MovErArm: Virtual Reality Game for Physical Rehabilitation

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Abstract. Post-stroke individuals may suffer from long term or permanent physical impairments. Physical Rehabilitation is an important process to help post-stroke individuals to regain motor ability and reduce impairments. Traditional methods such as Constraint Induced Movement Therapy (CIMT) and modified Constraint Induced Movement Therapy (mCIMT) are common effective physical rehabilitation methods however due to the characteristics of physical restraining, individuals tend to have compliance issues. This research explores using immersive technology such as Virtual Reality to reduce compliance issues and encourage individuals to use their affected arm. Techniques such as visual amplification and power-ups are implemented to further encourage the individuals to perform various activities using the affected arm. We have conducted preliminary feedback gathering with 6 participants aged between 18–21 with game development background, and a preliminary validation from an academic expert using a recorded video walkthrough. 1 out of 6 participants tested the game on a Virtual Reality (VR) device. Overall the VR game requires more visual improvements especially the User Interface (UI) design. Both VR game tester and academic expert agreed that using visual amplification with customizable settings can encourage individuals to use more of the affected arm. However it requires more testing from actual clinicians and stroke patients.

Keywords: Virtual Reality · rehabilitation · Constraint Induced Movement · Oculus Quest 2 · Visual Amplification

1 Introduction

Immersive Technology integrates the virtual world and the physical world to allow users to interact with the blended reality [1]. There are various immersive technologies, for example: virtual reality (VR), augmented reality (AR), mixed reality (MR), etc. The umbrella term for these is called extended reality (XR). In VR, there are 3 degrees of freedom (DoF) and 6 degrees of freedom (DoF). 3 DoF only tracks the rotational motion, in other words, the pitch, yaw and roll whereas 6 DoF tracks the rotation and positional motion, in short, it allows the freedom of moving freely in the virtual world. A 6 DoF VR tracks the movement by having an accelerometer and a gyroscope to track the rotation.

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This allows translation of the real-life movement into the virtual world which enables the possibility of performing various activities, which adds immersion and experience to the user.

Besides gaming, VR is also used in many other fields for example, healthcare, military, education, etc. The benefit of using this technology is that it allows the user to perform activities that would otherwise be dangerous in the real world, such as skydiving [2]. It can also be used for physical and cognitive rehabilitation. Physical rehabilitation is a process to reduce the physical impairments or disabilities thus improving quality of life [3]. Cognitive rehabilitation helps relearning cognitive skills for instance, perception, memory, learning, attention, decision making, and linguistic ability, in other words, the mental activities such as knowledge acquisition, information manipulation, and reasoning [4].

Research shows that the use of VR is comparable or even better than traditional rehabilitation methods, it even shows promising results of reducing compliance issues faced in stroke rehabilitation methods such as Constraint-Induced Movement Therapy (CIMT) and modified Constraint-induced Movement Therapy (mCIMT) [5]. Thus, this research will be exploring using VR techniques to reduce compliance issues. For instance, not being present during the rehabilitation or refusing to comply with instructions given.

2 Related Works

Stroke patients with affected limbs often encounter learned non-use phenomenon where an individual suppresses the use of their affected limb, often after a stroke has impaired movement on that side [6]. In order to reduce learned non-use, patients need to undergo the rehabilitation procedure. One way to reverse the effect of non-use is through CIMT. This is a type of rehabilitation method in which the patient's stronger arm is restrained, forcing them to use the affected arm, breaking the cycle of learned non-use. Another procedure is mCIMT. It is similar to CIMT except that the mCIMT is less intense and has a shorter session but spans over a longer period of rehabilitation. It's found that efficiency of both is equivalent, however both are found to have compliance issues [5, 7].

In a research paper, instead of the traditional method in which the stronger arm is physically constrained, psychological constraint is used instead. For example, the system provides more scores when the patient is using the affected arm [5].

There is research that aims to promote arm usage by using visual amplification. In visual amplification, the subjects' arm movement is amplified in VR. It is achieved by multiplying the difference of the hand position in reality and the starting position by a desired value. The study used 1.5 and 2.0 as the value to multiply the difference. The result is that the subjects' targeted arm usage increased. It is found that the two levels of multiplication have no significant difference [8] (Fig. 1).

In another research that uses visual amplification, a combination of VR and leap motion is used. A head-mounted display (HMD) is worn on the head with leap motion attached in front of the HMD can be seen in Fig. 2. Leap motion is used to capture the hand movement of the participants. To simulate the affected arm of stroke patients, a wrist weight is attached to participants as shown in Fig. 2(a). In Fig. 2(b), the visual amplification in this research is done by displaying the virtual hand at α times linearly

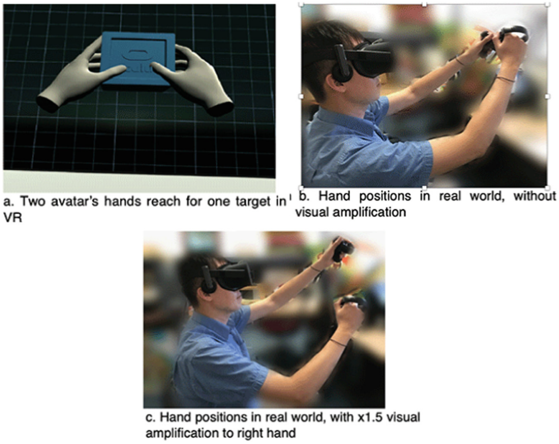


Fig. 1. (a), (b) and (c) Demonstration of visual amplification [8]

apart, that is, the virtual hand's position vector was increased α times in respect to the actual hand position vector, starting at a home position. It was found that the visual amplification affects the usage of the hand [9].

3 Game Concept

We have developed 3 mini-games in VR which are inspired by Fruit Ninja, Whack-a-Mole and Shooting Range. The main objectives of the game design are to incorporate techniques such as visual amplification and power-ups to encourage the usage of affected arm and to further reduce compliance issues. There is no losing condition for all the mini-games as the intention is to allow the patient to continuously play the game without any unwanted interruptions. To reduce the risk of injury while playing, the game is designed to be played while sitting on a chair.

3.1 Basic Input

A 6 DoF HMD is used to track the position and rotation of the head in real life. This allows the player to look around the virtual world freely. The player interacts with the virtual world by using a 6 DoF VR controller. The controllers are used to track the position and rotation of the hands in real life, which allows the player to move and rotate their hands freely and interact with the virtual world. The player can interact with the virtual world by exerting force on the input buttons or thumbsticks. Figure 3 shows the oculus quest 2 controllers' control and Table 1 shows the input mapping of the controllers in the game [10].

3.2 Basic Gameplay

To play the mini-games, the player must grab any of the weapons provided on the table near the minigame's play area to interact with the game objects spawned in the game,

(a)

(b)

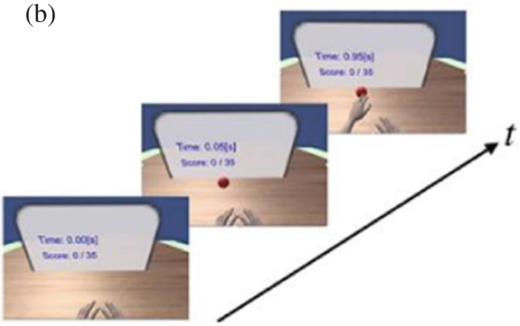


Fig. 2. **(a) and (b)** Shows a participant wearing a HMD with a leap motion attached in front, the wrist weight is to simulate the affected arm of stroke patients [9]

then press the start button to start the spawning of the game objects. The game will stop if the player pressed the end game button (Fig. 4). The player can navigate around the world by teleporting. The teleportable areas are limited to ensure that the player stays within the area. Signs are placed as a visual cue to help the player to locate the mini-games. When nearby the play area, a black board will pop up with a timer, score and a start/end game button. The game will also stop when the player exits the play area.

3.3 Visual Amplification and Psychological Constraint Design

Visual amplification is used to amplify the movement of the arm. The design will encourage patients to use the affected arm more frequently to perform in-game tasks through amplifying the in-game movements of the affected arms. As a result, the affected arm will move faster in-game compared to the unaffected arm.

Psychological constraint is a method in which the patient is rewarded virtually such as more scores earned in game when the patient complies by using the affected arm [5]. We propose the use of power-ups as psychological constraint design. When power-up is triggered, the patient can gain extra scores for using the affected arm. For example, a patient using the affected arm to hit a fruit, the gain score of 10 will be multiplied by

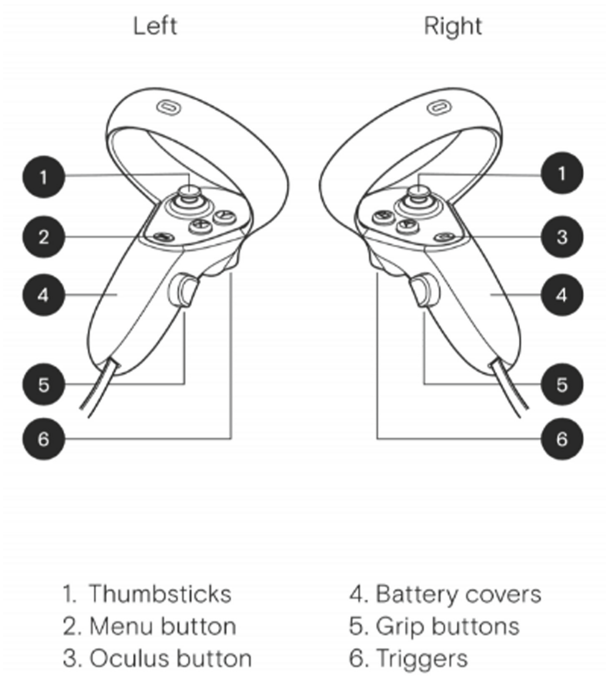


Fig. 3. Oculus controllers' controls [10].

Table 1. Input mapping of the game

Input	Function
Y button	Power-up 1
X button	Power-up 2
A button	Open/close main menu
Right thumbstick	Rotate left/right or rotate 180°
Grip buttons	Grab a grabbable object or teleport to the pointed area
Triggers	Fire a grabbable object

2 with the total of 20. Whereas if the patient uses the unaffected arm to gain a score, he/she will only gain a fixed score of 10. This will also encourage patients to use more of the affected arm in the game.

4 Implementation

4.1 Oculus Quest 2 and SDK

In this project we use Oculus Quest 2. It includes a 6 DoF HMD and a pair of controllers. The HMD and controllers are equipped with an accelerometer and a gyroscope. Oculus

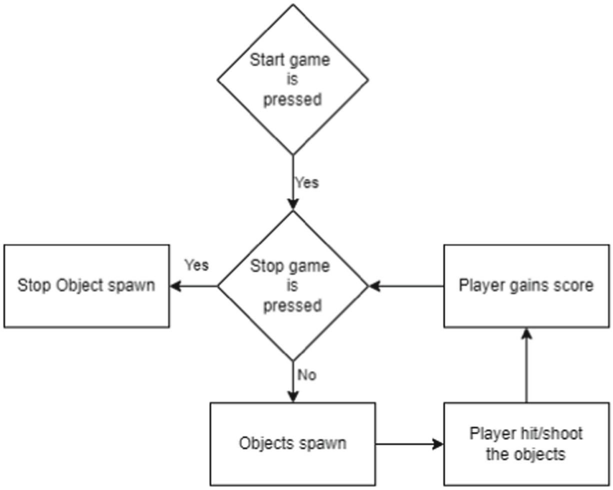


Fig. 4. Core gameplay loop

Quest 2 has 6GB RAM and uses a Qualcomm® Snapdragon XR2 Platform CPU [11]. As the Oculus Quest 2 runs on Android Operating System. We use Unity Android SDK to develop the project.

4.2 Unity

The VR game was implemented using Unity version 2020.3.31f1 with XR Plugin. The XR Plugin allows the ease of implementing VR functions as it is a plugin that contains a library of scripts that helps with VR development. We used many plugins in Unity's Universal Render Pipeline (URP) Template to develop the game. We also use the Animation Rigging plugin for example applying Multi-Aim Constraint to the Non-Playable Characters (NPCs) to aim and look at a target and Two Bone IK Constraint to do animation blending.

4.3 Settings

The settings option that appears in the game world enables the caretaker to set the configurations to motivate the player to use the affected arm in the rehabilitation process as shown in Table 2.

4.4 Amplification Mechanics

To achieve the visual amplification, the controller game object is set as the child of an empty game object. The difference of the previous position and the current position of the controller is multiplied with a value then added to the position of the empty game object to achieve the effect. In simple terms, the movement of the controller is tracked every

Table 2. Functions in the Settings

Tabs	Details
Amplification Figure 5	This tab sets the amplification settings for the patient. The objective is to identify the affected arm and use the amplification method to motivate the player to use the affected arm. The arms can be clicked to turn the amplification on or off. White color means it's activated, black color means it's deactivated. Once activated, the amplification value can also be increased or decreased through the minus and the plus button.
Score Figure 6	This tab sets the scores earned in the game. The objective is to allow caretakers to configure the scores for the rings in the target. This is a way to constraint the player psychologically to encourage the usage of the affected arm by awarding more scores. The yellow, red and black rings represent the hitbox of the target (Shooting Range and Whack-a-Mole). The yellow, red and black rings can be clicked to decrease or increase the score using the minus and plus button.
Dominant Figure 7	This tab sets the dominant arm of the players. The objective is to allow players to use their affected arm to hit the target and the scores gained from the affected arm will be multiplied. This is a form of psychological constraint design. Both arms can be clicked to turn the multiplication on or off. White color represents on, black color represents off. The score multiplier value can also be increased or decreased by pressing the minus or plus button.
Power-up Figure 8	This tab sets the power-up configurations. The objective is to motivate players to experience a short boost of gaining extra scores. This is a form of psychological constraint design. The cooldown for the individual power-ups, the power-ups score multiplier and the power-ups duration can be set here. The values can be decreased or increased by pressing the minus or plus button.

frame. And the displacement of the previous frame and the current frame is multiplied by an amplification value (Fig. 9).

If *Amplification* is True

$$currentPosition = localPosition$$
$$inGamePosition + = currentPosition \text{ - } previousPosition) * amplificationValue$$
$$previousPosition = currentPosition$$

4.5 Mini-games

There are 3 mini-games, Fruit Ninja, Shooting Rage and Whack-a-Mole. The mini-games' gameplay are rather similar, the player must use the weapon to hit or shoot the game objects popping up to earn scores. For the Shooting Range and the Whack-a-Mole mini-games, the player needs to hit towards the centre to earn the highest scores.

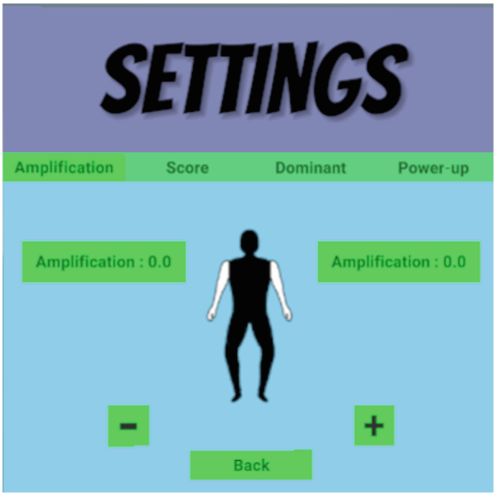


Fig. 5. Amplification settings

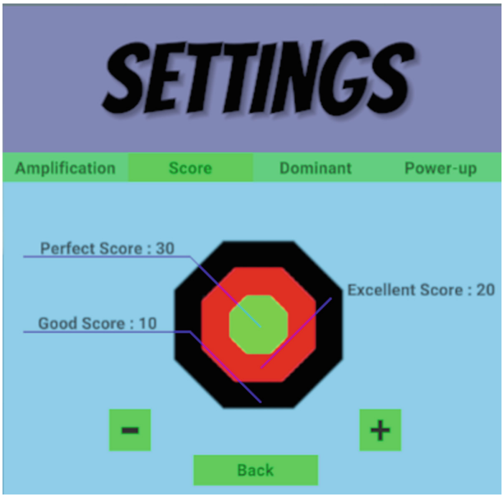


Fig. 6. Score settings

However the scores can be configured on the settings option (Fig. 6). Sound effect is also added to enhance the feedback when the player hits or shoots the game object. When the game starts, the player can press Y or X button to activate different power-ups depending on the game such as spawning more game objects or to increase the scoring through score multiplier (Figs. 7 and 8). There are also NPCs in the game to deliver encouraging dialogue to motivate the players as shown in Fig. 10(a), (b) and (c).

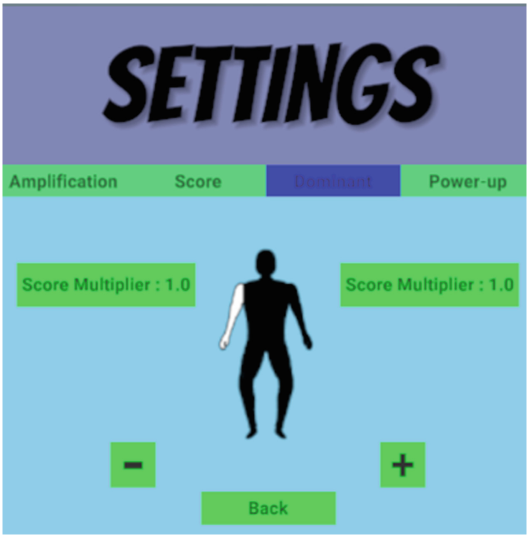


Fig. 7. Dominant arm settings

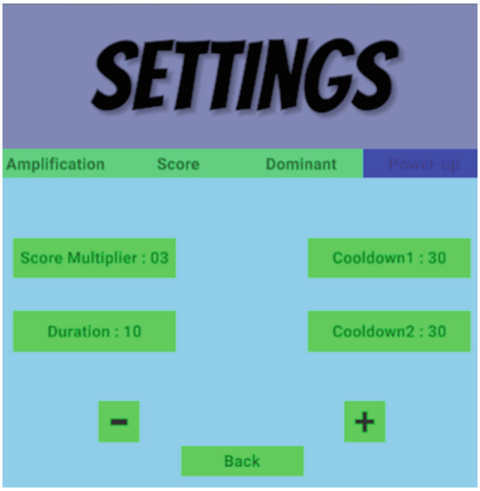


Fig. 8. Power-up Settings

In Fruit Ninja (Fig. 11), random game objects will spawn and be propelled upwards. The player grabs the knife then slices the fruits to gain score. Players can press the X or Y button to increase the spawning rate of the fruits or multiply the scores.

In the Shooting Range (Fig. 12), targets will pop up randomly. The player grabs the gun and shoots the targets to gain score. Shooting the center grants the player the most points. Players can press the X or Y button to increase the spawning rate of targets or multiply the scores.

If *Amplification* is True

currentPosition = *localPosition*

inGamePosition + = *currentPosition* - *previousPosition*) * *amplificationValue*

previousPosition = *currentPosition*

Fig. 9. Pseudocode for Amplification Mechanics

In Whack-a-Mole (Fig. 13), moles will be popped up randomly. The player grabs the mallet and hits the moles to gain score. Hitting the center grants the player the most points. Players can press the X or Y button to increase the spawning rate of moles or multiply the scores.

4.6 Teleportation

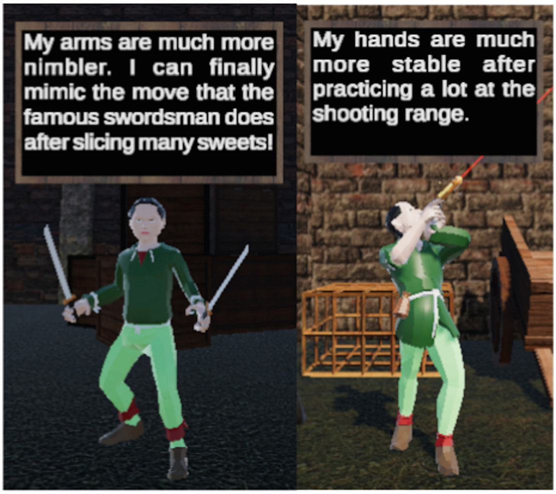
Motion sickness applies when riding a vehicle. It's a common occurrence when using interactive technologies such as console video games and tablet PCs [12]. Using virtual reality devices also causes motion sickness such as disorientation and discomfort [13, 14]. It happens to both males and females, however it's much more prevalent among females [12]. This happens due to visual and vestibular conflict. In short, it means that the eyes perceive motion, however the vestibular sends signals to the brain that it detects no motion, creating a mismatch between visual and vestibular [13, 15].

Fortunately, there are ways to reduce motion sickness in the virtual environment. One of the ways is using locomotions that induce lesser motion sickness as there are various locomotions available to traverse around in the virtual world. Each locomotion has their own pros and cons. Commonly used locomotion in VR is using the joystick and teleporting. Joystick based locomotion causes more motion sickness compared to teleporting based locomotion. However, joystick based locomotion is more immersive than teleporting based locomotion [16]. The best solution would be to navigate around the virtual world by moving in the real world. However, the limited physical space in the real world poses a problem which causes it to be impractical [17]. Therefore, this paper uses teleportation as a means to reduce motion sickness.

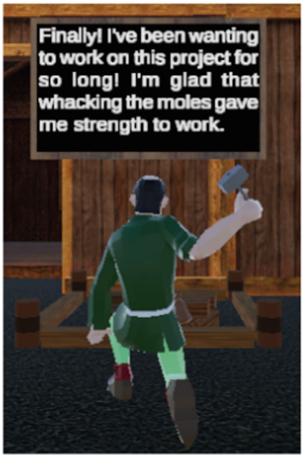
5 Preliminary Testing

5.1 Preliminary Feedback Gathering for Gameplay and Visual

Preliminary feedback gathering was conducted online on 9th April. A total of 6 participants took part in the event. All participants have a background in game development and are between 18–21 of age. Due to the constraints that most participants do not own a VR device, and the feedback is conducted online, a video of the entire VR walkthrough was recorded [18] to gather feedback. All participants are required to watch the video at least 2 times to ensure that they fully understand what it is about before they proceed with the questionnaires. The questionnaires focus on the visual feedback of the game. 1 out of the 6 participants, played the game on a VR device and conducted the gameplay test.



(a) NPC for Fruit Ninja (b) NPC for Shooting Range



(c) NPC for Whack-a-Mole

Fig. 10. (a), (b) and (c) NPCs informing the player on the benefits of playing the mini-games.

5.2 Gameplay and Observation Result

After gathering feedback from 6 participants on the visual of the game, it was concluded that the game requires more visual improvements especially in the User Interface (UI) design. Some did mention that the functionality of the UI in the settings is straightforward. Some suggested adding tutorials to the game so users will be more familiar with the gameplay. A participant suggests adding more side-activities to the game such as the "Tower of Hanoi" to improve the learning of grab and release mechanics using the controllers. The ambient and sound effects were motivating for the participants.

Fig. 11. Fruit Ninja

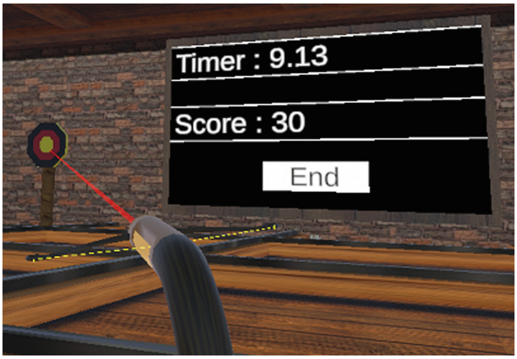


Fig. 12. Shooting Range

Fig. 13. Whack-a-Mole

As for the gameplay, the participant feels that the visual amplification and power-ups work very well in the mini-games, as the caretaker or user can configure the setting according to their needs. The amplification allows the participant to use the targeted arm more than the other. Besides, power-ups actually increase the frequency of using the targeted arm to gain more scores. It was highlighted that the grip and teleport button should be separated to individual buttons to avoid accidental input of the button. The gameplay area allows the player to teleport freely as the result of that, the player will be wandering off to unnecessary places. It should be limited in some way for players to focus on getting to the mini-games.

5.3 Preliminary Validation from Academic Expert

This research was inspired by Project Star Catcher, an immersive virtual reality game that motivates individuals post-stroke to perform intensive repetitive task-based therapy [19]. The author of Project Star Catcher, Dr. Aviv Elor is a leading researcher for immersive systems on assisting reality, recovery, and rehabilitation. We have requested him to validate our project using a recorded walkthrough video [18] on the use of visual amplification in the VR Game for post-stroke individuals that suffer from physical arm impairment.

The author agrees that the visual amplification techniques used are valid. In addition he commented that the settings are very customizable and flexible and that the power-ups and NPCs are a strong approach in achieving principles of Self-determination theory. However, the author couldn't affirm the settings and upper body rehabilitation works because it requires testing from clinicians and stroke patients.

6 Limitations

Due to the Covid-19 situation in Malaysia, we are encouraged to practice physical distancing. We are unable to test our VR game with post-stroke patients that are suffering from upper arm impairment. As the country is transitioning to the endemic phase of Covid-19 [20], we are looking forward to conducting more comprehensive face-to-face testing with patients with arm impairment.

7 Conclusion

In this project we have implemented visual amplification and power-ups to encourage patients to use their affected arms for the rehabilitation procedures. According to the preliminary feedback gathering we have received positive feedback on the use of visual amplification and power-ups. Nevertheless to ensure the methods work, it's important to conduct more tests on stroke patients and clinicians on the effectiveness of the program.

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