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Explorando os Efeitos de Jogos Sérios de Realidade Virtual Personalizada para Reabilitação de AVC

Exploring the Effect of Personalized Virtual Reality Serious Game for Stroke Rehabilitation

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Plano de Investigação apresentado no âmbito da unidade curricular de Metodologias de Apoio a Projeto/Dissertação da Universidade de Aveiro em Desenvolvimento de Jogos Digitais, realizado sob a orientação científica do Doutor (Bernardo Marques), Professor auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro, da Doutora (Beatriz Sousa Santos), Professora associada com agregação do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro.

palavras-chave

Acidente Vascular Cerebral, Reabilitação, Realidade Virtual, Jogos Sérios, Personalização, Design Centrado no Utilizador

resumo

O Acidente Vascular Cerebral (AVC) é uma das principais causas de incapacidade a nível mundial, existindo um número crescente de sobreviventes com incapacidades motoras, psicológicas, cognitivas e sociais. Apesar do seu papel importante, os métodos de reabilitação convencionais sentem frequentemente dificuldades em manter a motivação devido à sua natureza repetitiva, o que pode levar a repercussões sociais e na saúde mental. Para ajudar a superar alguns destes desafios, as tecnologias de Realidade Virtual (RV) oferecem benefícios promissores ao imergir os sobreviventes de AVC em ambientes dinâmicos e multissensoriais que replicam cenários da vida real. Explorar soluções de RV como uma abordagem complementar à terapia tradicional tem o potencial de aumentar a motivação e o envolvimento durante as rotinas de reabilitação, permitindo prolongar o tratamento por longos períodos. Este trabalho propõe a utilização de serious games (jogos sérios) de RV personalizados, seguindo conhecimentos recolhidos através de uma metodologia de Design Centrado no Humano (HCD) com uma equipa multidisciplinar do Centro de Reabilitação Rovisco Pais. Em particular, o foco incidirá na capacidade de ajustar diferentes aspetos do jogo de acordo com regras pré-estabelecidas (por exemplo, a duração de uma tarefa, se um sobrevivente de AVC atinge os objetivos pretendidos, etc.). Deste modo, pretendemos compreender o seu impacto na motivação, no envolvimento e nos resultados terapêuticos.

keywords Stroke, Rehabilitation, Virtual Reality, Serious Game, Personalization User-centered design

abstract Stroke is a leading cause of disability worldwide with an increasing number of survivors with motor, psychological,cognitive, and social handicaps. Despite their important role, conventional rehabilitation methods often struggle to maintain motivation due to their repetitive nature, leading to potential social and mental health repercussions. To help overcome some of these challenges, Virtual Reality (VR) technologies offer promising benefits by immersing stroke survivors in dynamic, multi-sensory environments that replicate real-life scenarios. Exploring VR solutions as a complementary approach to traditional therapy has the potential to boost motivation and engagement during rehabilitation routines, enabling to prolong their treatment over extended periods. This work proposes the use of personalized VR serious games, following insights collected through a Human- Centered Design (HCD) methodology with a multidisciplinary team from the Rovisco Pais Rehabilitation Center. In particular, it will focus on being able to adjust different aspects of the game according to pre-established rules (e.g., duration of a task, if a stroke survivor achieves the intended goals, etc.). By doing so we aim to understand their impact on motivation, engagement, and overall therapeutic outcomes.

acknowledgement of use of AI tools

Recognition of the use of generative Artificial Intelligence technologies and tools, software and other support tools.

I acknowledge the use of Gemini (Google, https://gemini.google.com) for text translation and grammatical correction, and NotebookLM (Google, https://notebooklm.google.com) to verify the consistency of the written content against the references.

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CHAPTER 1

Introduction

Stroke is a medical condition that affects severely the global population. It occurs when a blood flow to the brain disrupted, due to a blocked artery (**ischemic stroke**) or a ruptured blood vessel (**hemorrhagic stroke**).This disruption deprives brain cells of oxygen causing their deaths and possibly leading to a range of neurological impairments[1]. Accordingly to the **World Stroke Organizition**, over **100 million** people have already experienced stroke and over **12 million** people will have their first stroke this year of whom **6.5 million** will die[2].

Despite, **54 %** of people survive to stokes their life after the event is often followed by a new set of challenges. The majority of strokes result in permanent disabilities, that can affect physical mobility, swallowing, speech, vision and cognition. These impairments impact the survivor's ability to perform daily activities and diminish their quality of life, which can make them feel useless and lead to serious psychological problems, such as depression and social isolation[3][4][5][6].

While survivors may not fully return to their pre-stroke state, it is recommended that rehabilitation begin as soon as possible to maximize the recovery of lost capacities and improve performance in daily activities[3]. Although it might seem good in theory, traditional rehabilitation methods have significant constraints. To understand these limitations, the rehabilitation process can be conceptualized through an analogy of building a brick house, where the structure represents the recovery of the survivor's capacities. Just as a house cannot be built without bricks and mortar, successful rehabilitation requires fundamental components. In this analogy, the survivor's spirit, motivation, determination and engagement are the bricks the essential, foundational elements without them no progress can be made. The exercises constitute the mortar, binding the components together and translating motivation into visible progress. However, traditional rehabilitation often relies on the repetitive practice of the same exercises. This can make them feeling tedious, monotonous over time, detouring the patient's

motivation and engagement the essential ***'bricks'*** thereby compromising the entire recovery process[4][5][6].

Another major constraint of conventional rehabilitation programs is often establish identical exercises to everyone. As a result, survivors who struggle with the tasks while seeing their peers succeed may become demotivated, which again breaks the essential ***'bricks'*** of this process. This brings to mind a famous quote by **Albert Einstein**, ***"Everyone is a genius. But if you judge a fish by its ability to climb a tree, it will live its whole life believing that it is stupid."*** In this context, the quote suggests that the issue is not with the survivors, but with the programs that simply don't adapt to the specific needs and pace of each patient[4][5][6].

This leads to an important question, **How can we create rehabilitation programs that adapt to the individually needs for each survivor?** The solution relies in introducing a certain degree of personalization into these programs focusing on adapting to the survivor's specific needs and progress.

However, monitoring a survivor's progress with the accurate precision and adapting the exercises in real-time based on their performance is overly complicated for healthcare professionals. Manually recording times, comparing results across sessions, and analyzing various performance parameters is time-consuming and inclined to error. Therefore, there is a clear need for a tool that can automatically make these adjustments and assist professionals in monitoring progress.

When considering automation, digital solutions such as computers are what comes to mind. A bright approach is to consider the use of **Virtual Reality Virtual Reality (VR)** combined with **Serious Games**. Virtual Reality environments are well know for creating immersive experience that increases user engagement engagement. In addition, VR Headsets can track users hand/arms, allowing users to control VR applications in a natural way. This feature cab be useful for stoke survivors practicing specific movements required to recover their lost motor skills. Serious Games are digital games which are designed for purposes beyond entertainment, bu they incorporate gamification elements similarly or equal to those found on traditional digital games, which are responsible for keeping player motivated and engaged. Other similarity between this type of games and the traditional one they also have the benefit of improving cognitive functions. Serious Games are particularity known to be use to adapt to user's performance through automatic algorithms such as **Dynamic Difficulty Adjustment Dynamic Difficulty Adjustment (DDA)** ensuring that the challenge still remains in the new level of difficulty and still maintaining the fun of playing the game. When combined these technologies have the potential to boost user motivation and engagement[4].

1.1 Goals and Contributions

This dissertation aims to develop a functional VR-based Game Prototype for physical rehabilitation that train the upper limbs and cognitive functions of stroke survivors. The upper limb aspects that the games will focus on include arm and hand movements, gripping strength,

and motor coordination, while the cognitive functions addressed are planning, attention, and reasoning.

In the games developed in this thesis, it is expected that the initial difficulty will be the same for all users. However as survivors begin playing, the game will evaluate their performance and automatically adjust the difficulty level.

After each rehabilitation session, the survivor's performance will be stored, allowing the game's algorithm to better understand the user's overall progress and adjust the difficulty at the start of the next session. In this way the algorithm can make the exercises more challenging to promote improvement without causing frustration.

This thesis will adopt a human-centered methodology (**HCD**) with a multidisciplinary team from the **Rovisco Pais Rehabilitation Center**, in order to conduct user tests with stroke survivors and healthcare professionals and gather feedback on the games. This process will help to achieve a better understanding of the survivors' and professionals' needs regarding rehabilitation.

In the end the goal of this project is to demonstrate the importance of personalization in rehabilitation and to reinforce the idea that virtual reality and serious games can serve as valuable complements to traditional rehabilitation programs, increasing patients' motivation and progress.

The main goals of this thesis are:

- Develop a Functional VR-based Game Prototype;
- Develop algorithms for dynamic difficulty adjustment based on user performance;
- Test the protype with users(if possible, Rovisco Pais Rehabilitation Center).

The expected contributions are:

- Increase survivors' motivation;
- Improve survivors' progress;
- Contribute to VR Rehabilitation Research.

CHAPTER 2

State of the Art

This chapter addresses the most relevant topics for this study, exploring the causes and consequences of stroke in each individual, as well as the importance of the rehabilitation process. It also explores previous work in the same research area to understand the importance of virtual reality and serious games in stroke rehabilitation, as well as the role of personalization.

A summary is presented at the end to motivate the work described in the next section.

2.1 Stroke Causes and Consequences

Stroke definition has changed over the years, being the current one an acute episode of focal dysfunction of the brain, retina, or spinal cord leading to death or lasting longer than 24 hours. This medical condition can be divided into 3 types[1]:

- **Ischemic stroke**: Occurs when there is a lack of blood flow to a specific area of the brain, spinal cord, or retina, leading to neurologic dysfunction;
- **Intracerebral hemorrhagic stroke**: Occurs when there is bleeding within the brain tissue or the ventricular system, leading to rapid and severe neurological problems. This type of stroke is not caused by trauma;
- **Subarachnoid hemorrhagic stroke**: A subarachnoid hemorrhagic stroke is a type of stroke that occurs when there is bleeding in the subarachnoid space, which is the area between the brain and the membranes that cover it. This type of stroke can cause rapid and severe neurological problems and/or a headache and is not caused by trauma.

As mentioned earlier, according to the **World Stroke Organization**, over 100 million people have already experienced a stroke and over 12 million people will have their first stroke this year[2].

These are frightening numbers, so it is important to understand the causes of stroke in order to alert the population to reduce the risk of a stroke.

91% of stroke risk is caused by obesity, hyperglycemia, hyperlipidemia, and renal dysfunction. Poor lifestyle behaviors such as smoking, a sedentary lifestyle, and an unhealthy diet account for 74% of stroke risk. Air pollution can cause 29% of stroke risk [7].

Stroke can manifest impairments in different areas such as cognitive, physical, and speaking abilities[3].

2.2 Stroke Rehabilitation Methods

In order for survivors to regain most of their lost abilities, it is advised to start rehabilitation as soon as possible[3].

For improving motor function, the most recommended approaches are Constraint-Induced Movement Therapy (CIMT) and Mirror Therapy (MT):

- CIMT: Rehabilitation technique that constrains the patient's non-affected arm to promote greater use of the affected upper extremity. In general, the patient needs to do repetitive task-oriented exercises, during a determined period of time each day, with his non-paretic arm constrained;
- MT: Rehabilitation technique that uses a mirror to create the illusion of movement in a paralyzed limb. The treatment consists of placing a mirror in the midsagittal plane of the patient, hiding his paretic limb, and reflecting the non-paretic side as if it were the affected one.

Both of these methods appear to be beneficial and easily integrated into rehabilitation strategies for acute, subacute, and chronic post-stroke phases[8]. Despite their benefits, these methods rely on systematic repetition of the same exercise, which can make the rehabilitation process tedious and monotonous, leading to patients demotivation and lack of interest. To overcome these problems, VR rehabilitation exercises offer a great solution since they have been proven to boost patients' motivation and engagement[4][5][6].

2.3 Previous Work

2.3.1 Overview of VR Technologies and Serious Games

Based on a scoping review of **39 publications** selected from an initial pool of **82** listed in the SCOPUS database (2020–2024), emerging technologies within the scope of Extended Reality (**XR**), including VR, Augmented Reality (**AR**), and Mixed Reality (MR) have shown great potential in overcoming the limitations of conventional stroke rehabilitation. Of these technologies, VR is the most prominent, appearing in **84.6%** of the analyzed studies. This preference exists because VR has the capacity to generate fully immersive, controlled environments that can be personalized to meet the specific needs of stroke survivors[4].

Serious Games have been shown to be the primary intervention method, appearing in **67%** of the reviewed rehabilitation exercises in VR environments. These games are designed to improve both physical and cognitive functions by converting repetitive therapeutic exercises into engaging and interactive experiences, such as virtual basketball, table tennis, or cognitive puzzles. By including gamification elements, immediate feedback, and adaptive difficulty levels, serious games promote greater motivation and engagement compared to the monotonous and tedious nature of traditional rehabilitation. This method may improve survivors' adherence

to rehabilitation by giving them the chance to practice motor skills and cognitive exercises in secure and simulated environments that mimic real-life scenarios[4].

2.3.2 Challenges and Importance of Personalization

Stroke rehabilitation plays a crucial role in helping survivors regain their lost abilities. However, conventional programs often rely on **"one-size-fits-all"** methods that fail to take into account each person's particular needs, goals, and disabilities. This lack of personalization can lead to frustration, demotivation, and reduced engagement, which compromises the recovery process and slows progress. To solve this problem, VR technologies can be used to create dynamic, adaptable environments that can be customized to the survivor's individual needs and preferences. Despite the solutions VR offers, current implementations often ignore individual physiological and emotional needs, and other challenges still remain regarding data privacy, system complexity, and the integration of advanced adaptive algorithms.[4][5][6]

The viewpoint of healthcare professionals must be taken into account in order to close the gap between technological capabilities and clinical reality. In a recent survey involving experts from the **Rovisco Pais Rehabilitation Center**, professionals identified cognitive changes (such as attention deficits and memory loss) and communication difficulties as the primary challenges in implementing personalized rehabilitation, with both issues cited by **90%** of respondents. As a result, in personalized VR exercises, healthcare professionals prioritize the survivor's ability to concentrate and their level of engagement.[5]

Healthcare professionals obviously preferred a hybrid approach in implementing customization in VR systems. According to the survey, **70%** of them favor a system that does not rely solely on automatic adjustments but includes an option for manual intervention, ensuring greater clinical decision-making authority.

Furthermore, when asked about the most critical data for personalizing the process, professionals ranked motivation **(70%)** and emotional state **(60%)** as highly as physical metrics, highlighting the need for an integrative rehabilitation tool. To be effective, personalized VR environments must therefore include features such as adaptable difficulty levels and immediate feedback mechanisms to guide survivors when they feel confused or lost.

2.4 Summary

This chapter provided an overview of the impact of stroke and the importance of rehabilitation. While traditional methods such as Constraint-Induced Movement Therapy and Mirror Therapy are effective, they are often prevented by monotony and lack of interest , leading to reduced patient adherence. The literature review highlights VR and Serious Games as great alternatives to overcome these limitations by stimulating motivation, engagement and allowing to be customized for survivors individual needs. Furthermore, insights from healthcare professionals emphasize a clear demand for hybrid systems that integrate physical, cognitive, and emotional metrics while allowing for clinical oversight. These findings expose a gap in current research and underscore the necessity for a personalized, adaptive VR framework, which motivates the work proposed in the following chapters.

CHAPTER 3

Research Plan

3.1 Research Questions

The main research question regarding this project is:

- *Can VR based environments be personalized to adjust to individual needs and help boost motivation?*

3.2 Methodology

Figure 3.1: Methodology illustrating 8 phases to support the design and development of a VR Personalized Game for the rehabilitation process of stroke survivors

This project will adopt the **Human-Centered Design (HCD)** principle and fits into the **Design-Based Research (DBR)** method:

Figure 3.1 shows the stages of the research process. It will start with the **review of the state of the art** and **analysis of previous studies/questionnaires**. This will help to understand what type of activities the games should implement, and also what stroke survivors and healthcare professionals need/expect from these games. The next phase will be the **Game Concept**, which will define the chosen activities, game environment, and mechanics. After the game concept is finished, the next phase will be to determine which elements/mechanics of the game can be personalized. The following phase will be the development of a **game prototype**. This will later on lead to **contextual interviews and usability tests**, and final adjustments (**Fine-Tuning**). At any of the three points that have an asterisk (*****), it is possible to go back to the game prototype and make the necessary adjustments.

3.3 Research Instruments

Questionnaires Conducted at Rovisco Pais

- Focused on understanding the needs of stroke survivors and also the perspective of healthcare professionals. I participated in one session (Figure: 3.2 in July 2025).

Analysis of Previous Studies

Figure 3.2: Illustration of the Research Team conducting a user study, with a stroke survivor answering a post-task questionnaire, with the support of the research members

- Previous studies were analysed to understand the efficiency of virtual reality, serious games in rehabilitation scenarios and the importance of personalization in the same scenarios.

User Study

- A combination of contextual inquiry and usability tests to understand user preferences and behaviors, and to gather feedback for improving the game prototype.

3.4 Conceptual Framework

Based on the analysis of previous studies[5][6], figure 3.3 shows the conceptual framework of this project, where a stroke survivor plays the VR game. While the survivor is playing,

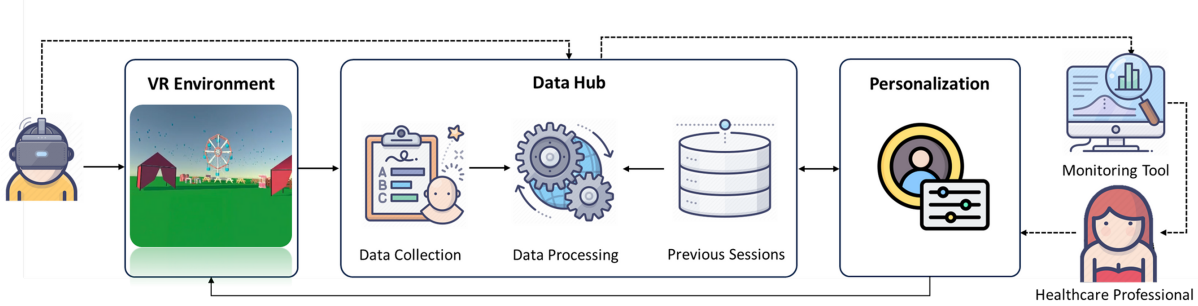

Figure 3.3: Conceptual framework for combining VR and a hybrid personalization aproach for stroke survivors' recovery.

the **Data Hub module** collects parameters about their performance in real-time, such as task execution time, game score, etc. This collected data is processed in the same module alongside previous sessions data to have a better evaluation of the user's performance. The processed data will be sent to the **Personalization module**, which will adjust the game difficulty based on this data.

The **Monitoring tool** shown in this framework **is not a goal of this project** but rather a long-term vision. It will be a visual tool that shows the survivor's data and current performance to the healthcare professional, this allows the professional to keep better track of the survivor's progress. In this tool, there will also be an option for the healthcare professional to manually adjust the game's difficulty, enabling a hybrid approach to adjust the game difficulty, which was the preferred method according to the survey of healthcare professionals at the **Rovisco Pais Rehabilitation Center**.

3.5 Contigency Plan

One of the goals of this project is to test a functional VR game prototype at Rovisco Pais Rehabilitation Center with stroke survivors. If it is not possible to go to **Rovisco Pais**, the testing will be conducted at the **Var Lab** (**IEETA**'s Virtual and Augmented Laboratory) with stroke survivors, by contacting other organizations such as **Portugal AVC** or **GAM Aveiro**(which meet annually at **ESSUA**).

3.6 Timeline

Figure 3.4 shows the timeline of the project tasks in the format of a **Gantt chart**, where all the time intervals between the tasks are represented using a monthly scale and they are divided into **four** groups:

- Investigation;
- Development;
- User Study;
- Dissertation Writing.

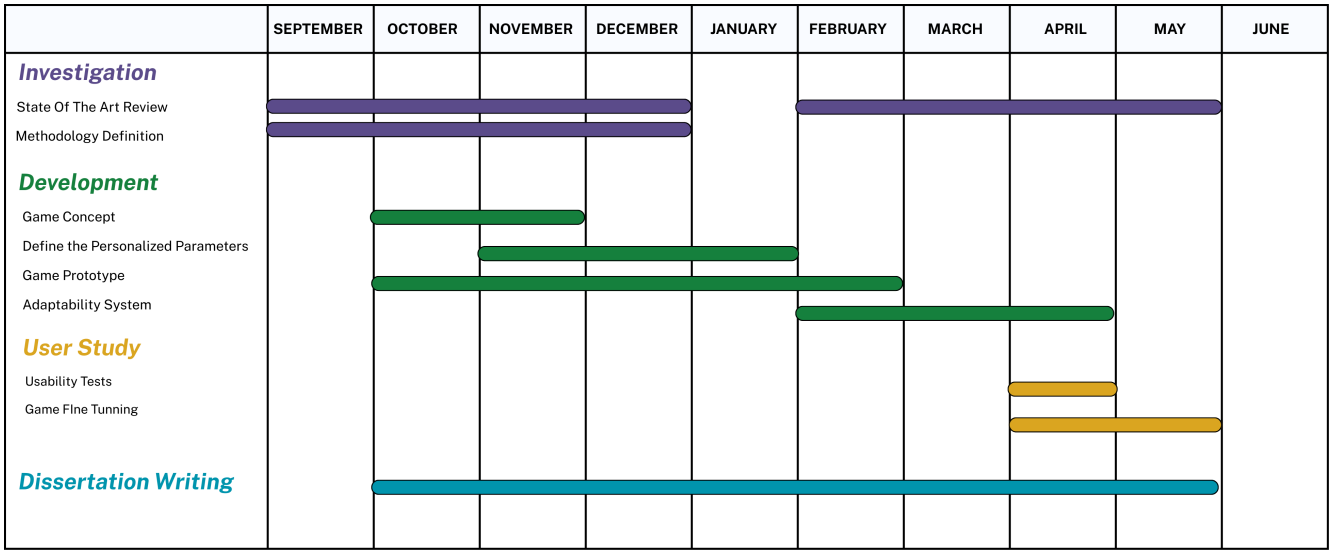

Figure 3.4: Gant Chart illustrating the proposed work between september 2025 and June 2026 with 4 workpackages

The Investigation tasks will include the review of the state of the art and methodology definition. The development tasks will focus on the development of the game prototype from its concept to the adaptability system. The user study will include the tasks of usability tests and game fine-tuning. Finally, the dissertation writing will be carried out throughout the school year.

3.7 Expected Results

At a development level

- Implement at least one VR-based serious game, that can be personalized;
- Have different variations of the functional prototype to test different approaches to dynamic difficulty adjustment (having a version where the game adapts in real-time, and another at specific time intervals).

At a therapeutically level

- Reinforce the use of serious games with VR-environments as as complementary methods to the traditional ones, to boost survivors's motivation and engagement.

3.8 On-going work

At the moment, the game prototype is under development. Figure 3.5 illustrates the current game environment: a country fair. This choice was made due to the country fair's cultural resonance, emotional value, and ability to promote an engaging environment.

Upon entering the game, the survivor sees two tents, each displaying the name of a mini-game. To select and play a game, the user must point with his finger and perform a pinch gesture. The available mini-games are an archery game (Figure 3.6), where the targets are balloons, and a frisbee game (Figure 3.7), which involves throwing a frisbee to a dog. These

Figure 3.5: Country fair envirnoment of the VR game prototype

Figure 3.6: VR archery mini game where the targets are balloons

Figure 3.7: VR frisbee mini game where the player must throw a frisbee to a dog

activities were selected because they are entertaining and target upper limb functions, such as hand grip, as well as cognitive functions, such as hand-eye coordination[9][10]. Furthermore, these games can be easily personalized by adjusting parameters such as the number of balloons or the distance between the player and the dog.

Currently, a paper describing this prototype is being prepared for submission to the **XRIOS 2026, IEEE VR 2026 Workshop**.

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APPENDIX A

Additional content

Var Lab(**IEETA**'s Virtual and Augmented Laboratory)'s website:

`https://sites.google.com/view/varlab/home`