Gamified Rehabilitation Education with Wearable Sensing-Assisted Extended Reality

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ABSTRACT

Venous thromboembolism (VTE) is one of the diseases that requires focused prevention during the perioperative recovery process and is a critical component of postoperative rehabilitation. This project integrates the needs of multiple doctors to create a virtual reality(VR) game that teaches and trains patients in VTE leg rehabilitation exercises through the use of wearable sensors. Finally, a series of experiments were conducted using this system, testing various metrics including educational effectiveness, user experience, and its ability to reduce pain and increase motivation for recovery compared to traditional rehabilitation methods.

Index Terms: Rehabilitation, VTE, virtual reality, gamification, wearable sensor, education.

1 INTRODUCTION

From the emergence of the VR headset known as the "Sword of Damocles" in 1968 to the current pervasive presence of extended reality (XR) in various aspects of life, the technology enabling interactive environments that blend real and virtual elements through computer technology and wearable devices has undergone rapid development and holds the potential to shape the future.

This project aims to explore the development of intelligent rehabilitation and health education branches in the medical field through the combination of XR and sensor technology. In this context, the project is applied to the Enhanced Recovery After Surgery (ERAS) domain. ERAS represents a novel concept and therapeutic recovery framework within 21st-century medicine. The primary objective is to mitigate the impact of surgery and its associated physical and psychological stress by optimizing various interventions during the perioperative phase. This, in turn, expedites patient recovery, diminishes postoperative complications, reduces mortality rates, shortens hospital stays, curtails healthcare expenditures, and eases societal and familial burdens. In general, this is an excellent rehabilitation model, but it is difficult to implement because of the need for joint coordination in many aspects. The output of this project will serve as a component of the ERAS initiative, intended to enhance the ERAS process and facilitate its smoother implementation.

To enhance the alignment of project outcomes with the hospital's requirements, the project team convened in-person meetings with the medical professionals and nursing staff responsible for post-surgical rehabilitation within the hospital. This exchange of information enabled us to gain insight into the challenges faced by the hospital in implementing the ERAS protocol and the hurdles encountered by patients during their post-surgical rehabilitation journey.

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To begin with, the hospital expressed the intent to utilize Extended Reality technology for perioperative measures aimed at preventing venous thromboembolism (VTE), a condition characterized by abnormal blood clot formation in the deep veins, particularly prevalent following surgical procedures and radiotherapy, primarily affecting the lower extremities. In principle, the risk of disease can be efficiently mitigated through mechanical preventive strategies, specifically VTE preventive exercises. This postoperative exercise regimen is a crucial component within the framework of ERAS.

Nevertheless, in the practical clinical context, the following challenges arise. First, VTE leg rehabilitation movements can cause pain for patients, often leading to their reluctance to engage in this preventive activity, thereby increasing the risk of thrombosis. How to motivate patients to complete these movements is a significant challenge. Second, VTE leg rehabilitation movements require teaching by medical professionals to ensure patients grasp and remember them, followed by further supervision to ensure the movements are correctly performed. This can lead to the issue of substantial medical resources being invested. Third, how to effectively integrate sensors, VR games, and medical rehabilitation, and ensure that all three components function effectively while maintaining patient interest, is a question that needs to be addressed.

To address the aforementioned issues, this project will develop a VR game on the Oculus Quest 3/Pro platform. Sensors will be integrated into the VR game as a module for detecting leg movements. Through the integration of VTE preventive exercises within the game, the objective is to preempt the development of perioperative VTE symptoms. Simultaneously, the game also serves the purpose of facilitating the comprehensive realization of the ERAS protocol. At the same time, both the content and process of the game have educational purposes. Patients, through playing this game, will acquire knowledge of VTE leg rehabilitation exercises.

2 RELATE WORK

This project integrates VR, gamification, sensors, rehabilitation, and education. It represents a highly unique research direction, and concurrently, it is just a small branch within the broader field of VR rehabilitation. This section elaborates on existing research in the field related to the project's relevant technologies and its theme. It is essential to demonstrate the feasibility of the project by analyzing the current state of the field.

2.1 Virtual Reality in Rehabilitation

Compared to traditional rehabilitation models, the application of VR in rehabilitation offers the following advantages, which align with the challenges faced by doctors in their practical work. Firstly, VR rehabilitation training, through gamified design and virtual environments, combines visual, auditory, and tactile sensory stimuli to provide a richer rehabilitation experience. This makes the rehabilitation process more engaging and appealing, thereby increasing patient participation and training motivation. At the same time, traditional rehabilitation models usually struggle to provide comprehensive multi-sensory training, resulting in relatively singular effects. VR rehabilitation effectively improves this aspect. Furthermore, VR systems can monitor patients' movements in real-time and provide instant feedback, helping patients promptly correct incorrect movements. The system can offer features such as real-time performance feedback, response modifications contingent on users' performance, and self-guided exploration. This helps to improve the inefficiencies and resource consumption issues associated with manual record-keeping in traditional rehabilitation.

In research on VR applications for lower limb rehabilitation, VR rehabilitation has demonstrated a variety of formats and minimal differences in effectiveness compared to traditional rehabilitation. Gazendam et al. (2021) compared the outcomes reported by patients using VR-based rehabilitation with those using traditional rehabilitation after total knee arthroplasty (TKA). The study demonstrated that VR-based rehabilitation could save significant costs and may offer advantages over traditional therapy for some patients. At the same time, VR rehabilitation can benefit from advanced rehabilitation models and medical concepts. For instance, VR applications based on the 'Bio-Psycho-Social model' (BPS) are proposed for pain management. In Ricardo et al.'s experiment on physical rehabilitation using serious games with smart wearable devices and virtual reality, smart sensors based on the Arduino Nano platform were developed for VR serious games aimed at hand and finger rehabilitation. By collecting and analyzing sensor data, this system can provide physical therapists with an objective assessment of rehabilitation effectiveness and help optimize training plans.

2.2 Gamification in Healthcare

In a research which organized most of the published literature on gamification in the fields of health and well-being and concluded: Most studies show that gamification has a positive impact on health behavior, especially in promoting activity. However, the motivation and pressure brought about by gamification vary according to different gamification methods [?]. This means that further exploration is needed on how to best design and implement gamification interventions.

Games can offer interesting and engaging tasks in purposeful and motivating environments, making them more dynamic than traditional repetitive rehabilitation treatments. Additionally, games can provide enjoyable and rewarding experiences, thereby increasing patient engagement and enthusiasm [?]. In the research by Oliver and Stefan, it is indicated that even simple gamification mechanisms can increase patient motivation(korn2017strategies). Gamification, by reorganizing existing activities rather than imposing additional demands, can align more seamlessly with individuals' daily lives, making it easier to be accepted and integrated into everyday routines. In a preliminary randomized controlled trial of using Nintendo Wii Fit for outpatient rehabilitation after total knee arthroplasty, long-term controlled experiments did not reveal significant differences in various measured indicators between the two methods. The positive impact of this study is that gamified sensors are acceptable as a physical therapy supplement for outpatient rehabilitation after total knee arthroplasty.

2.3 Game in Education

Teaching during the game is considered useful, especially for content that requires more memorization [?]. Basic elements in games, such as challenge and exploration, combined with the principles of game design, create more engaging learning environments to enhance student engagement and learning outcomes [?].

For educational purposes, games need to follow some patterns during the design phase [?]. Firstly, it is important to adhere to cognitive learning theory, which emphasizes interaction and feedback to facilitate learning. Specifically, challenges and tasks can be used to stimulate players' cognitive processes, helping them construct new knowledge structures [?]. When game design adheres to the concept of flow, players, with the progressive increase in difficulty levels, intentionally grasp more content to meet the challenges presented in the game [?]. Additionally, by following situated learning theory, learning content can be embedded in meaningful contexts and stories, enabling players to learn and apply knowledge in practice. The game framework should also adhere to constructivist learning theory, which posits that learning is an active, constructive process where learners build knowledge through interaction with the environment [?].

3 METHODOLOGY

To address the issues outlined in the introduction and to achieve the goals of education and rehabilitation, we developed the following system. Firstly, a game developed in Unity will be packaged into an APK and run on the headset. The sensor data worn by patients will be analyzed through the Python side and then sent to the game. The game is a story-driven first-person adventure game, where levels are completed by performing specific leg movements. The game component is central to achieving the project's objectives. The design and development of the game referenced the four elements of games proposed by Professor Jessel Schell from Carnegie Mellon University, the views on flow in games by Jenova Chen, as well as various other game design frameworks and theories.

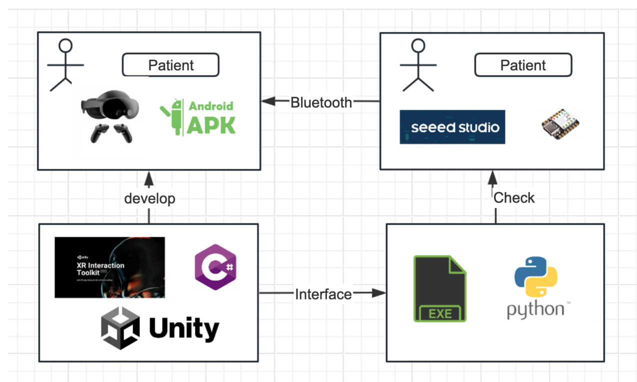

Figure 1: Project Overview Architecture

This section will elaborate on the project from three perspectives: project hardware/software components, mechanism design (functionalities, motivation, flow, etc.), and implementation (VR game, sensors).

3.1 Project Composition

The game is developed using the Unity3D game engine (2020.3.18f1c1) on the software side. Utilizing the Oculus Integration SDK. In terms of hardware, this project utilizes the Oculus Quest3 head-mounted display (HMD). This device supports 6 degrees of freedom inside-out SLAM tracking. Its powerful performance can support a gaming experience with 2K resolution at 120 frames per second, as well as rendering high-quality post-processing and global illumination [?]. Utilizing the XIAO SAMD21 sensor, which is the size of a thumb, facilitates easy wearing. Meanwhile, it supports Bluetooth for information transmission, contributing to a convenient wearing experience [?]. In this project, participants are required to lie semi-recumbent in bed, with three sensors attached to each leg to monitor leg movements. The three sensors are fixed on the patient's dorsum of the foot, calf, and thigh, respectively. The sensors will be encased in a 3D-printed shell and attached to the patient's leg with an elastic band.

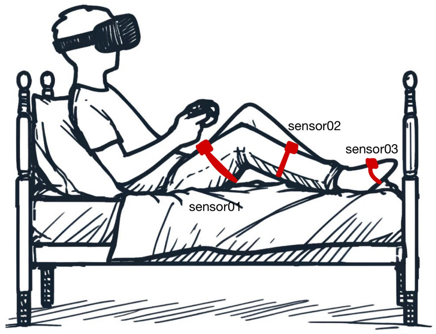

Figure 2: Project User Posture

3.2 Mechanics

Mechanics are a crucial aspect of game design and are the underlying reason why this game is able to achieve its educational goals and enhance motivation for rehabilitation. This section will explain how gameplay, flow, and motivation are integrated.

3.2.1 Basic VR Game Function

The game will be designed as a linear first-person story-driven VR game, using a closed sandbox map environment set in nature. The essence of the game is a walking simulator, where obstacles on the road require the player to perform specific leg rehabilitation movements to pass through. The game's user experience will be designed in a relaxed and soothing mode. Along the way, players can enjoy beautiful natural scenery while having appropriate goals to motivate them to move forward. The game experience will be relatively easy, and the difficulty level will be set low. The purpose of this is to consider that patients undergoing leg rehabilitation may be unfamiliar with VR games, and complex game content may affect the overall rehabilitation effect. VR rehabilitation games based on HMD devices can attract patients to actively engage in rehabilitation behaviors through gamification of the rehabilitation process, thereby promoting the implementation of the ERAS process. Due to the instructive nature and educational purposes of the game, players gradually master the relevant actions in VTE rehabilitation during the gaming process. They can subsequently complete these actions without the guidance of a doctor, thus accelerating the recovery process. Meanwhile, wearable sensors, serving as a reliable data acquisition tool, ensure the standardization of patients' rehabilitation movements.

3.2.2 VR Game Motivation Design

In addition to the intrinsic motivation brought by the VR medium itself, there is also sustained motivation during the gaming process [?]. Humans need to repetitively perform tasks in which they excel in the game to receive positive feedback, acquire attributes within the game to compensate for inherent deficiencies, and alleviate potential feelings of insecurity. The positive feedback in the game refers to the achieved outcomes of actions on environmental objects aligning with the player's expectations. When receiving positive feedback, the brain produces positive responses such as dopamine and serotonin, creating successful scenario memories, environmental memories, and behavioral memories in the brain. On a specific level of behavior, it involves seeking similar environments in the game and validating them through actions [?, ?]. This positive feedback loop can drive memory to achieve the educational goals of the game. In games, human deficiencies are commonly manifested as a lack of positive feedback and a sense of achievement deficiency. Meanwhile, abilities in games are demonstrated through operational proficiency, such as movement, exploration, destruction, and repetition. To achieve these motivations, simulation, and optimization are necessary in the game world [?]. In other words, players need to leverage their strengths in similar situations and/or fulfill external conditions required to compensate for deficiencies. It is important to note that the construction of scenarios is not about real-world situations but rather the contexts understood by the players [?]. For example, players may not pay attention to why there are pipes on Mario's journey to rescue the princess but will instead employ their skills in jumping.

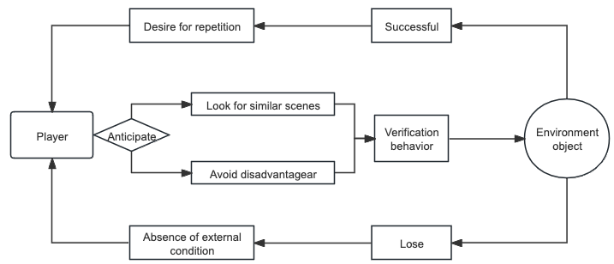

Figure 3: Game Motivation Design

In this project, the positive feedback received by players upon completing leg training, along with the motivation to repeat the process by seeking similar scenarios in the game, forms a positive feedback loop. To avoid getting stuck in the game and to promote learning behaviors, the psychological drive to overcome obstacles in the game is encouraged [?]. The synergistic effect of these two forces ensures that players have sufficient motivation during the gaming experience.

3.2.3 Game Flow and Narrative Rhythm Design

The flow in the game refers to a state similar to a time standstill that occurs when players are fully immersed in the game. Being in a state of flow in the game signifies the utmost engagement, and to achieve this, it is necessary to provide players with challenges that align with their current abilities in the game [?]. The escalation of this difficulty creates a pathway(flow path), and we must ensure that the challenge level currently faced by the player is within that pathway. If it is excessively easy, players may find it boring; conversely, it can lead to anxiety if it is too challenging [?]. In the current project, the level of difficulty is manifested by the number of leg rehabilitation movements that players need to memorize. In the beginning, there is only one action, In the end, six actions need to be applied in the map. The gradual increase in difficulty aligns with the concept of flow, and such a design also follows the process of learning and then reviewing in the sequencing of rehabilitation movements within the game [?].

In this project, to better achieve educational objectives, we employ the tension curve method for difficulty settings. The tension curve, which represents the tension of the player in the game, can be determined by the narrative rhythm, and the game difficulty [?]. It is worth noting that, while the overall tension should continue to rise to align with the flow, it should not be a constant upward trajectory. When constructing narrative pacing and difficulty, it is necessary to segment them to allow players to invest their attention more effectively in the game. This kind of narrative design is applied in most games, and another purpose is to help players master the introduction of new mechanisms in the game [?]. This pattern is

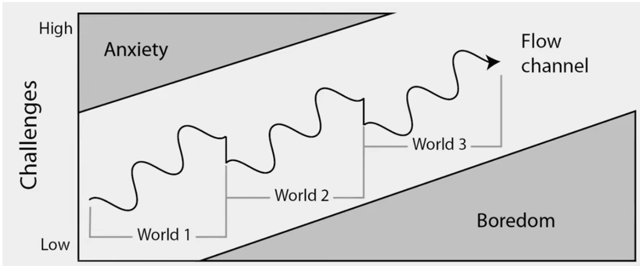

Figure 4: Game Flow

also used in the project to enable players to quickly remember the leg rehabilitation exercises during the game process.

3.3 VR Game Implementation

The implementation section will detail the specific realization of the mechanism design as well as the design of the game UI/UX.

3.3.1 Level Implementation

The game's storyline is inspired by the book ”A Man's Pilgrimage.” The game tells the story of an introverted and sensitive old man who suddenly receives a letter from an old friend he hasn't seen in years. In the letter, he learns that his old friend has cancer and doesn't have much time left, so he decides to set off to visit his friend. Along the way, the old man unveils the secrets buried in his heart. In his youth, the old man's timidity hurt the old friend mentioned in the letter, which led to his attitude of avoiding and escaping into a solitary life, and also caused his wife and children to leave him. The people and scenery he encountered on the road made the old man reflect on himself and decide to face the future life with a new attitude.

In the game progression, players need to pass through four scenes: a riverside village, a rainforest cave, a volcanic island, and a Chinese-style city. To navigate through these scenes, players must complete seven different types of levels that cover the range of motions required for VTE leg rehabilitation. The levels take the form of obstacles along the path, such as boxes that need to be climbed over and log bridges that need to be crossed. To pass the levels, players must perform the corresponding leg movements. When players encounter a level for the first time, there will be a tutorial on the movement. Levels are repeated to help the player review the actions, and players can pass if they remember the actions, but need to check the prompts if they forget them.

To align with the teaching function mentioned earlier, the rehabilitation movements comply with the flow state in the following two aspects. First is the frequency of new movements appearing, which indicates the intensity of active memory required by the player, as well as the intensity of recall needed. In the early stages of the game, players need to master fewer movements, which are repeated frequently.

The second aspect is the difficulty of the movements. As the player's understanding of the game deepens from beginning to end, the movements that need to be mastered gradually become more challenging. For example, in the early stages, the movements only require reaching a specific position, while in the later stages, the movements require maintaining a position for a certain period after reaching the specified position. Such implementation ensures that the design matches the player's abilities, keeping the player in the flow channel at all times, thereby increasing their sense of immersion.

The essence of the levels is the specific environment, which provides stimuli and aids in the player's memory [**?**]. Players form positive feedback through specific environments, creating motivation for repeated experiences when encountering the same environments. Such level design aligns with the motivation design in game design and helps increase the player's motivation to play the game.

3.3.2 User Experience & User Interface Implementation

The game's UI is divided into two types: non-interactive narrative UI and interactive instructional UI. In order to achieve the teaching objectives, the design of UX and UI should adhere to the following principles.

- **Responsiveness:** Interactions are smooth and responses are prompt
- **Intention:** Focus is directed to key actions and paths as needed
- **Awareness:** Elements adaptively respond from their respective positions
- **Consistency:** Elements employ repeated dynamic patterns to reinforce habits
- **Physical Intuition:** Create content that aligns with the intuitive understanding of game elements

The non-interactive narrative UI serves to complement the game's storyline, enhance the motivation to play the game, and increase immersion. Additionally, their appearance provides guidance on the direction of progress for characters within the game. For example, if the player needs to pass through a cave to reach the next level in the game, this type of UI will appear at the appropriate time to tell the player that the cave seems to be inhabited and they should hurry through. These UI elements inform the player of their current status and the upcoming task, increasing their motivation to play and enhancing immersion through clear guidance.

For interactive instructional UI, the interaction occurs when the player's controller's ray touches an interactive object. The object will highlight, the controller will vibrate, and the UI will appear. When the player presses the middle finger trigger on the controller, more UI content will be displayed. The purpose of this design is that the UI content that appears after pressing the trigger contains game hints, which should not be directly shown to the player. To help players master this UI system, the first segment of the game, ”Reading the Letter,” teaches this function. Players need to learn the most basic interactions: highlighting interactive objects (selecting the mailbox) and selecting interactive objects (opening the letter). This approach breaks down the operations, starting with the simplest steps for teaching, to bring a good experience for the subsequent game.

3.4 Wearable Sensing Method

The sensors will be attached to the patient's legs, and based on their position and angle, it will be determined whether specific leg movements are completed and the degree of completion. These data will be input into the game as conditions for level pass. In the project, motion detection and Bluetooth auto-connection are implemented using Python code and packaged into an executable (exe) file. Once the exe file is executed, the computer automatically connects to the sensor Bluetooth, a process that takes about 10 seconds. The external exe file connects with the game inside Unity using UDP communication to send and receive data, enabling remote operation or monitoring. IP endpoints and ports for sending (tx) and receiving (rx) data are defined in Unity, meaning that the Unity side will first send data to the exe side to notify it of the type of action to detect. Data is continuously received through a background thread to ensure that information is still received even when the game is processing other tasks. Once an action is detected and verified, data is

Figure 5: Instructional UI Interaction Process

Figure 6: Levels in Game

sent back to Unity. Additionally, the receiving thread is terminated and the UDP client is closed upon application exit or disable events to handle cleanup and prevent resource leaks.

4 'Experiment' or 'Evaluation'

The main purpose of the experiment in this project is to assess the user experience of the game and determine if its educational objectives are being achieved. Unlike other types of rehabilitation, VTE leg rehabilitation exercises is preventive, making it difficult to assess its effectiveness. The following outlines the questions this project aims to explore.

- Does this game provide players with positive cues that promote a positive feedback loop?
- Whether using VR for VTE leg rehabilitation training can reduce pain and increase motivation for recovery compared to traditional methods.
- Does the game achieve its educational objectives? Whether the game level scenes help patients remember the rehabilitation exercises.
- The level of the game's Sensory and Imaginative Immersion, level design flow, and narrative tension.

4.1 Method

This section introduces the data collection methods and procedures used in the experiment. To cover all the research questions, the project includes two stages of experimentation, which will be referred to as Study 1 and Study 2 in the following sections. Participants in each group will complete either one or three questionnaires at the conclusion of the experiment.

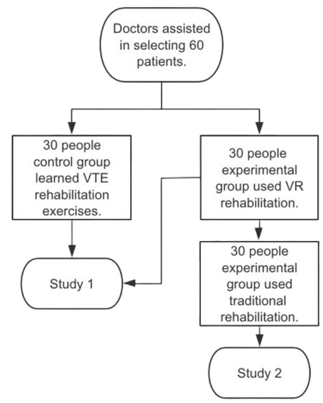

Figure 7: Project Two Stages of Experimentation Process

4.1.1 Procedures

The project first involved relevant hospitals to determine the testing requirements, followed by related doctors playing the game and providing evaluations. Due to VR-induced dizziness, this game is not suitable for everyone. Based on the patients' physical conditions and willingness, doctors gradually arranged for 30 patients to experience the game. The procedure for **study2** is as follows:

1 Explain the purpose and process of the game to the patients and have them sign the relevant consent forms (3 minutes)

2 Assist patients in wearing sensors and display devices, providing a brief explanation of their usage (3 minutes).

3 Patients commence the gaming session (15 minutes).

4 Patients complete the survey questionnaire (GEQ, UEQ, VAS) and relevant tests (5-10 minutes).

5 One day later, the patients will perform VTE rehabilitation exercises using traditional methods and complete the related questionnaires (UEQ, VAS, Supplementary Questionnaire) (5-10 minutes).

6 Conduct a brief interview with patients (3-10 minutes).

Figure 8: The participants played the game under the supervision of a doctor

About **study1**, to test the educational effectiveness, a control group was set up to learn the VTE leg rehabilitation process using traditional methods, including doctor explanations and reading relevant materials. Based on the doctor's experience, this process will take approximately 5 to 10 minutes. Next, test how many VTE leg rehabilitation movements the control group can accurately remember after one day. This data will be compared with the data from the Supplementary Questionnaire previously completed by the experimental group. All studies in this paper were approved by the Ethics Committee of the University of Nottingham Ningbo China and informed consent was obtained from all participants.

4.1.2 Data Collection Method

Study 1 utilized the Game Experience Questionnaire (GEQ), the User Experience Questionnaire (UEQ) and Visual Analog Scale (VAS) for Pain. The GEQ was developed based on rigorous academic research. It involved empirical testing, validation, and refinement to ensure that it reliably measures the constructs of interest [**?**]. GEQ is authoritative and can measure various indicators such as immersion, flow, and motivation to play. Since this project involves not only the game part but also a sensor-based leg rehabilitation system, the UEQ is used to measure the test subjects' overall user experience of the system. The UEQ is an authoritative user experience questionnaire widely used in the field of human-computer interaction and product testing [**?**]. It provides an overall user experience across three aspects: sensors, VR games, and rehabilitation tutorials, covering six dimensions, including Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. Additionally, some metrics of this questionnaire, such as "easy to learn," can also measure the success of the game UI design. By comparing the user experiences of the two groups, we aim to explore the advantages and disadvantages of VR rehabilitation compared to traditional methods. The VAS was used to verify whether VR rehabilitation is more effective in reducing pain compared to traditional rehabilitation. This is a commonly used method for assessing pain levels, which collects subjective pain perceptions through a simple line-marking.

Supplementary Questionnaire was used in Study 2 to assess the educational effectiveness of the project. The questionnaire collected data on how many VTE leg rehabilitation movements participants could clearly remember and whether they agreed that specific level scenes were helpful in remembering leg rehabilitation movements.

Table 1: Supplementary Questionnaire for Education

Items (5 point Likert scale, 0 = strongly disagree, 5 = strongly agree)
- How many VTE leg rehabilitation movements can you clearly remember? - Specific level scenes are helpful for you to remember leg rehabilitation movements. - Seeing the scenes in the game can remind you of the corresponding leg rehabilitation movements.

Additionally, the patients' states during gameplay and their verbal feedback upon completion will also be considered as part of the evaluation. These interviews help us better explain some of the phenomena observed in the data.

4.2 Results

According to the scoring guidelines of the GEQ core module, scores were obtained for the following aspects: Competence, Sensory and Imaginative Immersion, Flow, Tension/Annoyance, Challenge, Negative affect, and Positive affect. Under the premise of a full score of 4, the scores from the first stage of the experiment were 3.27, 3.83, 3.22, 2.2, 2.16, 0.94, and 3.32, respectively. The data indicates that the vast majority of players felt they had good control over their character and were fully immersed in the game. The game can provide most patients with appropriate levels of pressure and tension, placing them in a state of flow. Additionally, the last two data points indicate that the game brought about positive emotions, which aligns with the expected user experience the game aims to provide to players.

The analysis of UEQ data is conducted according to the UEQ data analysis tool version 12. The UEQ consists of 26 questions that can reflect the performance in six dimensions: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. According to the data analysis standard, scores between -0.8 and +0.8 are considered neutral evaluations, with scores greater than or less than these values representing positive or negative evaluations, respectively. After observing the values of individual items to detect anomalies according to the rules, the data distribution of the two groups is as follows:

UEQ Scales (Mean and Variance)				
	Experimental Group		Control Group	
Attractiveness	↑2.237	0.16	↑0.896	0.53
Perspicuity	↑1.012	0.53	↑2.323	0.08
Efficiency	↑0.979	0.47	↑2.279	0.26
Dependability	↑1.137	0.34	↑1.763	0.17
Stimulation	↑2.058	0.19	↑0.944	0.32
Novelty	↑2.182	0.35	↓0.675	0.41

Figure 9: UEQ Scale

The average VAS score collected after VTE leg rehabilitation using the VR method was 1.82, while the traditional method yielded an average score of 2.66. In interviews, volunteers indicated that the VR environment helped reduce their attention to leg movements and pain, as part of their focus was diverted to whether they could pass the level.

In the test of the game's instructional content, participants in the study1 remembered an average of 5.8/7 leg rehabilitation movements after one day. This is a significant improvement compared to the control group, which only watched text and illustrations, with an average of 4.3/7 movements remembered after one day. In exploring the question of whether specific level scenes are helpful for remembering leg rehabilitation movements, the collected data supports this view (4.34/5). Regarding the question of whether one can associate the level with the corresponding leg rehabilitation movement, the score was 4.65/5.

5 Discussion

The data for each dimension of the GEQ aligned well with expectations. These results indicate that most players were immersed in the game, quickly mastering it and entering a state of "flow." Based on observations during the experiment, players rarely encountered difficulties in understanding how to operate the game after completing the first level and were able to quickly progress through the game. The questionnaire results indicate that the game provides an appropriate level of pressure and challenge while also eliciting positive emotions. This may be related to the strong guidance within the game and the absence of failure penalties. Interviews with participants who reported negative emotions on the questionnaire revealed that 3D motion sickness experienced during gameplay made them unwilling to continue the game. It is also worth noting from the interviews that the sense of immersion in the game is not only brought about by the game content itself, but also significantly enhanced by the VR medium.

Another noteworthy point is that after the game's development was completed, 20 student volunteers were invited to play and fill out the GEQ questionnaire. The comparison of data between the two groups is as follows.

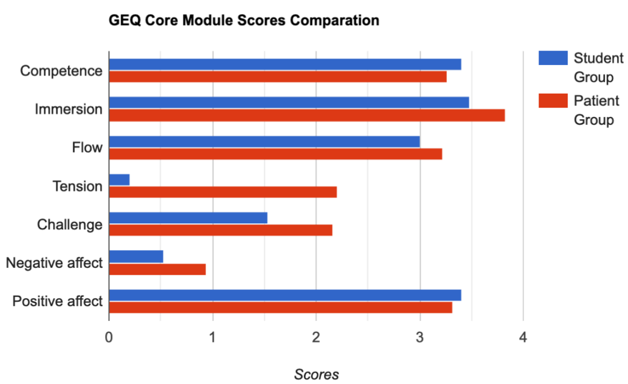

Figure 10: GEQ Core Module Scores Comparation

It can be observed that the student group exhibited lower levels of tension and challenge, indicating that the lack of these elements may be related to factors such as identity, age, familiarity with the gaming medium, and familiarity with the experiment's initiators.

The UEQ data presented the user experience of the same group of people after experiencing both VR rehabilitation and traditional rehabilitation. It can be observed that VR rehabilitation has significant advantages in the areas of attractiveness, stimulation, and novelty. These data suggest that the VR gaming experience plays a role in enhancing motivation during the patient's rehabilitation process. This perspective is also reflected in the VAS data, indicating that the VR virtual environment helps reduce the sensation of pain during rehabilitation. The traditional rehabilitation method performed better in terms of perspicuity, efficiency, and dependability. Possible reasons for this, based on interviews, include: 1) the time required to put on sensors and VR equipment, 2) slight dizziness and comfort issues during gameplay, and 3) the virtual environment diminishing the player's sense of movement perception and control. Overall, the UEQ scores of the experimental group were all above 0.8, indicating a positive range, which demonstrates that the system provided a good user experience. It is worth noting that during the questionnaire completion process, patients occasionally requested explanations of the questions, which may have contributed to the larger variance in some of the data.

Since the supplementary questionnaire was not professionally designed, its content may contain leading questions or unreasonable question arrangements, which greatly reduces the reliability of the overall data. Additionally, there are issues with the design of the control group in the experiment. Although the experiment increased the average number of leg rehabilitation movements compared to the control group, this only proves that the game has a teaching effect. However, it cannot prove that the game is a better teaching method than watching written tutorials. This is because it is impossible to control the time players spend watching tutorials in the game, so the duration and frequency of tutorial viewing cannot be standardized between the two groups of players. Regarding the question of whether the levels in the game help with memory, the questionnaire attempts to answer this through a series of questions about whether the levels can be associated with leg rehabilitation movements. However, to prove this, it should be based on whether the environment can evoke forgotten movement memories, which requires more extensive data support. The current questionnaire's exploration of this issue may contain leading questions, and its reliability needs to be questioned.

During the interview phase of the experiment, we received much praise for the project's innovation, novel experience, and game content. However, we also learned that mild VR-induced dizziness and issues with the comfort of wearing the headset and sensors were significant factors affecting the user experience. According to the interviews, most participants considered the project to be a good one-time educational tool, but not suitable for regular use in rehabilitation activities, as the time required for donning the equipment was considered too long.

6 Limitation and Future Work

In terms of game, while VR provides a strong sense of immersion, it sacrifices the player's ability to see their own leg movements. Visual stimulation can enhance the memory of movements. This involves enhancing memory and perception of movements through visual information [**?**]. Another limitation occurs in the area of motion feedback. The addition of sensors allows the project to detect player movements, but there is a lack of guidance and feedback for the player's movements. In other words, players do not know whether they are correctly completing the movement; and if the movement fails, the reason for the failure is not clear. In terms of experimentation, the findings from Study 2 only demonstrate that the game has educational capabilities; however, they do not provide evidence that VR is a more effective medium compared to traditional methods. Additionally, more evidence is required to confirm that the in-game scenes effectively aid in completing movement memory.

In terms of the project's functionality, we recognize that due to the limitations of the game's story-driven mode, it is not well-suited for repeated play. The lack of corresponding reward mechanisms and challenging objectives that encourage players to spend more time in the game has resulted in low desire for replay. In the future, we may position it as a one-time experience game, with a focus on teaching VTE leg rehabilitation exercises.

In terms of game, the project anticipates implementing AR functionality in the future. Specifically, when the user presses the left trigger, part of the game's visuals will not be rendered, and instead, the external scene captured by the VR headset's built-in camera will replace the in-game visuals. Players can see their legs through this window. The game will also add text instructions and error prompts during the player's rehabilitation exercise to provide real-time feedback. It is hoped that this modification will enhance users' awareness of their actions through the system. To implement this feature, it is necessary to integrate an AI motion correction model into the Python side of the sensor, input the data into it, and after analysis, display it in a way that can be understood by the player on the game's UI interface. In terms of experimentation, future considerations include monitoring patients' EEG under different rehabilitation methods. This data will allow for a more objective analysis of the project's effectiveness in enhancing patient motivation for recovery and assisting in memory retention.

7 Conclusion

The project combines VR games with sensors to develop a training and instructional solution for VTE leg rehabilitation exercises and includes conducting a series of experiments. First, based on theories such as flow, positive feedback loops, and Jesse Schell's four elements of game design, the game was developed with mechanics and technology as the core, and aesthetics and user experience as the forms of expression. The subsequent experiments validated the project's performance in terms of user experience and educational capability, demonstrating that this VR rehabilitation model can help reduce pain and enhance motivation for recovery. Through experiments and reflection, we also identified shortcomings in the project, particularly in terms of player movement feedback and experimental design. We hope to improve this system in the future and conduct more objective experiments.

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