Universidade de Aveiro
2026

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Freitas Palricas

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

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

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.

# Contents

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# Glossary

| | |
|---|---|
| **AI** | Artificial Intelligence |
| **DDA** | Dynamic Difficulty Adjustment |
| **HCD** | Human-Centered Design |
| **VR** | Virtual Reality |
| **XR** | Extended Reality |

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 Design Human-Centered Design (HCD)** methodology 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 presents a complete review of the situation regarding stroke rehabilitation and the increasing role of interactive technology. It begins by introducing the subject by describing the causes of stroke and then how traditional rehabilitation is lacking due to a lack of motivation and repetition of physical activities (Section 2.1).

Subsequently, the technological shift towards **Extended Reality XR** is explored, and information from a very recent "scoping review" emphasizes the dominance of **VR** and "Hand-Tracking" solutions in this sector (Section 2.2). Finally, a close analysis of personalization evaluates a "taxonomy of adaptation approaches" from "rule-based systems" to "behavioral tracking," which is imperative for going "beyond the "one-size-fits-all" approach" (Section 2.3).

Moreover, the conceptual foundations of **DDA** and Flow Theory are reviewed with the aim of explaining how mathematical systems can adapt to a patient's changing skill levels (Section 2.4). Finally, this chapter highlights the crucial impact of **HCD**, presenting evidence regarding the acceptance of this approach and the preference of health care professionals for the proposed hybrid method of adaptation against fully autonomous systems (Section 2.5). This chapter ends with a summary of the gaps found that this body of research will cover in the following chapters.

## 2.1 Stroke Rehabilitation: Challenges and Current Methods

### 2.1.1 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].

### 2.1.2 Current 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. 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[8][4][5][6].

## 2.2 XR and Serious Games in Stroke Rehabilitation

Recent advancements made in the field of **XR** an umbrella term that encompasses any sort of technology that alters reality by adding digital elements to the physical or real-world environment to any extent, which encompasses **VR** view of a fully imersive digital environment, **Augmented Reality (AR)** view of the physical or real world within an overlay of digital elements and **Mixed Reality (MR)** blend of the physical or real world with digital or virtual elements where physical and digital elements can interact.These technologies have been promising to overcome the drawback of traditional stroke rehabilitation methods in which the motivation levels of patients remain low and the exercise routine is monotonous. Based on a scoping review of **39 publications**(Figure 2.1) selected from the **SCOPUS** database **(2020–2024)**, **VR** is identified as the most prominent technology, appearing in **84.6%** of the analyzed studies. This dominance occurs since **VR** technologies have the capacity to create fully immersive, controlled, and safe environments that can mimic real-life scenarios, allowing patients to practice motor and cognitive tasks without the risks associated with physical environments.[9][4][10].

From a clinical perspective, there is a prominent concern for **upper limb rehabilitation** involving arms, hands, and shoulders, which is targeted by **66.7%** of the papers. Notably, this interest aligns with an urgent clinical need, as upper limb hemiparesis is among the most common disabilities following a stroke event and has a significant influence on daily autonomy. In order to encourage user interaction within such virtual settings, recent tendencies specifically point to an increasing interest in the adoption of natural interfaces. Hand-tracking technology is used as the main interface option within **41%** of the studies, outperforming the use of physical controllers by **25.6%.** This specific point is important since hand-tracking does not require the use of a physical controller that needs to be grasped by the patient, which can create significant difficulties for stroke survivors with very limited motor functions.[10][4]

In terms of intervention strategies, **Serious Games** represent the primary method, appearing in **67%** of the reviewed rehabilitation exercises. These type of games are designed for a principal use that is different from mere entertainment, such as education/training purposes, health, etc., by incorporating entertainment-related game mechanisms that help engage users to learn complicated subjects or behaviors in an entertaining manner.. In this way, serious game can be used to translate repetitive physical therapy motions to enjoyable activities, such as virtual sports and cognitive puzzles, to promote motivation as well as compliance with the therapy sessions. Additionally, aside from applications to platforms for games, simulations for real-life therapies were also cited within the literature at **23%**, such as mirror therapies, as well as simulations for Activities of Daily Living at **10%**, such as shopping or house chores, with the main idea of regaining autonomy. The addition of elements for gamification within such platforms has effectively tackled monotony commonly seen with physical therapies.[11][4][6]

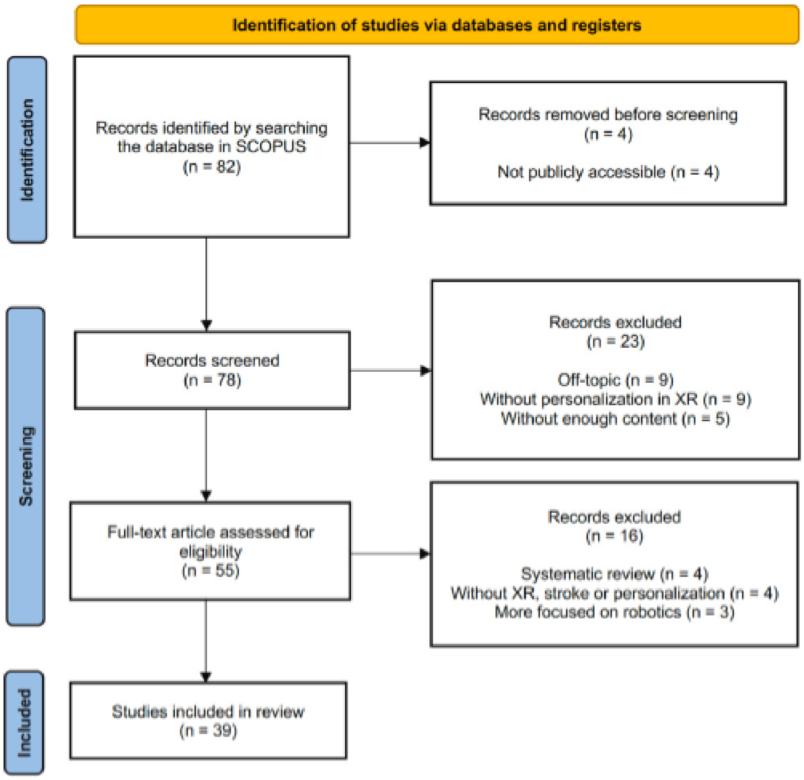


**Figure 2.1:** PRISMA diagram showcasing the approach for the review of personalized **XR** applications in stroke rehabilitation, resulting in the inclusion of 39 publications, according to the criteria established.

## 2.3 Personalization Strategies in VR Rehabilitation

Personalization is identified as a key element of effective therapy due to the recognition that each stroke survivor's course of recovery is unique and varies according to factors like physical, cognitive, and emotional impairments. Mainstream approaches to this issue through rehabilitation also offer standard or "one-size-fits-all" methods that do not adequately address individual needs. The inadequacy of these processes is also established to hinder recovery due to factors like frustration and lack of motivation on the part of survivors.[4]

### 2.3.1 Taxonomy of Personalization

Current research has offered a type of taxonomy to structure how **XR** environments can be adapted. From a scoping review(Figure2.2),the following have emerged as five key personalization approaches:[4]

- **Behavioral Tracking (30.8%)**: Involves tracking actions to monitor movement, postures, as well as engagement to identify frustration or fatigue;
- **Rule-based Systems (25.6%)**: use logical rules (such as "if the patient fails X times, change difficulty") to adapt the experience;
- **Bio-Feedback (23%)**: Use bio-feedback, like heart rate or muscle activity or EMG signals, for real-time adaptation ;

- **Contextual Adaptation (21%)**: Modify the session depending upon external variables, such as the timing of the session or the patient's mood;
- **Intelligent Monitoring**: Use machine learning algorithms to forecast the needs of users, although this area has been relatively under-explored in current literature because of the complexity of its implementations.

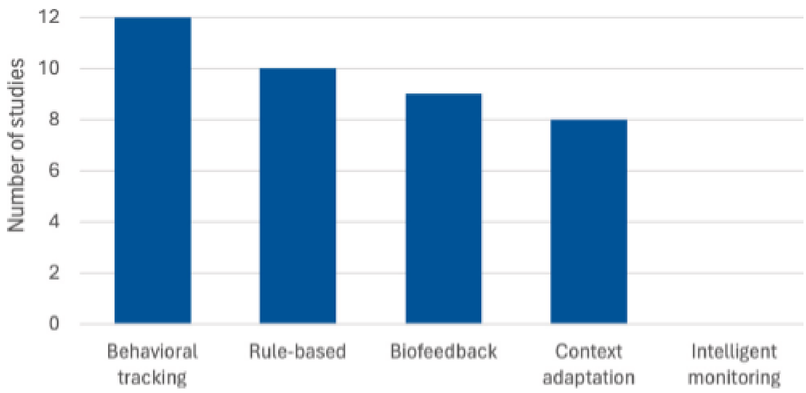


**Figure 2.2:** Distribution of publications across different personalization methods,highlighting Behavioral tracking as the most studied approach, followed by Rule-based and Biofeedback methods.

### 2.3.2 Automation vs Clinical Control

One major issue associated with personalization is methods and styles of adaptation, and more generally management or orchestration. While it appears that there is a preponderance towards automatic personalization **(46.2%)** in existing literature, this does not necessarily reflect professional preference.[4]

Recent studies of healthcare professionals working at **Rovisco Pais** rehabilitation center show a dominant leaning toward the hybrid model **(70%)**(Figure 2.3). The preference is for systems that can either suggest or execute the changes through software but still enable the therapist to correct the system with their own interventions whenever deemed necessary. The system designed for human involvement allows for oversight and reduces the therapist's burden of working manually. Additionally, concerning the point of executing the modifications, **50%** of healthcare professionals lean toward the Hybrid model of synchronization, which aims to modify the system both during the actual process and subsequently using historical data.[5]

With respect to the data used as inputs for the personalization process, although traditional measures of physical activity (such as range of movement) were common, personalized therapy requirements for the survivor were seen as motivation levels **(70%)** and emotional state **(60%)** by health professionals. This is an indication that the survivor's psychology has been targeted for enhanced therapy compliance.[5]

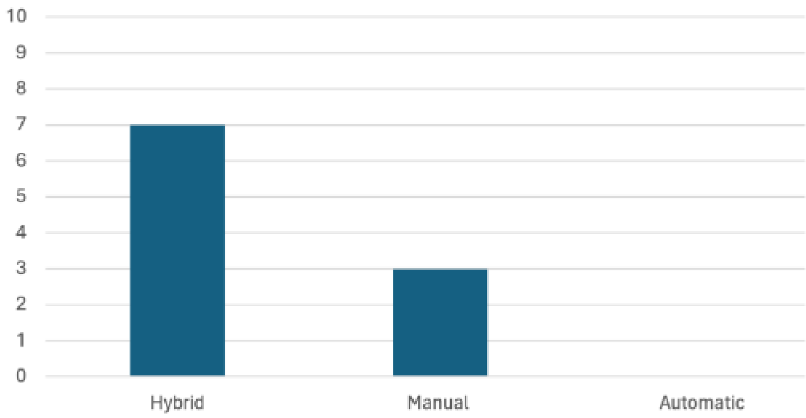


**Figure 2.3:** Distribution of healthcare professionals votes for each personalization mode: hybrid (7); manual (3); automatic (0)

## 2.4 DDA and Flow Theory

One of the major concerns associated with stroke rehabilitation is keeping the patient actively involved in a series of repetitive exercises. In this regard, modern studies increasingly suggest incorporating concepts related to the **Flow Theory**(Figure 2.4), proposed by **Csikszentmihalyi**. According to this theory, a person reaches a point where they are in an ideal mental setting, a skill level known as the **Flow Zone**, in situations where they experience equal levels of challenge and skill. The challenge that is too high generates frustration, and tasks with low levels generate a boring experience.[12]

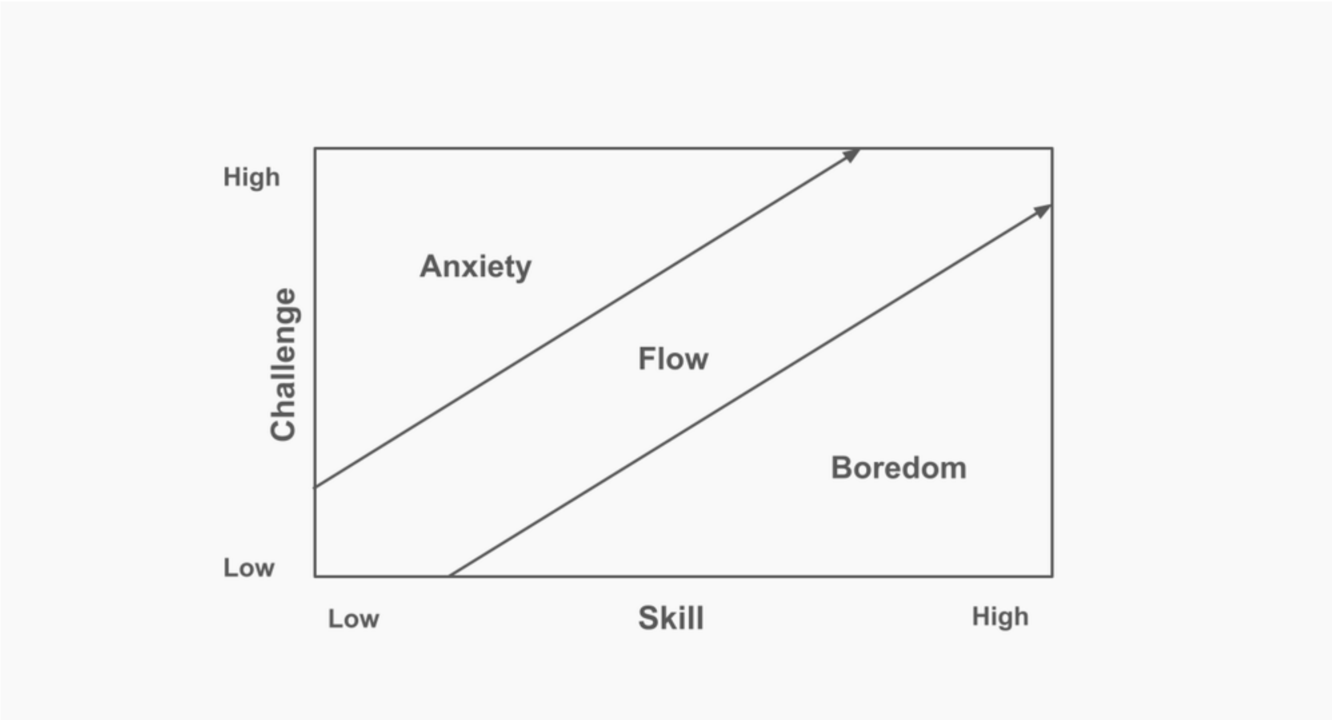


**Figure 2.4:** Mihaly Csikszentmihalyi's Flow Theory

### 2.4.1 Mechanisms of Adaptation

In order to maintain this, **VR** systems use a **DDA** technique, which is basically the "capability of the system to change parameters in real time in accordance with the player's performance during playing."

In the literature, approaches to the problem of difficulty adaptation and adjustment are presented under many categories, ranging from heuristic methods such as "if the patient fails three times, reduce difficulty" to more complex approaches using **Artificial Intelligence Artificial Intelligence (AI)** techniques. Although heuristic methods are more common and easier to understand, recent research has shown them to be potentially less representative of the dynamic nature of the patient's motor skills.[12][4]

### 2.4.2 Machine Learning in DDA: The Clustering Approach

An example of sophisticated **DDA** in upper limb rehabilitation is the utilization of unsupervised machine learning methods, namely clustering algorithms. A study highlighted the potential for the use of the **K-means algorithm** for personalized hand rehabilitation exergames. In contrast to the static level of difficulties, the system not only analyzes the patient's performance data (such as the extent of the patient's range of motion and the number of tries for the patient to grasp an object) but also clusters the instances of patient performance (such as low, medium, and high performance) and adjusts the difficulties dynamically using the group with the largest number of instances. The approach is most relevant for stroke survivors, who tend to have fluctuating levels of performance since they may do well at times and poorly at others as a result of fatigue. The approach is significant because it is able to sense the levels of failed attempts or fatigue and immediately decrease levels of difficulty as a result of such fatigue.[10]

## 2.5 Human-Centered Design and Clinical Acceptance

The effectiveness of innovative rehabilitation technologies is not just contingent on their ability to function correctly, but also on how well they integrate with the clinical environment, along with the needs of the users. As such, the latest trends in rehabilitation technologies focus on the use of the **HCD** approach, which entails the participation of end-users (stroke patients, along with healthcare personnel) throughout the entire process of development.[5]

### 2.5.1 Bridging the Gap: Role of Health Care Professionals

Though the final beneficiaries of rehabilitation games are stroke survivors, the prescribers and monitors of these interventions are healthcare professionals. A study had been recently conducted at the *Centro de Reabilitação Rovisco Pais*, showing that technological solutions in this context neglect the realities of physical therapy and hence fail in their aim to deliver an effective treatment process in an engaging manner.[5]

For this purpose, the designing of rehabilitation systems needs to be done in a manner that goes beyond a technical and engineering outlook and, instead, takes into account medical practices related to therapy customization and management.[5]

### 2.5.2 Preference for Hybrid Personalization

One of the most important findings in the current state of art in relation to clinical acceptance is adaptation mode. Indeed, most academic frameworks attempt to incorporate fully independent adaptation of **AI**, while in reality, a different requirement is to be expected in a clinical setting. There is also resistance to fully automated systems among healthcare professionals surveyed, as indicated by the result that **70% of healthcare professionals favor the Hybrid Personalization approach**. This is often referred to as the 'Human-in-the-loop' method, wherein the system independently provides or changes the level of difficulty (for example, employing **DDA** algorithms), while still allowing the therapist to make changes manually.[5]

### 2.5.3 Data Priorities: Beyond Motor Metrics

Moreover, the **HCD** methodology highlights the paradigm shift in the value of data. While the former systems focus on the use of biomechanical data (e.g., range of motion, speed), healthcare practitioners recognize the vital role of psychological aspects for successful recovery. Upon being asked which type of data is of prime importance to tailor the repair process, the practitioners cited Motivation **(70%)** and Emotional State **(60%)**. This observation reemphasizes the need for a **VR** application to integrate gamification features that, besides training the user on motor functions, monitor and optimize engagement to avoid treatment dropout.

## 2.6 Summary

This chapter provided an overview of the challenges in stroke rehabilitation and the potential offered by **VR** for its solution. Although rehabilitation techniques, for example, Constraint-Induced Movement Therapy (CIMT), prove effective, this is hampered by the dullness of the exercise, which might affect patient compliance. It is evident from a literature search study that **VR** has been the leading solution, used in **84.6%** of current studies, with a growing trend towards Natural Interfaces, for example, Hand-Tracking **(41%)**, for upper limb rehabilitation .[8][4]

Further, the importance of a Hybrid Personalization strategy cannot be overstated, as supported by feedback from medical professionals, showing a strong preference for such a strategy **(70%)** in which the system provides recommendations and the therapist provides supervision. Finally, the importance given to 'motivation' and 'emotional state' cannot but support serious games beyond simple physical repetitions.[5]

These results validate the research pathway that involves creating a serious game in **VR** in a **"Country Fair"** environment that incorporates hand-tracking, a hybrid approach for personalization, and a **DDA** aproach to enhance both motivational and recovery results for stroke survivors.

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

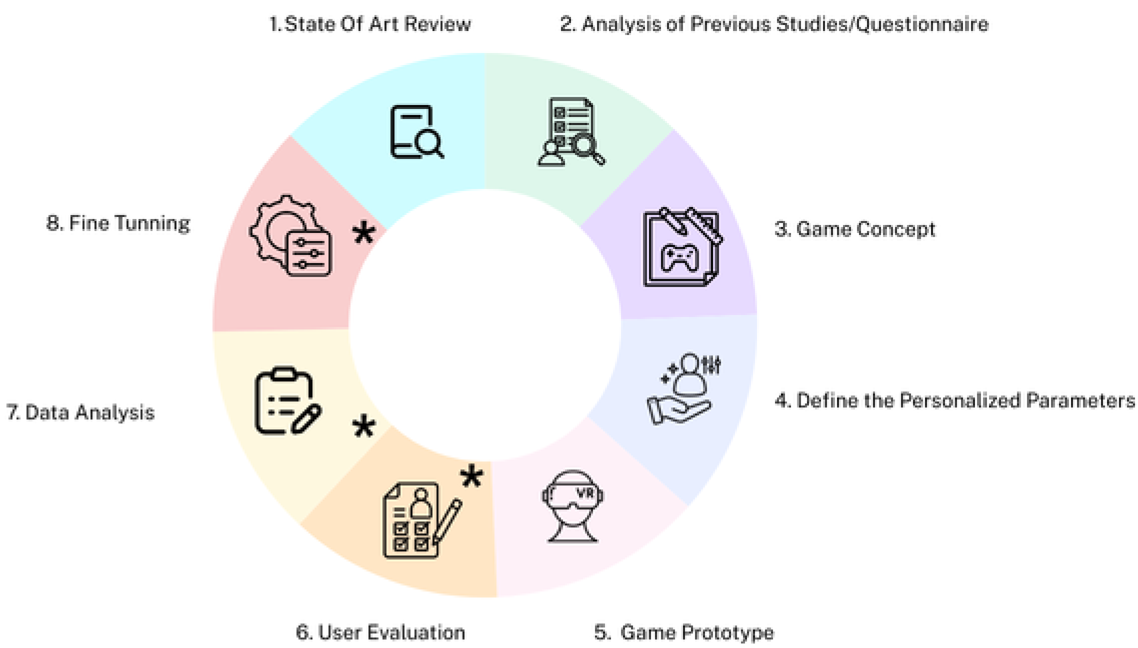


**Figure 3.1:** Methodology illustrating 8 phases to support the design and development of a VR Personalized Game for the rehabilitation process of stroke survivors

This project will adopt the **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).

**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

**Analysis of Previous Studies**

- Previous studies were analysed to understand the efficiency of **VR**, 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

Linked to the **HCD** method and the adaptive model presented in Figure 3.3 shows the conceptual architectural design for the project.[5][6]

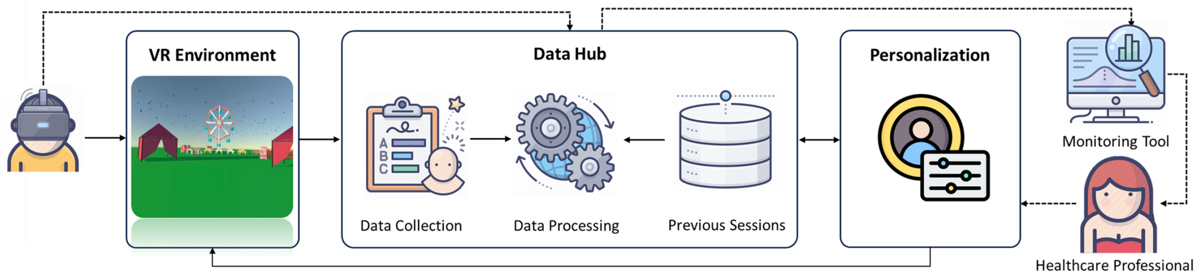


**Figure 3.3:** Conceptual framework for combining VR and a hybrid personalization aproach for stroke survivors' recovery.

The architectural design represents more than data flow, it represents a closed-loop system designed to maintain the stroke survivor's motivation and promote neuroplasticity through its four components:

### 3.4.1 The VR Environment (Interaction Layer)

The stroke survivor participates in the **"Country Fair"** serious game scenario, which acts as a controlled multisensory environment. Unlike traditional therapy methods, this environment models real-world motor activities such as reach and grasp, at the same time recording key data metrics such as the user's score(performance).

### 3.4.2 The Data Hub (Processing Core)

The Data Hub is the system's brain that has the task of analyzing the data. Importantly, the Data Hub does not have the task of analyzing the data on its own. Instead, the system provides a comparison between the current performance and the previous historical data kept in the "Previous Sessions Database". Similar to the research by **Bouatrous et al.**, this model implements a **"Fatigue Check"** logic. By checking user's sudden drops in performance(e.g., consecutive failing a task), the system can determine whether the user lacks skill for a specific level or is physically exhausted.This distinction is vital to ensure that the subsequent adaptation is therapeutic rather than frustrating.[10]

### 3.4.3 The Personalization Engine (Adaptation Layer)

In this module, **DDA** is used as an approach that places the user within the **state of "Flow"**, which is an optimal balance between skill levels and challenge that maximizes engagement. In accordance with the identified classification of the scoping review, this engine will use rule-based adaptation, using pre-defined rules (for example, "if accuracy $>$ 80%, then target distance + 10%") to quickly change gameplay. In the long v term it is expect this system to implement behavioral tracking, tracking survivors's facial expressions to check their levels of motivation, frustration and fatigue.[12][4]

### 3.4.4 Monitoring Tool & Hybrid Approach (Clinical Oversight)

One of the key features of the proposed framework is the integration of a Monitoring Tool, specifically designed for use by professionals in the health sector. This feature has been supported by empirical evidence from a survey carried out in the Rovisco Pais Rehabilitation Center, in which **70%** of health sector professionals preferred a Hybrid Personalization strategy to fully automated systems[5]

The presence of self-authority in altering levels of difficulty using DDA is in the Monitoring Tool, which allows the human therapist to manually override or set boundaries for safety. This meets clinical safety standards while guaranteeing that the therapy is in line with the feelings and physical condition of the survivor.However this module **is not a goal of this project** but rather a long-term vision.[5]

## 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

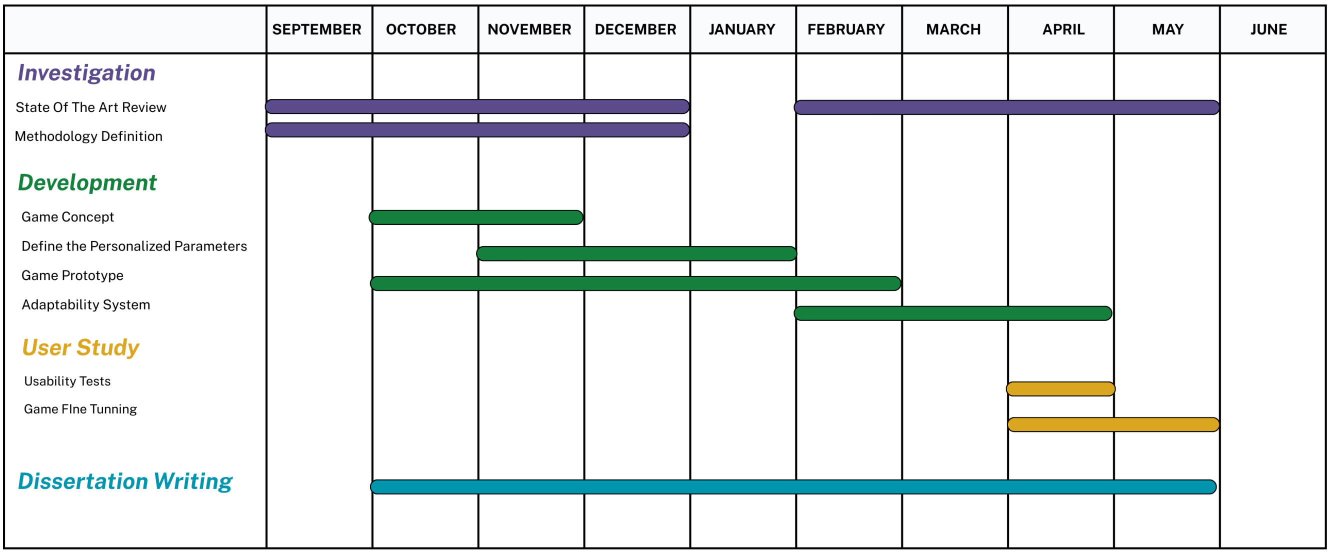


**Figure 3.4:** Gant Chart illustrating the proposed work between september 2025 and June 2026 with 4 workpackages

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.

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 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. 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.[13][14]

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

**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

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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`