game, score and time counter and finally the score board.

3.4 Development

In development phase, the developer start with crafting 3D models that suitable with the game environment and also for the elderly user. It is important to ensure that the 3D

models not only look good but perform well. Next is the process for executing 3D engine using Unity software. Designing and development process needs skill sets ranging from UX and UI and also skills in 3D modelling, particles and lighting. The VR game was also integrated with the database to make sure the score capture for each player can be stored at the end game session.

3.5 Implementation

This phase consists primarily of deploying the VR game software with the Oculus Rift consisting of the hand controllers and the headset. Calibrating the game with light and sound conditions as well. Calibration is very important to enhance the VR experience such as haptic interaction where the elderly patient's must see the touch in the actual position.

3.6 Evaluation

The following Fig. 3 depicted formal evaluation session between the developers team and researchers.

Fig. 3. Evaluation of iVRRehab Game

Basically, evaluation of the VR game is done thoroughly during the whole project. Every each development and changes should be tested repeatedly by the developer to observe the game flow. The evaluation encounter not only for the scripts, but also all the assets together. The goals for evaluation is not solely focusing on the errors and unhandled exceptions in the code, but also for the overall user experience of the virtual environment.

4. Result and Discussions

4.1 iVRRehab Game

In this project, the aim is to develop a set of VR game built on clinically valid exercises and comprehend both monitoring and adaptability. This game was designed with game concept that address control rehabilitation. The iVRRehab is also known as 'ice-cream making' game. The exercise requires the elderly patient to be in front of the display and to move the impaired upper limb to touch the target, which are represented by an empty ice-cream cone that need to be filled-up with requested flavour and topping from customer order. First step, the player or elderly patient need to wear headset, one hand controller aither left or right, being in front of the game and enter their nick name to start playing the iVRRehab game. The purpose of entering player name is to capture the performance of the player for each game round.

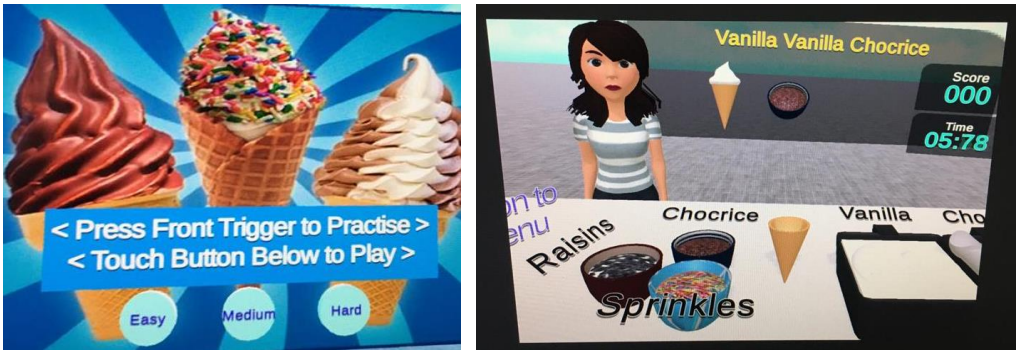

Fig. 4. iVRRehab Game Interface

Next, the player need to choose the game level either easy, medium or hard. Each level has been set differently where type or ice-cream order is differ in terms of selection of flavour and topping. There will be two ice-cream flavours which are vanilla and chocolate and three types of topping which are chocolate rice, sprinkles and raisins as depicted in Fig. 4. Basically, the game level arrangement aims to help exercise the upper limb control of the player, and the structure for each level is as shown in Table 1.

Table 1. Structure for Each Game Level

Game Level	Ice-cream Filling	Total Steps
Easy	1 flavour + 1 topping	2
Medium	2 flavour/topping + 1 flavour/topping	3
Hard	2 flavour + 2 topping	4

In this game, player will be allocated with time duration for each game round that can be set in initial game setup. This is to ensure that the total score for each game round can be captured and evaluated later by the physiotherapist. In order to make sure that the game comply with elderly patient's condition, it is designed to be simple enough for the player to play the game. Player just need to moved their hand to hover over the correct flavour or topping selection in game, then used a button to put it inside the ice-cream cone. For each incorrect ice cream, it can be thrown into the bin which is located on the right side of the screen. There is no compulsion for the player to complete the round and if they intend to sytop the game they can just click on the stop button on the left side of the screen.

Fig. 5. Score board in iVRRehab Game

In addition, when the player finish each of the game round, the marks will be displayed on score board as in Fig. 5. It is up to the player to repeat the game play while there is no restriction for the player to play with any standard round. The more round player's play,

the more data can be captured and it helps a lot in the theraphy session. In addition, total score achieved by player for each round will be stored in game database and later can be downloaded and send to physiotherapist for the elderly patient's performance analysis. The scoring system reflects the rehabilitation nature of the game.

5. Conclusions

This paper described the processes of developing a VR game to support elderly patients with upper limb motor impairment in doing rehabilitation. To ensure that this VR game is align with clinical requirements, collaboration between game developers, researchers, geriatric specialist and physiotherapist is taken into account. The aims is to ensure that the development of VR game is tailored to elderly patient's needs and they did their rehabilitation exercise at home. Moreover, with doing rehabilitation exercise at home can helps in reducing costs, increase interest and frequency of doing exercise, easy monitoring and effective way of patient's progress evaluation using recorded results. Based on the review from previous scholars work, this game incorporated three game design principles which are meaningful play, sense of presence and motivational. Altogether, rehabilitation following stroke in elderly is a growing medical and research discipline. Future research should get insight into the concept of motor learning in VR and also the effect of VR game on cognitive functions in elderly.

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