Final Project Book
Aqua Guardian

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August 2024

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Chapter A: Problem Statement and Background

Introduction to the Problem

In our project, we aim to assist patients undergoing rehabilitation. These patients are typically those who have experienced a stroke, resulting in impaired hand movement. They struggle to move their fingers easily, and actions such as opening or closing the hand have become particularly challenging for them. They are required to perform various exercises to train their hand movements, which, in turn, help in rehabilitating their mobility. However, performing these exercises is difficult for the patients, and their motivation is often low due to the associated challenges.

Currently, there is a rehabilitative game that offers a solution to this problem. The game allows patients to practice hand movement, but it fails to engage and motivate them. According to the doctor we worked with, some patients even fall asleep while playing the existing game. We realized that a more engaging and attractive game would lead to better and more enjoyable rehabilitation outcomes for the patients.

Current Rehabilitation Tools

At present, there is a rehabilitative game at Beit Loewenstein Rehabilitation Center that visually presents the exercises patients need to practice. The game is connected to the Amadeo device, which is attached to the patient's hand, so every finger movement is reflected on the screen. The goal of the game is to encourage patients to perform exercises relevant to hand rehabilitation. The game instructs the patient on which finger to move in the following way:

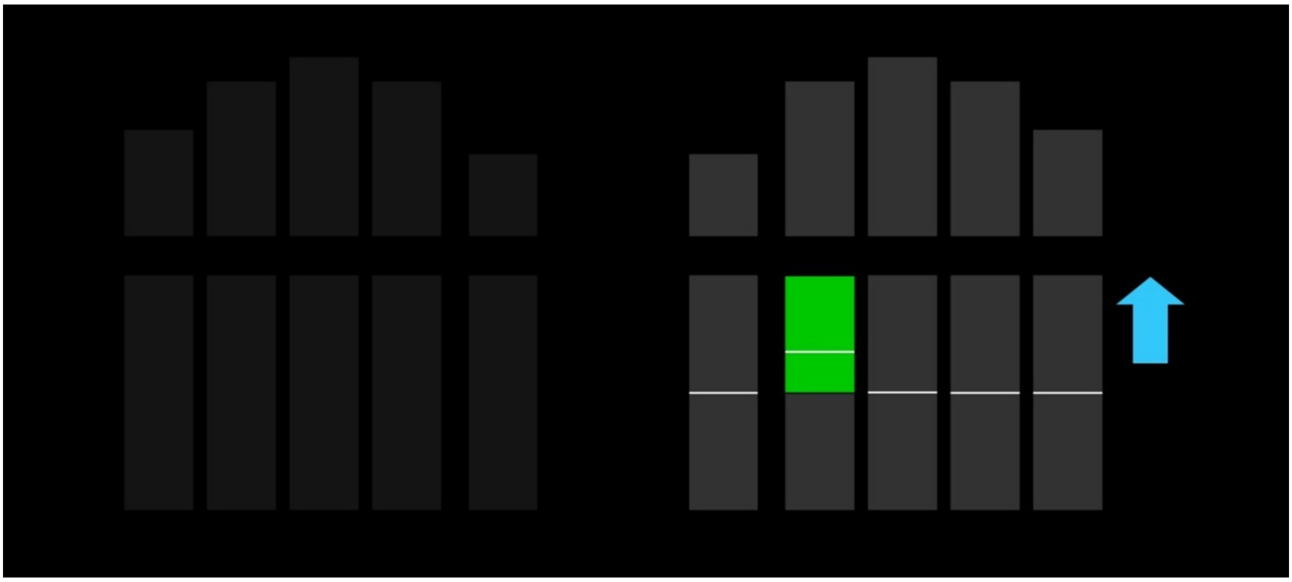

Figure 1: Visualization of finger movement in the existing rehabilitative game.

The upper rectangles provide a visualization of two hands and ten fingers, with each of the lower rectangles representing a corresponding finger. All force measurements for each finger connected to the machine are displayed immediately and continuously in real-time during the experiment using white horizontal lines. These lines are controlled by the participant.

Blue arrows indicate the desired directions of movement:

- An upward arrow signifies extension.
- A downward arrow signifies flexion.

Throughout the experiment, only one hand is connected to the machine, so only that hand will appear on the screen. The inactive hand will be dimmed and should be ignored. The horizontal lines on the screen represent the position of each finger. When the patient is required to work on a particular finger (as shown in the image above), they must move it upward while keeping it within the green zone. Similarly, for downward movement (as for the middle finger):

Figure 2: Visualization of finger movement with downward direction in the existing rehabilitative game.

When the patient connects to the Amadeo device, a calibration process (ZeroF) is conducted as follows: Initially, the patient should connect to the machine and ensure that the fingers are in a relaxed state—as relaxed as possible (with no force applied at all). This allows the analysis of the forces acting on the device when the hand is at rest. When the hand applies force, the resting forces are subtracted, ensuring that only the forces exerted by the patient are measured accurately.

Chapter B: Project Objectives and Methodology

Project Objectives

The current game used at Beit Loewenstein Rehabilitation Center, as previously described, has proven to be less engaging for patients, resulting in limited motivation to engage in therapeutic exercises. Our goal was to develop a game that offers a more engaging experience, encouraging patients to overcome the challenges associated with moving their hands.

Given that the game is designed for individuals who have suffered a stroke, it needs to be adjusted to their specific needs and abilities. The game is integrated with a device that detects the Newtonian forces applied by the patient's fingers. These forces dictate the movement of a diver within the game. Due to the varying strengths of individual fingers, and the differences in maximum force each finger can exert—particularly when comparing stronger fingers like the index finger to weaker ones like the little finger—individualized adjustments are necessary. To address this, Dr. Shay, our mentor and physician, applies a balance parameter (factor multiplication) to calibrate the forces for each patient, ensuring that the game is appropriately challenging.

In our project, the objective is for the patient to guide a diver through a series of caves and reach the finish line before the oxygen supply runs out. The patient, who controls the diver, must avoid colliding with the caves, as each collision depletes the diver's oxygen. If the oxygen level reaches zero, the player fails the game. We recognized the need to implement varying difficulty levels for different patients, as each patient has unique performance capabilities and potential. This will be further elaborated on in subsequent sections.

We understood that our target audience is unique, and therefore special adaptations are required. For example, stroke survivors may have slower reaction times, from the moment they see a cave to when they understand the need to move up or down in response. Additionally, the strength in their hands, and specifically in each finger, varies, necessitating individual consideration of the forces applied by each finger.

Moreover, we aimed to encourage patients to improve their finger movement while avoiding frustration if they struggle. To achieve this, we ensured that oxygen depletion upon collision is set at a specific percentage determined by the doctor. This allows the patient to make multiple mistakes without significant penalty, giving them a chance to complete the game, even if their performance is not optimal. Our goal was to provide a sense of achievement and motivation to improve, contributing to both the physical and psychological well-being of the patients.

In collaboration with Dr. Shay, we decided to focus on one finger at a time rather than the entire hand. This approach allows us to monitor the improvement of a specific finger over a period of time, with each session targeting a different finger for focused rehabilitation.

Gameplay Mechanics

At the beginning of the game, various parameters are defined to adjust the difficulty level to the individual patient's abilities. In our game, the patient controls a diver, which symbolizes the finger the patient is training.

The diver appears on the screen and must navigate through a course consisting of walls and caves of varying sizes (the configurations of which are drawn from an Excel file, as will be detailed later). After each cave, the patient encounters a wall, directional arrows, and an oxygen balloon. The diver must follow the arrows to ascend over the wall and collide with the oxygen balloon to increase their oxygen level. The diver then continues to dive towards the next cave, repeating this sequence.

During the game, any collision with a cave results in a loss of oxygen, according to the parameters established at the start. Upon clearing the final cave, a treasure chest appears. Reaching this chest signifies the patient's victory in the game.

The objective for the diver is to successfully navigate through all the caves and reach the treasure chest before the oxygen supply is exhausted.

Critical Components of the Game Design

This section addresses the critical components and considerations that were essential during the development of our project. These include factors such as difficulty levels, patient focus, feedback on success or failure, the emotional experience of the patient, and the outcomes of gameplay.

Difficulty Adjustment Mechanisms

As previously mentioned, we ensured that the game could dynamically adjust to different difficulty levels, recognizing that each patient has a unique level of capability. The difficulty in our game is reflected in several aspects:

1. **Cave Quantity, Size, and Dimensions:** The number, size, height, and length of the caves are pre-determined and read from a data file. The longer the course, the smaller the caves, and the lower their height, the more challenging it becomes for the diver to navigate without colliding with the walls and thus losing oxygen. These parameters are set by the doctor based on the patient's abilities and the level of difficulty they can handle.

2. **Diver's Speed:** The upward speed of the diver is pre-set, while the downward speed depends on the forces exerted by the patient. As with the caves, the speed presents varying levels of difficulty. A higher upward speed demands quicker reactions from the patient to avoid obstacles, thereby increasing the difficulty level. The doctor can set the upward speed according to the patient's capability, ensuring the game remains challenging yet manageable.

3. **Oxygen Depletion and Recovery Time:** The amount of oxygen lost upon collision and the duration of the invincibility period (timeout) before the diver can be hit again are also adjusted based on the patient's level. Here, too, the difficulty varies: the more oxygen lost per collision, the lower the chances of completing the level, requiring the patient to

be more precise to avoid failure. The timeout between collisions allows the patient time to recover, preventing multiple consecutive hits from drastically reducing oxygen levels.

In summary, the doctor can adjust the game's difficulty to suit different patients. By adjusting these factors, the game can either challenge or ease the patient's experience, enabling a more focused, effective approach to improving finger movement.

Patient Engagement and Motivation

Our project aimed to achieve two crucial objectives:

1. Improving the patient's finger movement, with the ultimate goal of full hand rehabilitation.

2. Ensuring that the patient enjoys the game, motivating them to continue playing and, consequently, improving.

To accomplish these goals, we recognized the need for the game to be focused, visually appealing, dynamic, and enjoyable.

When we conceptualized the idea of the diver and the course that the diver would need to navigate, it became clear that we wanted to create an engaging experience. We aimed to make the patient feel as though they were genuinely a diver in the ocean, enhancing the game's appeal and drawing the patient into the experience.

We ensured that the ocean environment in the game looked as realistic as possible, with dynamic water visuals and a diver character animated with leg movements that simulate real swimming.

To maintain the patient's focus and minimize distractions from the gameplay and movement mechanics, we incorporated an oxygen meter that the player must monitor throughout the game. The patient needs to be aware of how much oxygen remains at each stage to avoid failing the level. Additionally, we implemented a progress bar to show the patient their current position on the course and how much further they need to go to complete the game. This approach allowed us to keep the patient focused on the primary objective of the game while simultaneously providing an engaging and visually appealing experience.

Feedback Mechanisms for Patient Performance

Providing feedback on success or failure during and at the end of the game is essential for motivating the patient and encouraging continued play. We implemented various methods to deliver this feedback throughout the game.

1. **Audio Feedback:** When the patient collides with a cave, a sound effect indicating impact is played, signaling to the player that a mistake has been made. Conversely, when the patient successfully collects an oxygen balloon, a positive sound is triggered, reinforcing the achievement. This auditory feedback helps the patient distinguish between correct and incorrect actions, guiding their behavior in the game.

2. **Visual Feedback:** In addition to audio cues, we incorporated visual feedback to enhance the patient's experience. When the diver collides with a cave, a red "blood" effect briefly appears around the edges of the screen, symbolizing the impact and indicating that the patient has made an error. However, this effect gradually fades, conveying that while the mistake was acknowledged, the patient can continue without being overly penalized.

3. **End-of-Level Feedback:** At the conclusion of a game session, the feedback shifts to either a success or failure screen, accompanied by corresponding music. If the diver's oxygen reaches zero, indicating failure, the patient is taken to a "Game Over" screen with an option to replay, accompanied by a tune that suggests disappointment. Conversely, if the patient successfully navigates to the end of the course, they are rewarded with a victory screen and triumphant music, reinforcing their success and encouraging further play.

This combination of auditory and visual feedback throughout the game ensures that the patients are continuously informed of their progress, receiving immediate responses to their actions, which helps maintain engagement and motivation.

Emotional Impact and Observed Outcomes

In a trial conducted with several patients, we observed a range of emotional responses as they engaged with the game. Patients exhibited a desire to progress further, often smiling when they succeeded and showing signs of disappointment when they collided with a cave.

These observations indicate that the patients were drawn to the game and emotionally invested in the experience. The patients' willingness to persevere, retry, and play the game multiple times to achieve success suggests that the game effectively motivated them and held their interest. This emotional engagement is a key indicator of the game's potential to support therapeutic outcomes by encouraging continued participation and effort.

Technical Explanations

To ensure that our project could meet its various objectives and cater to a broad range of patients, we needed to ensure that the game's parameters were both generic and precise, allowing for customization to meet each patient's specific needs. We focused on several key areas:

1. **Simulation Using Demo File:** We utilized a demo file containing force data provided by Dr. Shay to simulate the use of the device when we were not physically present with it. This approach allowed us to continue development and testing remotely, ensuring that the game could accurately respond to the forces that would be applied by the patient in a real-world scenario.

2. **Force Data Integration via UDP:** The forces applied by the Amadeo device were integrated into our game using a UDP connection. This connection enabled the game to read real-time data from the device, allowing the diver's movements to be controlled by the patient's finger strength.

3. **Cave Parameters from Excel File:** The parameters for generating the caves, such as their size, shape, and positioning, were read from an Excel file. This method allowed us to dynamically adjust the course design based on pre-defined data, making it easier to customize the difficulty level for each patient.

4. **Basic Game Parameters GUI:** We implemented a graphical user interface (GUI) to manage the basic parameters of the game. This interface made it simple to adjust the settings for different patients, ensuring that the game could be adjusted to their individual capabilities.

Detailed Explanation of Critical Components

Simulation Using Demo File: Reading from the demo file was particularly important for us. Since much of the project development occurred without physical access to the Amadeo device, we needed a way to accurately simulate the forces each finger would apply and how the game would respond to these forces. The data from these files also helped us calibrate the forces from the device, ensuring that the game accurately reflected the patient's interactions with the device.

As we can see here:

```
<Amadeo>17:48:48,13    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -0,400  0,000</Amadeo>
<Amadeo>17:48:48,14    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -0,450  0,000</Amadeo>
<Amadeo>17:48:48,15    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -0,500  0,000</Amadeo>
<Amadeo>17:48:48,16    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -0,550  0,000</Amadeo>
<Amadeo>17:48:48,17    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -0,600  0,000</Amadeo>
<Amadeo>17:48:48,18    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -0,650  0,000</Amadeo>
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<Amadeo>17:48:48,25    -0,250  -0,602  -0,561  -0,639  -0,751  -0,000  -0,000  -0,000  -1,000  0,000</Amadeo>
```

Figure 3: Simulation using demo file.

Force Data Integration: Real-time force data from the Amadeo device was transmitted via a UDP connection, enabling precise control of the diver's movements based on finger strength. We established a UDP connection on port 4444, as specified by Dr. Shay, to facilitate communication between the game and the Amadeo device. This connection allowed us to receive five distinct numerical values, each representing the force applied by a different finger.

Cave Parameters: For the creation of caves within the game, we read parameters from a file, including height, length, and diameter. The number of rows in the file corresponded to the number of caves generated in the game.

- **Height:** This parameter was designed to enhance the strength applied by the finger. By navigating lower caves, patients were encouraged to apply greater force.
- **Length:** This parameter was intended to improve the patient's ability to sustain the force over time. Longer caves required patients to maintain consistent pressure, aiding in the development of endurance.
- **Diameter:** This parameter aimed to improve the patient's precision. A narrower cave diameter demanded greater accuracy in finger movements to avoid collisions.

By carefully configuring these parameters, the game provided an adjusted experience that addressed different aspects of finger strength, endurance, and precision, thereby supporting the therapeutic goals for each patient.

As we can see here:

D	C	B	A	
cave length(0.2-1)	cave height(0-25)	cave diameter(0.2-0.8)	cave	1
1	5	0.5	1	2
0.8	10	0.3	2	3
0.7	8	0.5	3	4
1	7	0.5	4	5
0.9	4	0.3	5	6
0.7	1	0.2	6	7
0.6	5	0.4	7	8
0.4	10	0.3	8	9
1	7	0.4	9	10
0.4	6	0.3	10	11
0.8	4	0.3	11	12
0.5	8	0.2	12	13
1	6	0.5	13	14
0.6	10	0.2	14	15
0.7	4	0.3	15	16
0.5	6	0.2	16	17
0.5	7	0.4	17	18
1	6	0.3	18	19
0.8	7	0.4	19	20
0.5	10	0.5	20	21
				22

Figure 4: Parameters for generating caves.

Basic Game Parameters GUI: At the start of the game, the graphical user interface (GUI) allows for the configuration of several key parameters to adjust the gameplay experience for each session:

- **Finger Selection:** The specific finger to be used during the session can be selected, enabling focused training on individual fingers.
- **Forward Speed:** The general forward speed of the game can be set, independent of the patient's input. This controls the overall pace of the game as the diver progresses through the course.
- **Vertical Speed:** The speed at which the diver moves up or down is determined by the forces exerted by the patient. This parameter can be adjusted to match the patient's strength and responsiveness.
- **Oxygen Gain from Balloons:** The amount of oxygen increase when the diver collects an oxygen balloon can be configured, allowing for adjustments in the difficulty of maintaining sufficient oxygen levels.
- **Oxygen Loss from Collisions:** The amount of oxygen lost when the diver collides with a cave can be set, impacting the challenge of avoiding obstacles and conserving oxygen.

- **Oxygen Depletion Rate:** The rate and amount of oxygen depletion over time can be adjusted. This parameter controls the game's ongoing difficulty, independent of the patient's interactions, by setting how quickly oxygen decreases as the game progresses.

And on and on, that we will see in the image below.

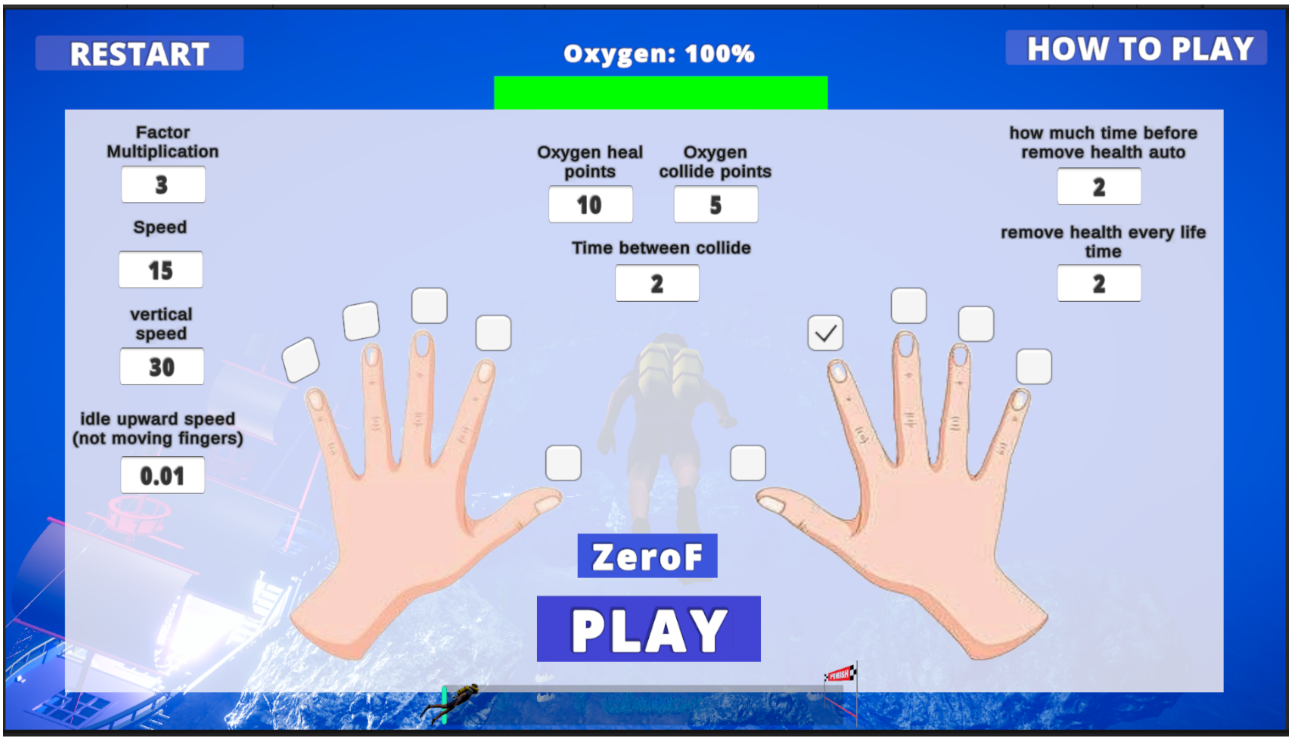

Figure 5: Graphical user interface for game parameters.

These configurable settings enable the game to be customized for each patient, ensuring that the gameplay experience is aligned with their therapeutic needs and abilities.

Chapter C: Evaluation of Game Performance through Patient Trials

Experimentation

Patient Participation and Methodology

Before conducting the experiment, we collaborated with the doctor who guided us throughout the year to ensure the game was optimally designed for the patients. The doctor explained that a patient's level of functionality could vary from day to day, making it difficult to predict their performance in advance. One of the key factors in a patient's success is their sense of achievement and motivation to progress. Therefore, it was essential to develop a dynamic game that adjusted in difficulty and responsiveness to the forces applied by the patient. Two games were developed to meet these requirements: one by our team and another by another group of students. Throughout the experiment, each patient played both developed games.

Experiment Procedure

1. **Participant Selection:** On the day of the experiment, we invited three participants with varying ages and functional abilities.

2. **Initial Setup and Testing:** The doctor connected each participant to the Amadeo device and allowed them to play the existing (old) game. This initial game served two key purposes:

   - **Assessment of Functional Level:** The doctor assessed the participant's current level of functionality, which enabled us to adjust the difficulty level of the new game accordingly. This approach aimed to ensure that the patient was sufficiently challenged to improve finger function while avoiding frustration.
   - **Immediate Feedback on Differences:** The participant experienced the physical and visual differences between the existing and newly developed games, providing real-time feedback on their preferences and areas for improvement.

3. **Gameplay and Feedback Collection:** After playing the existing game, the doctor assessed the participant's current functional level and adjusted the parameters of the new game (e.g., force, speed, and finger movement precision) to match their capabilities. We observed the participant engaging with the new game and tackling its challenges based on the assessed functionality. Following the completion of the first of the two new games, the participant was given a rest to allow their muscles to recover before playing the second game. After this break, the participant played the second new game.

4. **Post-Game Evaluation:** Upon completing each game, the development team conducted interviews with the participants to gather feedback on the respective game. This feedback provided valuable insights into the effectiveness of each game.

The experimental procedure was designed to ensure comprehensive evaluation of both games and to gather actionable feedback for ongoing improvements, ultimately aiming to enhance the therapeutic experience for patients.

Impressions from the Doctor

The experiment was conducted in collaboration with Dr. Shay. During the trial, Dr. Shay appeared satisfied with both the patient's responses and the level of force they were able to exert while playing our game. Dr. Shay observed that the patient's efforts were notably more pronounced and their motivation was higher, which in turn led to improved performance. Patients were able to engage with the game for longer periods of time and demonstrated a greater interest and willingness to continue playing, a significant improvement compared to their experience with the previous game.

Dr. Shay expressed approval of the game's dynamic nature. The ability to adjust the difficulty level for each individual patient was essential and provided valuable insight into each patient's progress in their rehabilitation process.

Ultimately, Dr. Shay enjoyed working with the patients using our game and believed that it could lead to better outcomes and offer a more tailored rehabilitation process for each patient.

Feedback and Responses from Patients

Participant 1: The first participant, a male in his 50s requiring rehabilitation for his left hand, expressed enthusiasm about playing the game. He shared that the game felt very realistic, drawing a comparison to real-life experiences. Having two stars in diving, he mentioned that the game brought back memories, even leading him to take deep breaths at certain points as if he were truly diving.

- **Design and Visuals:** He was particularly impressed with the visual elements, especially the diver character and the water effects. The oxygen balloons and caves significantly enhanced the gaming experience for him.
- **Understanding the Game:** He found the game easy to understand and user-friendly. Although he mentioned needing one practice round to familiarize himself with the controls, he quickly grasped the objectives. The upward-pointing arrows were especially helpful in guiding him through the game.
- **Difficulty Level:** The participant found the existing game (the one currently in use) more challenging and demanding than our game. In contrast, he didn't perceive our game as difficult because he was more engaged and interested in playing. The narrow caves in our game presented a challenge by requiring precision, which motivated him to continue playing. He appreciated the differences between the two games, noting that the existing game lacked a continuous process, as it simply required applying the right amount of force with the fingers to complete each level. In contrast, our game featured long caves where the patient had to maintain a consistent level of force throughout, with motivation provided by the oxygen level that decreased upon collisions. He emphasized that this element was missing in the existing game, and our game offered a better indicator of his abilities and the forces he could exert.

When asked which game he would prefer for continued rehabilitation, he was unequivocal in choosing our game, specifying the animations and overall experience as key reasons. He also shared that he generally feels anxious during tests, which affected his performance in the existing game due to repeated failures under pressure. In contrast, he didn't experience the same stress while playing our game and completely enjoyed the experience. When asked how long he could play our game, he responded that he could play for about an hour, whereas he could only manage 30 minutes with the existing game.

Participant 2: The second participant, a male in his 70s requiring rehabilitation for his left hand, reported enjoying the game during the post-game interview. He found our game easier to play, particularly because it focused on using one finger at a time, whereas the existing game required him to use multiple fingers simultaneously. When asked which game he would prefer, he clearly stated that he preferred our game, primarily because of the sound and visuals, which made the experience more pleasant and relaxing. He mentioned that he could play our game for about an hour, while he could only manage 30 minutes with the existing game.

Participant 3: The third participant, a 13-year-old male requiring rehabilitation for his right hand, expressed great enjoyment in playing our game. He stated that the gaming experience was much more enjoyable compared to the existing game, which he found less engaging. The participant was particularly impressed with the visual presentation, especially the treasure chest at the end of the game. The visuals contributed to a more pleasant and motivating experience, making him want to continue playing.

- **Challenge and Duration:** In terms of challenge, he noted that our game was more challenging but was interested in having breaks during the game. He mentioned that he could play our game for at least 30 minutes, whereas he could only manage about 10 minutes with the existing game. He felt that he was improving and becoming more precise as he played. At the end of the session, he mentioned that he already felt an improvement in the movement of his finger, even demonstrating a specific motion that he couldn't perform before playing our game.

These patient responses highlight the effectiveness and engagement potential of our game, proving that it not only provides a more enjoyable experience but also encourages longer and more focused play, which is critical to the success and improvement of rehabilitation.

Chapter D: Conclusions

Conclusion and Improvement Plan

In conclusion, our trial with the patients demonstrated that the rehabilitation experience was more enjoyable when using our game. The thoughtful attention to detail was evident in the positive responses from the patients, indicating that the game could be a valuable tool in their rehabilitation process. We were pleased to observe that the patients not only enjoyed the game but also showed a strong interest in continuing to play repeatedly.

However, we identified several areas for improvement to enhance the game further. First, we noticed that some patients required breaks during the game to adjust their fingers on the device or to rest them. Implementing a pause button would be beneficial, allowing the patient to resume the game from where they left off.
Additionally, we would like to introduce a scoring system at the end of the game to motivate patients for future sessions and to provide a clear indication of their progress. The score could be based on factors such as the amount of oxygen remaining at the end of the game or the difficulty level at which the patient participated. This feature would encourage patients to track their improvements and set goals for subsequent sessions.