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GAMIFICATION OF POST-STROKE NEUROMOTOR REHABILITATION EXERCISES USING HAND TRACKING IN VR

BY

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Abstract. The main goal of this study is to develop a gaming platform for people who have had a stroke and are going through various stages of neuromotor rehabilitation. The main idea is that regular recovery activities are boring and repetitive, which might make people less interested in being in therapy. By including enjoyable but practical games into workout routines, there is potential to enhance patients' motivation. To ensure the accuracy and reliability of the system, a validation process was conducted with the help of two stroke patients now undergoing rehabilitation at the Clinical Rehabilitation Hospital in Iași. The parameters were adjusted based on individual patient characteristics, and a total of 12 tests were conducted, from which various results were obtained. At the end of the clinical trial, feedback was gathered from patients in order to get first-hand perspectives from the intended users of the system and identify areas for potential system enhancement. In the end, this research has demonstrated some of the benefits and potential uses of virtual reality (VR) technology in patient rehabilitation, and the participants in the clinical study have found it to be positive and useful.

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Key words: medical recovery, serious games, upper-limb rehabilitation, clinical study.

1. Introduction

Stroke is a neurological condition characterized by impairment of the central nervous system, resulting in the potential for partial or total loss of motor function. This may significantly impact an individual's capacity to engage in fundamental tasks of everyday life. Throughout the years, a multitude of therapies have surfaced; nonetheless, neuromotor recovery activities have always maintained their significance within the realm of post-stroke rehabilitation. These interventions facilitate the restoration of mobility and motor coordination, as well as enhance hand and finger functioning.

The conventional exercises, while significant, may become tedious and uninspiring for patients, resulting in less involvement and suboptimal results over the rehabilitation journey. One potential approach is the use of gamification techniques in exercise regimens. By incorporating various methodologies, this strategy introduces an element of enjoyment for patients. Through the use of motion and hand tracking technology, individuals may engage in games that imitate certain interactions related to rehabilitation activities.

The use of Virtual Reality (VR) has seen significant growth in recent years, therefore establishing itself as a technology that is more accessible to individuals for personal usage inside their own homes. One notable advancement in the field of virtual reality (VR) pertains to hand tracking, which involves the capacity to monitor and record the motions of a user's hands and fingers inside the virtual world (Lupu *et al.*, 2018; Tsatsis *et al.*, 2017). This is achieved via the utilization of cameras, hence eliminating the need for supplementary control devices like controllers or specialized gloves.

For this reason, using virtual reality and hand tracking to add games to rehabilitation exercises has a lot of potential as a workable solution. This would let patients interact with the virtual world using their own hands and fingers. Virtual reality (VR) technology offers a highly immersive and engaging environment that enables patients to engage in workout activities in an interactive manner (Chatterjee *et al.*, 2022). Simultaneously, patients have the opportunity to engage in games using a scoring system that simulates ordinary life circumstances in a controlled setting, therefore exposing them to realistic scenarios and activities.

An application that utilizes virtual reality (VR) for this specific purpose must adhere to a set of fundamental requirements. First and foremost, the program should include a diverse range of exercises that encompass many facets of hand and finger mobility and coordination. The exercises need to possess adaptability in order to cater to the individual requirements of each

patient. This adaptability should manifest in the form of a gradual increase in difficulty level, thereby facilitating the patient's progress from one session to another.

Simultaneously, it is essential for the application to include gamification components in order to sustain patients' motivation during their rehabilitation sessions. This category encompasses several elements, including the incentive system, the system of levels or stages, and the capability to visually and interactively monitor personal progress. Simultaneously, the aforementioned data has significant importance and pertinence for therapists and clinicians in the process of modifying the recovery plan and assessing the efficacy of therapy.

1.1. Stroke

Stroke, referred to as the 'disease of the century' in popular discourse, is a medical phenomenon characterized by its sudden onset and potential for grave health implications (NINDS, 2023). Stroke is a medical condition characterized by the interruption or reduction of blood flow to the brain, resulting in the potential death of brain tissue. This process has the potential to elicit a variety of symptoms and impact crucial physiological systems, including motor skills and cognitive abilities.

The occurrence of a stroke may result in many manifestations inside the brain, which are contingent upon the specific region that has been impacted. In the event that a stroke impacts the cerebral region associated with motor abilities, individuals may experience a loss of movement control. For instance, individuals may have challenges or face limitations in raising an arm or leg or in effectively synchronizing their motions. In the event that a stroke transpires inside the cerebral region accountable for speech, the individual may encounter challenges in both verbal expression and comprehension of language. In some instances, it is possible for the patient to possess the ability to vocalize; however, they have challenges engaging in meaningful discourse due to incoherent or nonsensical speech patterns. Stroke has the potential to impact cognitive functioning, including reasoning abilities and memory.

The treatment of stroke varies across patients, depending upon the specific location of the afflicted region and the degree of severity of the problem. In some instances, surgical intervention may be necessary to extract blood clots or halt hemorrhaging. In some situations, giving drugs to lower blood pressure or lower the chance of blood clots forming is seen as enough. Physical and occupational therapy might potentially provide assistance in the restoration of motor abilities for patients.

In summary, stroke is a significant medical ailment that has substantial health implications, necessitating a multifaceted treatment approach including both medicinal treatments and rehabilitative therapy. Nevertheless, with

effective treatment and diligent care, a significant number of individuals afflicted by stroke may experience a substantial recovery and achieve an enhanced standard of living.

1.2. Post-stroke rehabilitation

The process of recovering after a stroke is known to be lengthy and challenging, necessitating a comprehensive approach that encompasses both medical treatments and rehabilitation therapy (Lupu *et al.*, 2018). There are several therapeutic modalities, including physical therapy, mobility exercises, occupational therapy centered on enhancing activities of daily living, and speech therapy aimed at the restoration of communication abilities.

Physical therapy plays a crucial role in the process of stroke rehabilitation. The activity entails engaging in deliberate physical actions that facilitate the reestablishment of brain pathways and enhance motor coordination. Physical therapy encompasses a range of therapeutic interventions, such as gait and balance exercises, along with muscle-strengthening activities. By engaging in these prescribed activities, individuals may start the process of reestablishing command over their bodily motions and enhancing their motor coordination abilities. Furthermore, the use of physical therapy has the potential to mitigate the occurrence of problems, such as muscular atrophy.

The significance of occupational therapy is equally apparent within the context of the rehabilitation process. The primary objective of this intervention is to facilitate the restoration of fine motor skills and hand-eye coordination while also enhancing the individual's ability to effectively engage in and manage their everyday activities. This therapeutic approach includes activities involving the manipulation of objects, as seen in Fig. 1, with exercises aimed at enhancing writing and speaking proficiency. Occupational therapy facilitates the restoration of patients' autonomy and enhances their ability to engage in everyday activities with greater ease.

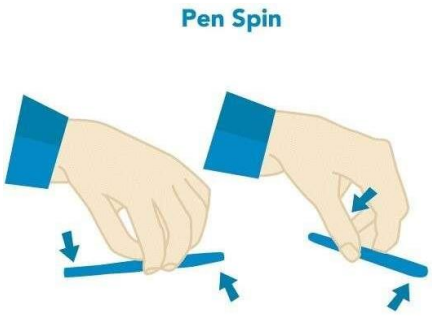

Fig. 1 – Example of an exercise (Hoffman, 2018) involving the turning of a pen.

In order to optimize stroke rehabilitation, frequent exercise is of paramount importance. These exercises have the potential to facilitate the restoration of mobility and motor coordination while also aiding in the recovery of hand and finger functions. The design of exercises should be customized to accommodate the specific requirements of individual patients, taking into consideration the afflicted region. Furthermore, it is crucial for these exercises to gradually increase in complexity in order to facilitate continuous improvement and development across successive sessions.

Post-stroke rehabilitation exercises

Exercise is essential for the rehabilitation of stroke patients because it helps therapists and medical professionals restore their functional abilities. Various activities, such as obstacle courses and skill games, might be used in this particular procedure (Hoffman, 2018). The exercises provided are customized to accommodate the individual patient's specific stage of rehabilitation and may be modified accordingly as they make advancements.

The use of physical games as a means of exercise throughout the rehabilitation process may provide patients with a stimulating and motivational experience, leading to enhanced mood and improved therapeutic outcomes. Furthermore, it is worth noting that physical games have the capacity to provide a gradual increase in complexity, facilitating the advancement of patients' motor skills and coordination throughout several sessions. This approach proves to be both effective and fun for those seeking to enhance their physical abilities.

Games of skill are well recognized as a very popular kind of physical rehabilitation activity for those who have had a stroke. These tools have the potential to assist patients in enhancing their dexterity and coordination abilities. Typically, these activities include the manipulation of small items, such as perforated plates, puzzles, and blocks. These activities require patients to use their fingers and hands with accuracy and coordination.

One instance of such a task is the act of positioning various items into certain apertures on a board, as seen in Fig. 2. The amount of difficulty in this exercise may be modified by altering the quantity and dimensions of the holes or by introducing other factors, such as a specified time constraint. The therapist has the ability to modify these settings in order to maintain an acceptable level of difficulty, depending on the patient's condition and objectives.

After the patient has developed familiarity with the task of correctly fitting things into designated openings, the therapist may introduce supplementary items to enhance the degree of challenge. For instance, it is recommended that the patient be taught to use bilateral hand coordination to manipulate things or to arrange objects in a predetermined sequence.

Fig. 2 – Example of a device (https://www.koreatechdesk.com/neofect-helping-millions-avail-rehabilitation-with-smart-devices/) for placing objects in holes.

In addition to enhancing motor skills and hand-eye coordination, physical exercise has been shown to have a positive impact on cognitive abilities, namely attention and memory. The patient should demonstrate attentiveness towards the dimensions and configurations of items, as well as the apertures, to effectively position the objects in their appropriate locations. Additionally, it is important for the patient to retain the sequence in which things should be arranged, as this might potentially enhance memory and cognitive abilities in cases where this aspect has been impacted.

Mirror therapy is an additional beneficial exercise used in the process of rehabilitation (Weber *et al.*, 2019), as seen in Fig. 3. This technique aids patients in enhancing their hand-eye coordination. This activity entails using a mirror to generate an optical phenomenon that gives the impression of regular hand functionality. Patients are instructed to execute accurate motions of the impacted hand while visually seeing the mirrored image of their unaffected hand.

Fig. 3 – Mirror therapy (Weber *et al.*, 2019) - the patient uses his healthy hand to rotate a cube in front of a mirror.

The assessment of progress can be conducted through the evaluation of the patient's capacity to execute accurate movements with the hand that has been impacted. The therapist has the flexibility to customize the exercises based on the individual requirements and the rehabilitation level of the patient. This involves gradually increasing the level of difficulty in order to facilitate advancement from one therapy session to another, thereby aiding in the enhancement of both motor and cognitive abilities of the patient.

The use of the mirror exercise has the potential to engender a heightened state of immersion among patients, hence fostering augmented levels of motivation and active engagement in the process of rehabilitation. Additionally, this intervention has the potential to enhance patients' self-efficacy and alleviate apprehension associated with using the impaired hand in daily activities. Mirror therapy is a valuable intervention used in the rehabilitation process, offering patients a very effective and pleasurable means of recovery. This therapeutic approach may be tailored and supervised to optimize the desired result.

2. VR technology applied to post-stroke rehabilitation

The healthcare business has seen considerable interest in the use of virtual reality (VR) technology in recent times. Post-stroke rehabilitation has emerged as an effective use of virtual reality (VR) technology. The efficacy of these treatments is more favorably perceived by patients compared to conventional rehabilitation procedures. Frequently, the repeated and monotonous nature of these activities may result in diminished motivation and a reduced level of dedication towards the process of rehabilitation.

VR solutions facilitate patient engagement and motivation throughout the healing process by creating a simulated reality that replicates a virtual environment. This is achieved through the use of gamification approaches. Physical activities often include the manipulation of various items, which might include actions like lifting, gripping, or moving those objects. The use of iterative exercises, characterized by a clearly defined objective and escalating levels of challenge, serves to enhance motor abilities.

Within this application, patients' progress can be systematically tracked and recorded. This lets therapists and doctors see how far their patients have come and change their treatment plans in a more streamlined and effective way. For instance, the monitoring of completion times and the quantification of mistakes may be facilitated. In the event that a patient encounters challenges in successfully executing a certain activity, the therapist has the ability to modify the exercise in order to align more effectively with the patient's current stage of recovery.

Several measures often used in the context of virtual reality (VR) for post-stroke rehabilitation to effectively monitor and assess progress encompass:

• The temporal duration required to successfully do certain activities, such as the act of retrieving and relocating an item to its designated position;

• The frequency of mistakes that occur during physical activities, such as unintentionally releasing things;

• The precision of motions, such as the patient's capacity to successfully access desired items or execute specified hand and finger movements;

• The extent of engagement and active involvement in physical activities, such as the regularity and length of sessions.

A specific architectural design of a virtual reality (VR) system is explained in the article (Weber *et al.*, 2019). The design includes a VR headset, controllers, and a computer or other similar device for running VR software. The often-used program is Unity, which facilitates the development of personalized virtual reality (VR) settings and activities. The system is equipped with sensors that monitor the patient's movements and progress, along with a data analytics platform that captures and analyzes the collected data. This enables healthcare professionals, such as therapists and doctors, to effectively track the development of their patients and make necessary modifications to their treatment strategies. An example of such an architectural design may be seen in Fig. 4.

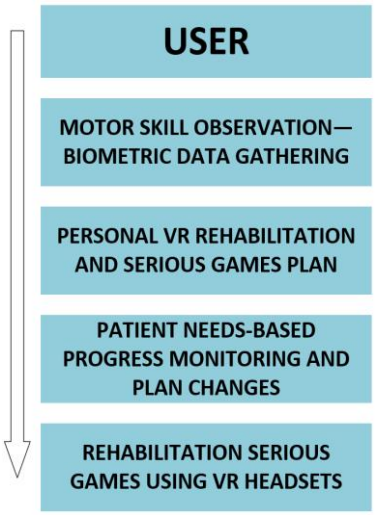

Fig. 4 – Example architecture for a VR system in stroke recovery.

Within this particular framework, the applications presented encompass two exercises that draw inspiration from physical activities often used in retrieval tasks. These exercises include the manipulation of virtual items via the act of picking them up and moving them, as well as the matching of cards using finger touch movements.

The first task involves selecting and relocating a set of cubes positioned in a randomized manner. As seen in Fig. 5 (left), the act of grabbing involves simultaneous contact of all fingers, whereas the act of releasing entails the subsequent release of the fingers. The level of difficulty may be manipulated by either augmenting the quantity of cubes or extending the duration of the solution process.

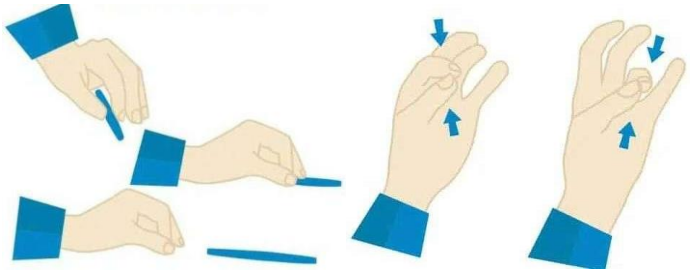

Fig. 5 – Illustration explaining the gesture of grasping and dropping (left) and the gesture of touching fingers (Hoffman, 2018) (right).

The second game serves as a simulation of the finger-tapping exercise, specifically designed for those at a more advanced stage of recovery. During the exercise, the tip of the index finger is brought into contact with the tip of the thumb, resulting in the formation of a ring shape, as seen in Fig. 5 (right). Apply pressure and afterwards release, followed by repeating the same action with the middle, ring, and little fingers.

The aforementioned motion serves as a remote trigger for the spinning of cards in a card matching game, therefore simulating the exercise. This intervention has the potential to enhance cognitive abilities related to memory and attention in a manner that is enjoyable and captivating for patients. The level of difficulty may be enhanced throughout consecutive sessions by augmenting the quantity of pairs, particularly by adjusting the dimensions of the game board in terms of height and breadth, as well as by extending the time for solving.

This card game may be modified to accommodate those with limited finger mobility by substituting the action of touching their fingers with the act of physically contacting the card with their hand.

3. Related work

According to the authors' study (Tsatsis *et al*., 2017), the goal is to improve the treatment of lateropulsion problems in people who have had a stroke, with the end goal of making it easier for people to regain full body mobility. The software was developed via a collaboration between Pace University and Burke Hospital Medical Research Institute, using Samsung Gear VR headsets and the Unity game engine. The primary goal of the designed game is to assist those who have had a stroke in improving their bodily balance through the process of centering their posture. The game is set in a maritime setting, as seen in Fig. 6. The user is required to use a leaning motion in order to avoid an incoming obstacle, namely a barrel that is propelled at the user. The objective is to collaborate with the user's inherent inclination to distance

themselves from the barrel. The user has the ability to modify the velocity of the barrel's movement and choose the specific body region impacted, thus customizing the game to accommodate diverse patient profiles.

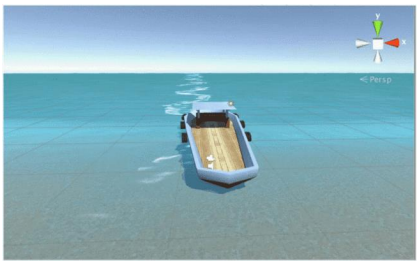

Fig. 6 – Image from the game presented in (Tsatsis *et al*., 2017) with the boat where obstacles must be avoided.

The aforementioned research (Majid *et al.*, 2017) focuses on investigating the efficacy of the Xbox360 Kinect sensor for arm rehabilitation performance. The study used the Unity game engine as the underlying framework for the rehabilitation system. The Xbox 360 Kinect sensor is used for the purpose of detecting arm movement and then translating the motion of the hand into a virtual world that is visually shown on the screen.

The objective for those who have had a stroke in this interactive activity involves the manipulation and relocation of an item to a predetermined location. While doing this activity, patients become more motivated when they can see their hand moving and doing things on the screen (Fig. 7), which makes it easier for them to interact with the virtual item. The degree of difficulty may be modified based on the patient's individual condition and rate of advancement. The primary rehabilitation activities included in this game encompass object manipulation by touch, arm elevation, object interception, and hand release.

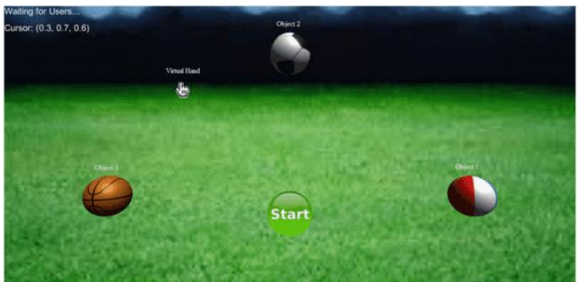

Fig. 7 – Game environment from (Majid *et al.*, 2017) developed in Unity with objects that can be grabbed.

Article by Chatterjee (Chatterjee *et al.*, 2022) examines the process of cognitive rehabilitation after a stroke by using a virtual reality platform known

as VIRTUE. This intervention employs Unity software and the Oculus Rift S virtual reality headset. In this particular application, individuals are fully engaged inside a three-dimensional virtual world, whereby they possess the ability to actively engage with numerous items and do a multitude of activities, including the act of cooking. As seen in Fig. 8, the individual is required to engage in the process of preparing a piece of toast.

All tasks have been specifically intended to be accomplished while in a sitting posture with a single handheld controller. This enables the use of the most powerful limb. The individual undergoing treatment is provided with auditory and written directions, as well as feedback, as they advance in completing the assigned job.

Fig. 8 – Example of a task from (Chatterjee *et al.*, 2022) where the patient has to practice making toast.

The research paper by Luo (Luo *et al.*, 2021) examines the communication process between a mobile application called "SilverTune" that detects motions and a PC application that offers a range of rehabilitative exercise-based activities. An example of a game may be seen in the context of horse racing (Fig. 9), whereby players are required to collect various currencies within a certain time period. Additionally, another instance can be found in a table tennis game, where players must serve the ball across the table in order to accumulate points. In the event that the accelerometer detects the motion of the device, the horse will engage in locomotion. Various incentives have been developed with the aim of stimulating client motivation.

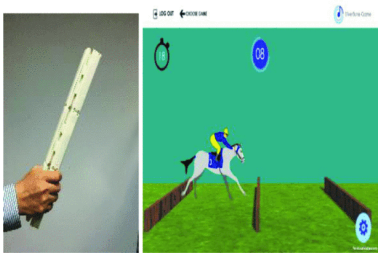

Fig. 9 – Game environment from (Luo *et al.*, 2021) where horse jumping is activated by hand movement.

4. Application design for VR post-stroke rehabilitation

The selection of the Oculus Quest 2 (Meta Platforms, 2020) VR headset (Fig. 10) was made for the purpose of designing the application, in conjunction with the use of the Unity (Unity Technologies, 2022) game development platform and the Visual Studio IDE (Microsoft Corporation, 2019). The program adheres to the standards set out by Khronos OpenXR (The Khronos Group, 2019) and incorporates the packages provided by Unity XR Interaction Toolkit and XR Hands.

Unity is well recognized and very influential within the field of game creation because of its substantial popularity and robust capabilities. One of the primary benefits of using Unity is its extensive array of tools and comprehensive documentation, which greatly facilitate the development of virtual reality (VR) experiences. The aforementioned features include compatibility with a diverse range of virtual reality (VR) devices, such as the Oculus Quest 2, an innovative product created and manufactured by Oculus. Notably, the Oculus Quest 2 offers users a wireless VR experience, eliminating the need for a tethered connection to a computer or external sensors. Unity provides a range of features and tools that facilitate the development of immersive virtual reality (VR) environments. These include 3D modeling tools, physics engines, and scripting tools.

The Khronos Group created the open standard known as OpenXR with the intention of facilitating the creation of applications for virtual reality (VR) and augmented reality (AR). OpenXR is a programming interface that has been specifically developed to be platform-independent, allowing it to be used across a diverse array of virtual reality (VR) and augmented reality (AR) devices. This characteristic renders it an optimal selection for the creation of applications that can be seamlessly executed on various devices and platforms. The use of this feature has been seen in combination with the pre-installed programs inside the Unity framework.

In general, the integration of Meta Quest 2, Unity, and Open XR offers a robust toolkit for the development of immersive and captivating virtual reality experiences with the potential to appeal to a broad range of users.

The XR Interaction Toolkit, which is talked about in reference, is a group of parts and scripts that make it easier to create complex interactions between users and virtual objects in augmented and virtual reality apps. The software offers a variety of preexisting components, including those designed for object interaction and human gesture detection.

The primary constituents used in this package were the XR Grab Interactor, XR Ray Interactor, and XR Direct Interactor. The XR Grab Interactor facilitates the user's ability to manipulate and relocate things inside the virtual environment. The XR Ray Interactor facilitates object and graphical user interface (GUI) contact by using a laser beam, while the XR Direct

Interactor enables direct interaction with things using hands, eliminating the need for controllers.

The XR Grab Interactor (Unity Technologies, 2022) was used to manipulate cubes by grasping them from one side and then propelling them into a designated region. From a technological standpoint, the system operates by using collision detection between the user's hand and the virtual item. This collision detection enables the user to manipulate and relocate things in accordance with their hand motions.

The XR Ray Interactor has been used in both interface design and card games to enable distant card selection via touch-based interaction, eliminating the need for physical contact with the cards. The functionality of this system involves the generation of a ray that serves as a cursor, enabling the detection of collisions between said cursor and virtual objects. Consequently, this detection triggers various actions, including, but not limited to, button activation and object selection.

The card game variant uses the XR Direct Interactor (Unity Technologies, 2022), a simpler version that enables direct touch interaction. The device is capable of detecting tactile contact between the hand and an item, therefore initiating several events, including the card spin event.

The XR Socket Interactor played a crucial role in the cube game by facilitating the secure placement of cubes inside the designated region upon user release. Virtual sockets serve as a means to attach items or establish connections between them.

XR Hands is a comprehensive collection of components and scripts designed for the Unity platform, enabling developers to accurately monitor and depict the intricate motions of a user's hands. XR Hands operates through the use of motion sensors and the integration of virtual reality (VR) devices' finger tracking capabilities. The sensors used in this system are capable of detecting and capturing the intricate motions of the user's hand and fingers, then transmitting this data to the gaming application. The scripts included inside the package use this data to monitor and record the motions of the hand and fingers, subsequently representing them within the context of the game.

Fig. 10 – Oculus Quest 2 VR headset and controllers.

Meta Company created the Oculus Meta Quest 2 virtual reality headgear. The device in question could be called an "integrated headset" because it comes with everything you need to play virtual reality (VR) games without having to connect to a computer or other device.

One of the main factors influencing the selection of this headset is its affordability, particularly for domestic consumers, since it boasts a very modest price in relation to alternative headsets now accessible on the market. Furthermore, the absence of a need for external device connectivity enhances its use, while its interface and configuration exhibit a higher degree of simplicity.

5. Designed VR applications for post-stroke rehabilitation

5.1. Playing with cards

The first game is derived from the traditional card memory game. In this game, the player is tasked with locating pairings of two cards from a board that is randomly produced within a certain time constraint, as seen in Fig. 11. Once a card is selected, it stays in an exposed position until the subsequent card is picked. If the second card discovered is matched with the first card, they will stay in an upright posture. However, if the cards do not form a pair, they will be temporarily shown in an upright position for one second to assist the user in visually memorizing their respective positions before returning to their normal face-down orientation. The aforementioned process is iterated until all couples have been identified.

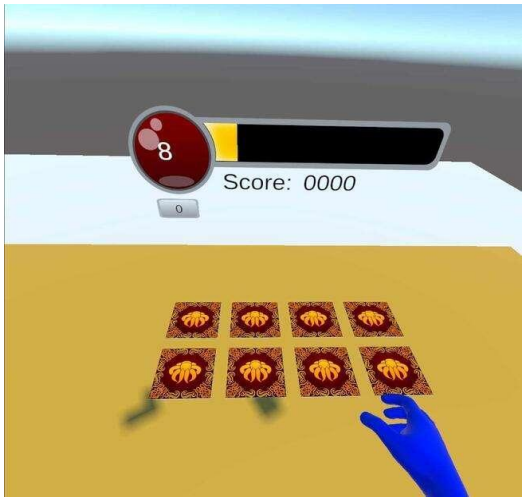

Fig. 11 – Image from *Playing with cards* game: patient has to make pairs by touching the cards.

There are two distinct categories of motions that are used as input to simulate traditional rehabilitation workouts:

• Physical therapy interventions for individuals in the early stages of rehabilitation often include exercises aimed at improving motor function and dexterity. In this context, a specific exercise is the repetitive vertical movement of the hand for a predetermined number of repetitions. This exercise is used as a means of selecting a card by elevating the hand and then making contact with the desired card.

• This exercise is designed for patients who have progressed further in their recovery and have already achieved a certain degree of finger mobility. In this exercise, a remote beam selects the cards, which the patient then spins with their fingers. Specifically, the thumb is used in conjunction with the other fingers, with each finger being engaged sequentially.

The statistics play a crucial role in this particular game. Metrics are measurements or techniques used to evaluate or quantify patient progress. By using these metrics, we are able to track the advancement of a patient over time, comparing their improvement from one session to the next. In this particular scenario, two key variables are being considered: the duration required to successfully solve the problem and the quantity of tries made in order to identify a suitable match.

Assuming a frequency of 10 daily sessions over a period of 30 consecutive days, let us consider the patient's engagement with the game. If the solution time and number of turns for the game are averaged on a daily basis, it is expected that both metrics will exhibit a gradual decline until day 30. In the event that the reduction does not occur, the therapist has the ability to modify the weight of the game in accordance with these factors. For instance, it is possible to start the game with a smaller number of cards and then increase the quantity of cards as time progresses.

5.2. The cube game

According to Fig. 12, the second game is based on a simple idea: the patient has to move a certain number of cubes from the right side to the left side of a randomly generated space within a certain amount of time. The target audience for this game comprises those who are at a more advanced stage of rehabilitation and possess the ability to manipulate their fingers, since the game requires more effort via arm movement and simultaneous gripping of the cubes by engaging all fingers.

The challenge of the game is to increase the quantity of cubes while simultaneously reducing the time required for solving. As the quantity of cubes increases, the effort needed to access them intensifies, given that the cubes positioned on the right are further from the player. One measure that may be used is the time needed to finish the game.

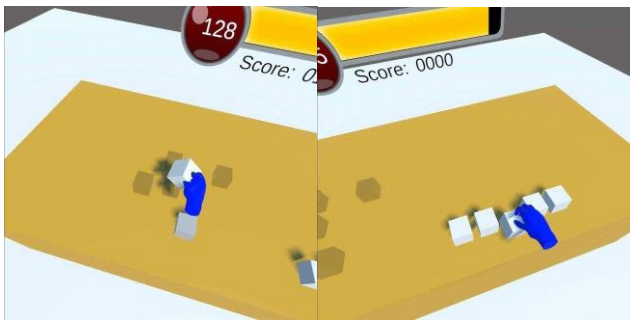

Fig. 12 – Image from the *Cube game*: patient has to move cubes from left to right.

6. Clinical trial: testing with patients

The process of testing an application is of utmost importance in the field of software development and serves a crucial role in guaranteeing the functioning, quality, and overall success of the program. Testing is a methodical procedure used to verify and authenticate a program with the purpose of identifying mistakes, malfunctions, and vulnerabilities prior to its release to the market or utilization by users.

Similar to the standard procedure for software products inside a firm, the application underwent initial internal testing conducted by the author of this statement. Following that, stroke patients at the Clinical Recovery Hospital in Iasi who were in various stages of recovery evaluated the application.

At the Clinical Recovery Hospital of Iaşi, we conducted a study to assess and authenticate the efficacy of three games among two stroke patients at varying phases of rehabilitation with varied upper limb impairments. During this study, we collected comments and gathered statistical data pertaining to certain aspects of the games. Both patients are in incipient clinical post-stroke rehabilitation, males, age range 30-45 years old, with previous experience using the VR technology. Therefore, they did not require previous familiarization with the VR headset.

Patient 1

The first patient exhibited signs of recovery, including verbal impairments, compromised motor function in the right hand, immobile fingers, limited arm mobility, and a reliance on the unaffected hand.

Due to the patient's limited finger mobility, we opted to administer a single game out of the three available options, namely the touch-adapted card game. Figure 13 displays visual representations of the specific sort of workout.

Fig. 13 – Picture during the rehabilitation exercise on patient 1 (left) and screenshot from the VR game (right), where it can be seen how the patient uses the healthy hand.

After running four such game sessions on Patient 1 and Patient 2 with different parameters, we extracted the following data regarding the time needed to solve the puzzle:

Table 1

Time-to-solve for 'Playing with cards' VR game (patient 1 and patient 2)

Session	Grid size (width x length)	Time needed to finish the game (s)	
		Patient 1	Patient 2
1	2x2	50.36	83.31
2	3x2	135.37	143.51
3	3x2	101.62	131
4	4x2	163.51	120.53

For the 1st patient Table 1 illustrates that during the first session, the duration required for problem-solving was comparatively longer. This may be attributed to the patient's initial struggle to familiarize themselves with the operational intricacies of the game mechanics. Following a period of acclimation, the dimensions of the board were expanded to 3x2, resulting in a longer duration for solving the game. This may be attributed to the heightened level of complexity in terms of cognitive abilities. During the third session, an improved performance was noticed on the same game board. Ultimately, the dimensions of the board were expanded to 4x2, resulting in the dispersion of the cards throughout a larger surface area. This adjustment introduced a heightened level of challenge for the participant, thus leading to an extended duration of time required for problem-solving. It is quite probable that an increased frequency of testing would have resulted in more substantial advancements.

Patient 2

The second patient presented with bilateral hand involvement. The left hand had finger immobility and limited arm control, but to a lesser extent than

the first patient. Conversely, the right hand showed less severe impairment, characterized by complete arm control and little difficulty in finger dexterity. After considering these variables, we chose to conduct an evaluation of the tactile card game shown in Fig. 14 for the left hand and the three-dimensional cube game illustrated in Fig. 15 for the right hand.

Fig. 14 – Picture during the rehabilitation exercise on patient 2 (left) and screenshot from the VR game (right).

Similar to the first patient, the data shown in Table 1 indicates that during the initial session, the duration required to do the task was extended. This may be attributed to the patient's initial challenges in familiarizing themselves with the game mechanics. During the two sessions using the 3x2 board, a time duration was noted that was somewhat comparable to the first patient's, although slightly longer. This discrepancy may likely be attributed to the first patient's use of their healthy hand to interact with the cards, while the current patient only relied on their afflicted hand. Upon first observation, it is evident that there is improvement between consecutive sessions. However, in order to arrive at a definitive conclusion, a much larger number of tests must be conducted.

Fig. 15 – Pictures during the rehabilitation exercise on patient 2.

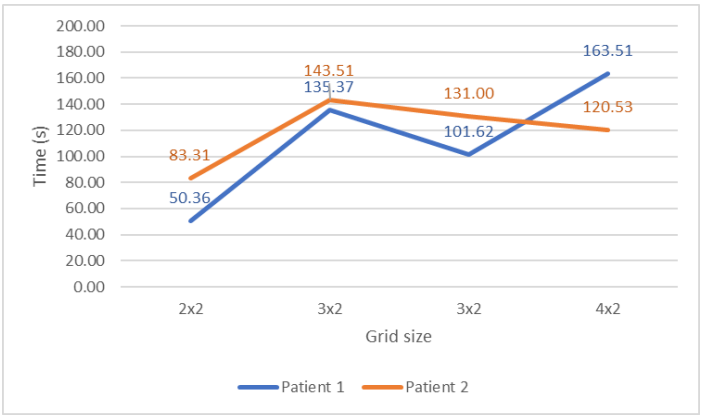

Fig. 16 – Time-to-solve for *Playing with cards* game tests on Patient 1 and Patient 2.

Usability feedback from patients

For patient feedback, a form was used, with simple questions answered from 1 to 5 (1 = *very negative* to 5 = *very positive*).

Table 2

Patient 2 feedback for 'Playing with cards' VR game

#	Question	Patient 1					Patient 2				
		1	2	3	4	5	1	2	3	4	5
1	Experience (how it was overall?)					x					x
2	How real was the interaction?				x				x		
3	How involved were you during the exercise?				x						x
4	During the process, what was the level of fatigue felt?		x				x				
5	Did you feel dizzy during your work?	x					x				
6	Did you feel nauseous during your work?	x					x				
7	Did you experience any anxiety or fear during your work?	x					x				
8	During the process, did you experience any physical discomfort due to the system?	x					x				
9	Was the perceived image clear?					x					x
10	How real did you find the exercise?			x				x			
11	How do you rate the VR helmet exercise compared to similar exercises in the physiotherapy room?					x			x		

12	How quickly did you get to grips with the system?					x				x	
13	Do you find such a system useful for recovery?					x				x	
14	How do you rate the movement of the paretic arm?				x					x	
15	Do you prefer watching recovery exercises on your monitor or with virtual glasses?					x				x	

According to responses collected from patient 1 in Table 2, he had a positive overall sentiment towards the event and showed active participation throughout the activity. The degree of exhaustion reported was negligible, and there were no instances of sickness, anxiety, or overall discomfort reported. The image was perceptible, but the practical activity did not evoke a strong sense of realism for the individual. The patient expressed a preference for the workouts conducted using the virtual reality (VR) headset, seeing them as more fun compared to traditional exercises. Additionally, the patient felt the use of the VR system to be beneficial in the context of their rehabilitation process.

Table 2 also illustrates that the feedback received from patient 2: it has a considerable degree of similarity to that provided by the first patient. The individual had a positive overall impression, actively participated in achieving victory in the games, and acknowledged the high quality of the visuals. There was a complete absence of discomfort, dizziness, and fatigue. The individual perceives the use of the system throughout the rehabilitation process as advantageous and exhibits a preference for engaging in exercises via the virtual reality (VR) headset. However, the individual expresses reservations over the system's ability to accurately replicate real-life experiences.

7. Conclusions and future directions

The system that has been built has made progress towards its objective by successfully implementing virtual reality rehabilitation exercises into serious games, allowing for little game adaptation, and enabling the extraction of metrics.

However, other enhancements may be implemented based on the testing conducted and the input received from patients and professionals in the respective domains.

One potential enhancement is the better visual appeal of the gaming scenarios. Currently, the application employs generic components that lack color and aesthetic appeal. Additionally, the absence of a contextual environment creates a disconcerting experience, particularly during extended use of the system. The enhancement of the gaming scene may be achieved by transforming it into a spatial setting comprising furniture, windows that allow

the ingress of natural light, and a visually appealing perspective, thus aiming to replicate reality to the greatest extent feasible. The cubes used in the cube game have the potential to be substituted with commonplace things, such as apples, as an alternative representation.

Another approach to enhancing the appeal and perception of security is to modify the game to suit the augmented reality (AR) setting. The use of cameras and sensors offered by the virtual reality/augmented reality (VR/AR) headset enables the generation of game components inside the patient's familiar environment.

Furthermore, while considering the visual aspect, it is worth noting that the games lack any auditory elements such as noises or music. As an example, an auditory stimulus may be included upon the player's action of spinning a card or successfully identifying a pair. The use of soothing background music has the potential to further increase patient immersion.

From a functional standpoint, it is worth noting that a system of this kind has the potential for more complexity beyond the scope of the current development. This complexity arises from the need for extensive parameterization in order to accommodate a diverse range of patients. Currently, the system has a limited focus on a certain subset of patients; nonetheless, it is important to acknowledge the existence of diverse exercise regimens and patients at varying stages of rehabilitation.

In order to enhance the monitoring of patient development, it is advisable to identify additional metrics of value, such as movement accuracy. Simultaneously, it would be beneficial to provide a distinct interface that enables therapists to access graphs and data in a more structured and comprehensive manner.

Overall, the system partially accomplishes its objectives, yet it may be seen as an initial iteration of the promise that virtual reality (VR) technology has within the medical domain.

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GAMIFICAREA EXERCIȚIILOR DE REABILITARE NEUROMOTORIE POST-AVC FOLOSIND URMĂRIREA MÂINILOR ÎN VR

(Rezumat)

Scopul acestui studiu este de a dezvolta o platformă de jocuri pentru persoanele care au suferit un accident vascular cerebral și sunt în diferite stadii de reabilitare neuromotorie a membrelor superioare. Ideea principală este că activitățile obișnuite de recuperare sunt repetitive și adesea plictisitoare, ceea ce putea face ca pacienții să fie mai puțin interesați de terapie. Prin includerea unor jocuri plăcute și practice, în rutinele de antrenament, există potențialul de a spori motivația pacienților. Pentru a asigura acuratețea și fiabilitatea sistemului, a fost derulat un proces de validare cu ajutorul a doi pacienți post-AVC aflați acum în diferite stadii ale recuperării la Spitalul Clinic de Recuperare din Iași. Parametrii mediului de Realitate Virtuala au fost ajustați în funcție de caracteristicile individuale ale pacientului și au fost efectuate în total 12 teste în urma cărora s-au extras statistici relevante. La sfârșitul studiului clinic, a fost colectat feedback de la pacienți pentru a obține perspectiva utilizatorilor finali vizați ai sistemului și pentru a identifica potențiale îmbunătățiri ale sistemului atât pe parte de

utilizabilitate, cât și în ceea ce privește soluția tehnică. În cele din urmă, acest studiu a demonstrat beneficiile și potențialele utilizări ale tehnologiei realității virtuale (VR) în reabilitarea pacienților, iar participanții la studiul clinic au găsit soluția propusă ca fiind una utilă și cu un impact pozitiv crescând imersiunea cognitivă pe parcursul procesului de recuperare neuromotorie.