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Analysis, Design and Implementation of Serious Game for Upper Limb and Cognitive Training Using Leap Motion for Multiple Sclerosis Patients

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eingereicht von

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an der Fakultät für Informatik

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Bojana Kecman, BSc

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Wien, 17. April 2024

Bojana Kecman

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Kurzfassung

Multiple Sklerose (MS) beeinträchtigt kognitive, emotionale, motorische, sensorische und visuelle Funktionen. Laut der Multiple Sklerosis Internationale Vereinigung (MSIF) sind weltweit etwa 2.9 Millionen Menschen von MS betroffen. Die MS-Symptome variieren, aber umfassen oft kognitive Beeinträchtigungen, Sehprobleme, Müdigkeit, Muskelschmerzen, Schwäche in den Gliedmaßen sowie Probleme beim Gehen und Balancieren. Die Behandlung umfasst üblicherweise Medikamente und Rehabilitation, abhängig von Symptomen, Stadium und Typ. Die Rehabilitation kann dazu beitragen, die Lebensqualität zu verbessern und Zittern, Muskelschmerzen und Krämpfe zu reduzieren. Aber die Motivation in der Rehabilitation zu erhalten, ist eine Herausforderung. Hierbei können Serious Games helfen. Mehrere Autoren haben die Entwicklung von Serious Games untersucht, die Patienten motivieren und die Therapietreue erhöhen können. Es besteht auch Interesse an Exergaming, das körperliche Aktivität fördert und motorische Fähigkeiten trainiert. Exergames verwenden oft Bewegungssensoren, wie Kinect für Xbox, Leap Motion Sensor und Wii Balance Board. Die aktuelle Forschung ist jedoch oft für alle neurologischen Erkrankungen verallgemeinert oder konzentriert sich nicht auf MS. Spiele in diesem Bereich sind in der Regel auf physische oder kognitive Aspekte ausgerichtet. Es gibt jedoch kein Serious Game, das ausschließlich für MS Patienten entwickelt wurde und sowohl kognitive als auch feinmotorische Übungen integriert.

Diese Arbeit untersucht, welche Anforderungen für ein Serious Game zur Feinmotorikrehabilitation der oberen Gliedmaßen und kognitive Übung für MS Patienten wichtig sind. Unser Serious Game verwendet den Leap Motion Controller als unterstützende Hardware. Ein Endprototyp repräsentiert die Umsetzung dieser Anforderungen, wobei wir unsere Lösung unter Berücksichtigung spezifischer MS-Symptome basierend auf dem User-Centered Design (UCD) entworfen haben.

Fünf Teilnehmer haben an der Evaluation teilgenommen. Unser Prototyp wurde mit dem Game Experience Questionnaire (GEQ) bewertet. Der GEQ ergab durchschnittliche Scores für das Spielerlebnis über sieben Komponenten: Kompetenz (3.04), Immersion (2.76), Flow (2.72), Spannung (0.13), Herausforderung (2.72), positive (3.26) und negative Auswirkungen (0.2). Außerdem haben wir einen System Usability Scale (SUS) Fragebogen durchgeführt, mit einem durchschnittlichen Ergebins-Score von 82.5.

Keywords: *Multiple Sklerose, digitale Rehabilitation, Serious Game, Exergame, Leap Motion Controller*

Abstract

Multiple Sclerosis (MS) is a neurological disease that impacts function in cognitive, emotional, motor, sensory, or visual areas. According to the Multiple Sclerosis International Federation (MSIF), it is estimated that approximately 2.9 million people worldwide are affected by this condition. Symptoms of MS vary from person to person, often including cognitive impairments, vision problems, fatigue, muscle stiffness, numbness in weakness in limbs, and trouble walking and keeping balance. Treatment, dependent on symptoms, stage, and type, typically involves medication and rehabilitation. Rehabilitation can help improve functioning, quality of life and reduce tremors, muscle stiffness and spasms. However, maintaining motivation in rehabilitation is a key challenge due to the decreasing engagement in repetitive exercises. Serious games, by providing knowledge, offer therapeutic applications suitable for MS rehabilitation. Several authors have explored the development of serious games that can motivate, engage and increase patients' adherence to their treatment. Additionally, there have been interest in exergaming, a specific genre of serious games, with primary goal to promote physical activity and to exercise different motor skills. Exergames often utilize motion sensors, including devices like Kinect for Xbox, Leap Motion Sensor and Wii Balance Board. However, state of the art research is often generalized for all neurological conditions, or just does not focus on MS. Furthermore, games in this domain are typically centered on either physical or cognitive aspects. There is no serious game available exclusively designed for MS patients, integration both cognitive and fine motor exercises.

This thesis investigates which requirements are essential for a serious game for fine motor exercising of upper limbs, and cognitive training for people with MS. Our serious game uses Leap Motion Controller as assisting hardware. A final prototype represents a utilization of these requirements, where we designed our solution with consideration of specific MS symptoms, based on the User-Centered Design (UCD) approach.

In the evaluation phase, five participants engaged in assessing our prototype using the Game Experience Questionnaire (GEQ). The GEQ resulted in average scores for gaming experience across seven components: competence (3.04), immersion (2.76), flow (2.72), tension (0.13), challenge (2.72), positive (3.26) and negative affect (0.2). We also employed the System Usability Scale (SUS) questionnaire, resulting in an average score of 82.5.

Keywords: *multiple sclerosis, digital rehabilitation, serious game, exergame, Leap Motion Controller*

Contents

CHAPTER 1

Introduction

The thesis analyzes serious gaming for cognitive and physical rehabilitation for patients with multiple sclerosis and proposes a prototype with game scenarios that address multiple rehabilitation techniques. In the following, we present a problem statement and motivation to outline the focus of the thesis. Then, in the aim of the work, we define the research questions, followed by an elaboration of the methodology used to answer these questions. In the methodology, we give a detailed overview of the applied methods. Finally, we present an outline of the thesis structure at the end of the chapter.

1.1 Problem Statement and Motivation

Multiple Sclerosis (MS) is one of the world's most common neurological disorders. The 2023 edition of the Atlas of MS shows there are 2.9 million people living with multiple sclerosis around the world [1]. Ghasemi et al. [2] define MS as a chronic inflammatory disease characterized by central nervous system (CNS) lesions that can lead to severe physical or cognitive disability. According to Spooren et al.[3], 66% of people with multiple sclerosis (PwMS) experience motor dysfunctions of the upper limbs. This includeas limited free movements of affected limbs, twitching and jerking of muscles, and involuntary contractions [1]. Our hands have a very delicate structure, and even the smallest movements require complex muscle activation patterns, making the simple daily routines for PwMS significantly harder. Furthermore, as the disease progresses, it commonly affects patients' cognitive ability. According to [4], cognitive impairments affect around 50-60% of MS patients. The book highlights that these impairments can manifest in various ways, including attention, memory, processing speed, problem-solving, and decision-making difficulties.

To improve their quality of life and related neurological damage, MS patients are usually involved in rehabilitation training. Various rehabilitation approaches include physical, cognitive, and sensomotoric integration exercises [5][4]. To increase muscular strength and endurance, motor training usually consists of repetitive movements that directly activate weakened muscles. Repeated practice of movements enhances neuroplasticity, which is the brain's ability to reorganize itself by forming new neural connections throughout life, allowing the neurons in the brain to compensate for injury and disease and to adjust their activities to new situations [6]. Physical exercise is crucial for the well-being of people with MS, as it helps improve their overall health. It is equally important to highlight the significance of cognitive training for several reasons, including greater independence in daily activities and a lower risk of depression. However, repetitive and monotonous activities tend to negatively affect an individual's motivation. Additionally, traditional methods may not always be tailored to each patient's individual needs and preferences.

Interest in serious games for rehabilitation has grown in the last few decades, as they offer a unique and engaging approach to therapy. Specially designed games, with a set of physical and cognitive tasks, can motivate and increase patients' adherence to their treatment by making the training sessions more enjoyable. Combining serious games with traditional rehabilitation techniques could lead to more effective and efficient rehabilitation. We aim to develop a game-based training assistant specially designed for PwMS by utilizing a highly accessible Leap Motion Controller. It is a precise and low-cost device, making it a suitable tool to assist PwMS with their rehabilitation, both with the assistance of a therapist and at home.

1.2 Aim of the Work

Although serious gaming in rehabilitation has been investigated in the last years, much less work has been invested in the exploration of serious games for cognitive and fine motor rehabilitation designed exclusively for people diagnosed with MS. Both repetitive motor exercises and brain training exercises have scientifically proven beneficial effects on neuroplasticity. This thesis aims to investigate motor impairments associated with muscle weakness and lack of movement coordination caused by MS and to develop a prototype of a serious game that would support patients' rehabilitation according to the treating medical practitioner's guidelines. Furthermore, our serious game will address MS-related cognitive dysfunctions. We aim to design a set of gamified brain exercises that could produce lasting benefits by enhancing and maintaining the speed of cognition and reasoning skills.

This thesis should provide answers to the following research questions:

- **RQ1**: What are the requirements for a serious game focused on cognitive and upper limb rehabilitation in individuals with multiple sclerosis, identified with specialists and MS patients?

The requirements engineering process is crucial to address this research question. Literature review, interviews with neurologists and occupational therapists, questionnaires completed by MS patients, and user feedback are primary sources used to specify requirements. We will apply a user-centered design approach to identify requirements, starting with the initial requirements specification in the research phase, followed by three iterations in the implementation phase. The methods employed during each phase will vary, including literature research, brainstorming, thinking aloud, qualitative interviews, semi-structured and Likert Scale questionnaires, and user testing.

- **RQ2**: Which traditional exercises should a game for fine motor training for PwMS imitate and are there any limitations of the Leap Motion Controller in translating these exercises into a game?

A combination of multiple methods is necessary to provide a comprehensive answer to this research question. The first step is to conduct qualitative interviews with specialists to obtain information about cognitive and upper limb symptoms of MS, as well as the relevant rehabilitation techniques. The interpreted results of the interviews will be integrated into the game design. In addition, the literature review will help us identify effective exercises and gain an understanding of the capabilities and limitations of the Leap Motion Controller. Next, prototyping will enable a direct assessment of the Leap Motion Controller's ability to track and translate the specific fine motor movements addressed by the game. Any issues or limitations identified during the prototype phase will be addressed through further iterations. Finally, the game prototype is handed in for usability testing to assess the effectiveness of the Leap Motion Controller in translating traditional exercises into a game and to gather feedback on the game design and mechanics.

- **RQ3**: Does the developed serious game captivate and engage players according to Game Experience Questionnaire [7]?

This research question aims to evaluate players' level of engagement and interest, and it is answered in the evaluation phase. The target group of this work is PwMS; however, finding an adequate number of MS patients to provide direct feedback on the prototype has proven challenging. Therefore, a smaller group of MS patients and an additional group of volunteers will be asked to provide feedback on the finalized prototype. Both groups will be presented with the finalized prototype and asked to complete the Game Experience Questionnaire and System Usability Scale to assess the level of engagement and captivation experienced while playing the game.

1.3 Methodology

The methodological approach in this thesis will consist of three distinct phases: *research*, *implementation*, and *evaluation*. Figure 1.1 illustrates the chronological order of the methods within the three phases and highlights the stakeholder involved in each method.

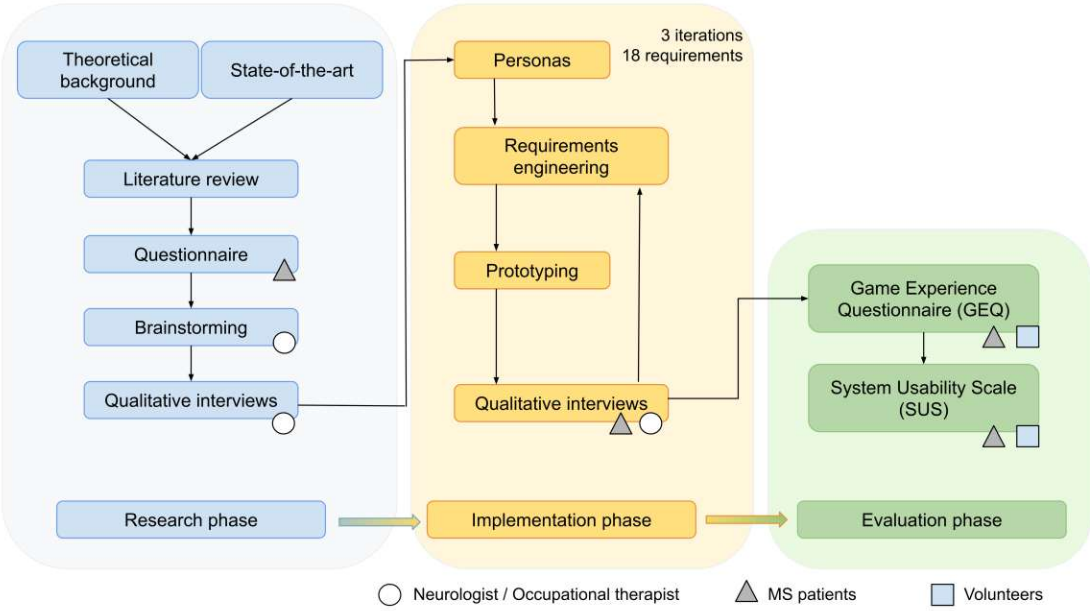


Figure 1.1: Flow chart associating methods with participating stakeholders

Research Phase

Literature review is selected as the initial method in the research phase. It will include research on theoretical background and the current state of the art solutions in serious gaming and exergaming. This step is essential in providing an objective and comprehensive overview of the topic, highlighting the benefits and limitations of the available training platforms.

As part of the methodology, *questionnaires* will be distributed to a group of MS patients to gather their opinions on serious games designed for cognitive and upper limb rehabilitation. The questionnaires will be created based on a review of the literature. The questions will focus on the symptoms that patients experience, their current rehabilitation practices, and their interest and suggestions in using serious games as part of their rehabilitation program. The data collected serves as a valuable source of information for the further design process.

Brainstorming will be used as a method to gather ideas and feedback from MS patients and neurologists during the design phase. During the brainstorming sessions, patients and neurologists are encouraged to share their experiences with existing rehabilitation methods and suggest features that would motivate and engage players. The resulting ideas will be recorded, analyzed, and used in the design phase. The goal is to ensure that the game is engaging, effective and meets the target audience's needs.

We define the expectations for the serious game in collaboration with two neurologists. This will be done through *qualitative semi-structured interviews*. In the initial phase, interviews aim to help define objectives and capture requirements that would support the rehabilitation of the PwMS with a serious game and distinguish functional and non-functional requirements. In the implementation phase, neurologists will be interviewed again after each iteration to give feedback on the design's current state. Finally, after finalizing a prototype, a semi-structured interview will be conducted to evaluate the prototype for its applicability in rehabilitation and its usability. It will include a combination of specific and open-ended questions.

Implementation Phase

The complexity of the developed system means that certain aspects cannot be fully specified at the outset of the design process. To address this uncertainty, an *iterative approach* will be used, whereby the requirements and prototype change according to newly gathered information. Each iteration will include qualitative interviews, requirements engineering, and prototyping.

The initial requirements will mainly be based on the state of the art, brainstorming, and the result of the interviews. The outcome should be a comprehensive idea for the game that would imitate the tasks included in the traditional therapy in a more enjoyable setting. However, *requirements engineering* is an iterative process in which the requirement list is adjusted in each iteration according to the specialists' feedback on the current state of the design. Therefore, the overall requirement analysis process will result in various requirements that are subject to change. Furthermore, the requirements will be derived based on the User-Centered Design (UCD) approach. By incorporating user feedback throughout the development life cycle, the requirements will be based upon an explicit understanding of users, where extensive attention is given to usability goals and user characteristics.

The next step in the implementation phase will involve *iterative prototyping* based on the identified requirements at each iteration. Just like requirements analysis, prototyping will be based on UCD. The objective will be to design a serious game that offers a great experience to PwMS. The iterative prototyping process will begin with a simplified implementation, such as sketches or low-fidelity prototypes, which will gradually become more complex until the final high-fidelity prototype is complete. At the end of each iteration, the state of the game will be analyzed and assessed together with the neurologists.

Iterative prototyping is closely linked with requirements analysis and evaluation, as changes in one phase can affect the other at the end of each iteration.

Evaluation Phase

The final step of the development process is the evaluation phase, which aims to gain a better understanding of the engagement and experience of players. The finalized prototype will be presented when possible to a group of MS patients, and volunteers. They will engage in a play session where they will interact with the game and perform the prescribed tasks. The level of engagement will be used as a potential indicator of the learning a serious game is capable of imparting. We will use *Game Experience Questionnaire* (GEQ) [7], as an evaluation tool to measure players' engagement after the play session. The questionnaire distinguishes between seven different dimensions of player experience: sensory and imaginative immersion, tension, competence, flow, negative affect, positive affect, and challenge. Additionally, the *System Usability Scale* (SUS) [8] will be performed to get further insight into the user's perception. This questionnaire consists of ten questions that provide an overall view of the subjective evaluation of usability. By analyzing the results, we can assess the effectiveness of the serious game in engaging players and provide insights for further improvements.

1.4 Structure

This thesis consists of five chapters that address different phases of the research. The introduction chapter outlines the problem statement, motivation, methodology, and expected results. In chapter 2, we delve into the theoretical background, starting with a detailed introduction to multiple sclerosis and rehabilitation to provide a better understanding of the disease. Next, we present the field of serious gaming and exergaming, focusing on games for rehabilitation to explore how games can be used to support the traditional rehabilitation process. In this chapter, we also discuss the concepts of user-centered design and requirements engineering as a core of software engineering in general. Chapter 3 focuses on the state of the art in serious gaming for rehabilitation. First, we select five serious games relevant to our topic. Then, we analyze the games in terms of their design and effectiveness in supporting the rehabilitation process. This analysis provides valuable insights into the best practices in serious game design for rehabilitation. Chapter 4 presents the results of the thesis, with subchapters dedicated to each phase of development (figure 1.1.) Furthermore, we provide the evaluation results gathered from Game Experience Questionnaire- [7] and System Usability Scale [8]. Finally, the discussion and conclusion chapter reflects on the research questions, findings, implications, and areas for improvement in the proposed serious game.

CHAPTER 2

Theoretical Background

Developing and evaluating a serious game for rehabilitation requires knowledge in multiple fields. For this thesis, we need basic medical knowledge in neuroscience. Understanding the nature of multiple sclerosis and the challenges of the individuals with this disease will help us understand their needs. Moreover, technical knowledge in game design and software development is necessary to effectively translate those needs into a serious game that will support patients in everyday rehabilitation.

The chapter starts with an overview of the etiology ("reason") and pathogenesis ("development") of multiple sclerosis. Subtypes of the disease are briefly explained, followed by the impact of MS on the patient's life. MS patients are typically involved in long-term rehabilitation. In this chapter, we also cover cognitive and physical rehabilitation training of PwMS. Understanding the exercises and training routines will help us identify possible impairments and potential exercises that could be included in the proposed serious game. In the subsequent chapter about digital rehabilitation, the concept of serious gaming and exergaming in healthcare is discussed, focusing on games for rehabilitation. Since we are developing an interactive system intended for patients, it is essential to keep the users in mind throughout the entire design. Therefore, this chapter also explains User-Centered Design (UCD) as a key tool used to create games that meet specific goals while being engaging and satisfying for players. All the gathered information must be translated from informal needs to formally specified requirements. Requirements engineering is a crucial step in the design process. Hence, the last part covers the elucidation of the requirements engineering process.

2.1 Multiple Sclerosis

Multiple sclerosis is an inflammatory disease that affects the central nervous system, i.e., the brain and spinal cord [9]. Simply put, CNS is a network of neurons responsible for coordinating and integrating the body's functions. Each neuron is built of a cell body and an axon, i.e., a nerve fiber. Focal lymphocytic infiltration, described in [9], leads to damage to axons and myelin - the protective covering around nerve fibers - resulting in the development of multiple sclerosis. According to Stadelmann et al. [10], myelin consists of protein and a fatty substance known as the myelin sheath, formed by cells called oligodendrocytes. Myelinated fibers play an essential role in the proper functioning of the CNS, as they facilitate fast and efficient propagation of nerve signals. Additionally, they protect nerve fibers from damage by providing an extra layer of insulation [10]. Figure 2.1 illustrates the structure of myelinated fibers.

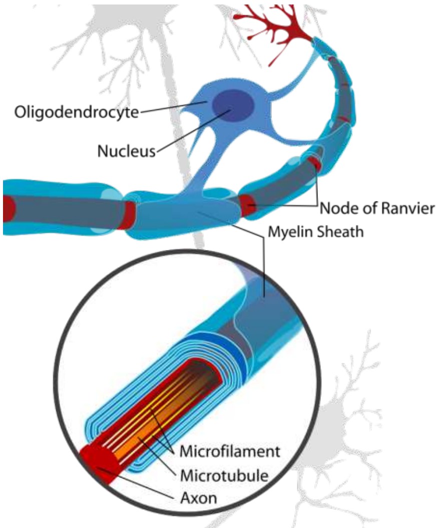


Figure 2.1: Neuron with oligodendrocyte and myelin sheath [11]

MS is the most common disease affecting CNS myelin in humans [9]. In [10], Stedelmann et al. investigated myelin's structure, function, and pathology. According to the study, the inflammation of myelin caused by MS damages the underlying nerve fiber, creating lesions along the nerve. Damages slow or halt nerve conduction, i.e., the transmission of nerve impulses. As a result, the patient initially experiences visual disturbances due to optic neuritis and a range of sensory and motor symptoms. The research conducted by Compston et al. [9] examines the parts of the CNS that are affected by MS. The study showed that the affected areas might vary depending on the individual and the stage of the disease. In some cases, the brain and spinal cord may be impacted, while in others, the optic nerves or other parts of the CNS may be involved.

The etiology of the disease remains unclear, but it is believed that MS is a result of a combination of genetic and non-genetic factors. Various studies [12][13] examine the genetic influence on MS prevalence, indicating that the generic risk is probably higher. Heines et al. [12] indicate that searching for individual genes affecting MS susceptibility has been challenging since the variations in dozens of genes are thought to be involved in the prevalence risk, as demonstrated in various studies. Despite the wide lack of association in genetic studies of MS, there was little uncovered evidence of linkage. Hollenbach et al. [14] provide a comprehensive overview of the multiple genome-wide association studies and other genetic linkage studies. According to the review, the human leukocyte antigen (HLA) gene cluster on chromosome 6p21 has consistently been identified as the most decisive genetic factor for multiple sclerosis through association studies of candidate genes and microsatellite marker genome-linkage approaches. The HLA genes are responsible for creating polymorphic cell surface glycoproteins that help regulate the immune system by recognizing either nonself intracellular proteins (class I) or extracellular proteins (class II) [15]. Patsopoulos et al. [16] indicate that the susceptibility of multiple sclerosis is primarily liked to the HLA genes of class II, specifically HLA-DRB1*15:01 allele. However, HLA class I genes have also been reported to have a weak association with multiple sclerosis susceptibility. To this day, the studied list of candidate genes is far from complete due to the heterogeneity of the human population and the complexity of the interactions in the nervous system. There are other risk-conferring genes associated with MS; however, we will not cover them in this thesis.

On the other hand, studies show that there are various non-genetic factors associated with an increased risk of MS. Waubant et al. [17] emphasize that different environmental factors, including low levels of vitamin D, exposure to certain viral infections, childhood obesity, and smoking, have been repeatedly proposed to contribute to the prevalence of MS. Moreover, the study suggests that hormonal factors may contribute to the disease, given the higher prevalence of MS among women than men, with a ratio of 1.6-2.0:1. This is supported by evidence of decreased relapse rates during pregnancy and a rebound of the disease after pregnancy, as well as a correlation between worsening MS symptoms during menstruation. Studies, such as [18], have found a relationship between high estradiol levels and low progesterone levels with increased MRI activity. Additionally, there are gender differences in susceptibility to EAE, with testosterone providing a protective effect and the therapeutic effects of estriol in relapsing-remitting MS. However, the exact role of the non-genetic factors in the development of MS is still not well understood, and more research is needed to understand their effects fully.

Due to heterogeneous factors, MS is a highly complex disease, with variations in causes, symptoms, and course. The heterogeneity in the etiology is the main reason why the disease is so difficult to diagnose and treat.

2.1.1 Subtypes of Multiple Sclerosis

Multiple sclerosis is a complex disease that can manifest in various clinical courses. An important area of research in MS is the classification of clinical subtypes, which can help specialists better understand the disease and tailor treatments to individual patients. In 1996, Lublin et al. [19] proposed the concept of four MS clinical subtypes, a widely accepted framework for categorizing clinical courses. A group of MS experts, including Lublin, continued to refine the clinical subtypes of MS and ultimately published a revised consensus in 2014 [20]. According to the revised consensus, we distinguish three MS subtypes:

- **Relapsing-Remitting MS (RRMS)** is characterized by periods of active disease, called relapses or exacerbations, followed by periods of remission, during which symptoms improve or disappear. A relapse can last from a few days to several weeks and can be triggered by various factors, such as stress, illness, or temperature changes. Only during relapse, new symptoms may appear, or existing symptoms may worsen. In the remission phase, there is no apparent progression of the disease.
- **Secondary-Progressive MS (SPMS)** follows an initial course of RRMS. This type of MS progresses steadily since there are fewer relapses and remissions. In most cases, relapses disappear altogether, but the patient's neurological condition continues to degrade. The majority of patients transition from RRMS to SPMS over time (approximately 82% by 20 years of onset [21]). A gradual worsening of symptoms, including numbness, muscle weakness, difficulty with balance and coordination, and cognitive impairments, characterizes SPMS.
- **Primary-Progressive MS (PPMS)** is characterized by a steady worsening of symptoms from the outset, with few or no relapses and remissions. Patients with PPMS experience similar dysfunctions as SPMS patients without experiencing acute relapses.

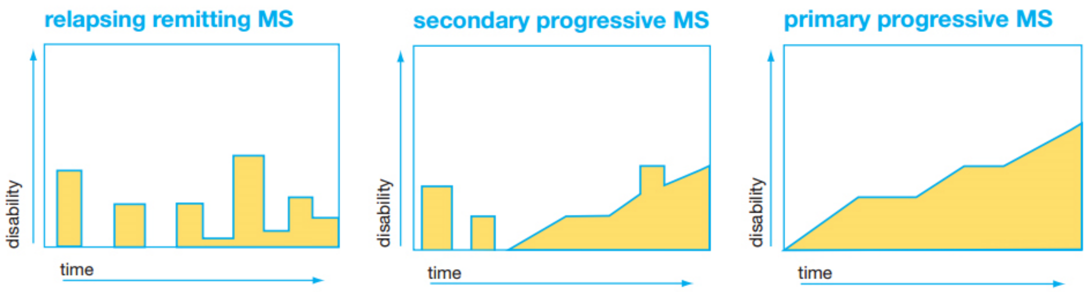


Figure 2.2: Clinical presentation of multiple sclerosis subtypes [22]

Figure 2.2 graphically represents the above-described clinical profiles of MS. Lublin et al. [20] further characterize each MS subtype as either *active* or *non-active*. Patients with active MS experience clinical relapses, i.e., magnetic resonance imaging (MRI) shows new brain or spinal cord lesions. On the other hand, in non-active MS, the disease is in remission, and MRI activity is absent. According to Multiple Sclerosis International Federation (MSIF), it is estimated that approximately 85% of MS patients have RRMS, 10%-15% have SPMS, and 5%-10% have PPMS [1]. It is important to note that the prevalence of different MS subtypes may vary depending on various factors such as age, gender, and geography. For example, RRMS tends to affect women twice as often as men, and it is common in younger individuals. However, SPMS is more common in men and mainly occurs in the elderly [1].

2.1.2 Impact of Multiple Sclerosis

MS can have a significant impact on patients, both on their physical and emotional well-being. Bass et al. [23] conducted a study on 1075 participants with relapsing-remitting MS. Approximately 42% of study participants reported that their ability to perform and manage daily activities had worsened in the past two years, and over 50% reported limitations in daily activities due to fatigue, problems with balance and coordination, sensitivity to temperature changes, numbness and tingling, memory problems and difficulty concentrating, impaired movement and muscle stiffness, and difficulty sleeping. The participants also reported negative effects on emotional and social factors. According to the study, the disease substantially impacts a patient's self-esteem, ability to start and maintain relationships, progress in career, and ability to fulfill life roles. These challenges and a constant sense of frustration can be decisive factors in developing anxiety and depression. A study by Boeschoten et al. [24], indicates that Major Depressive Disorder (MDD) in MS affects anywhere from 12% to 56% of individuals. This is significantly higher than the general population, where the lifetime prevalence ranges from 2% to 21% [25].

2.2 Rehabilitation in Multiple Sclerosis

Rehabilitation is an essential aspect of management for people with MS, as it can help to improve function, reduce symptoms and improve quality of life. It is a multidisciplinary approach that includes various therapies and interventions tailored to the individual's needs. It depends on several factors, such as the type and stage of the disease, the patient's symptoms and functional abilities, and their goals. MSIF published a discussion about the rehabilitation of the PwMS [5]. In the discussion, the classical fields of physical and occupational therapy are reviewed, as are speech and swallowing therapy and counseling. In this subchapter, we will briefly explain each rehabilitation approach mentioned by the MSIF. Furthermore, we will discuss the importance of cognitive retraining. We will specifically focus on physical and cognitive rehabilitation, as a starting point for our serious game.

Physical rehabilitation is a key component of rehabilitation in MS and can be beneficial in addressing various symptoms. During rehabilitation, the physical therapist will work with the person with MS to reach functional objectives (figure 2.3). The following MS symptoms are targeted by physical rehabilitation [5]:

- *Weakness* is a common symptom of MS that affects walking, standing, transfers, and daily living activities that involve the upper limbs. Physical therapy techniques such as manual resistance exercises, body weight exercises, and progressive resistance exercises using weights or elastic bands can help to improve muscle strength. During rehabilitation, physical therapy focuses on regaining control of weak muscles, correcting muscle imbalances, and restoring postural stability. Retaining strength usually helps with fatigue, balance, and coordination, as weak muscles are less efficient and tire more easily.

- Damage to nerve pathways can cause *reduced motor control* or paralysis in limbs. Recovery depends on the location and severity of the damage. For example, physical therapy may help restore movement when nerve impulses can activate weak muscles. If the movement cannot be restored, physical therapy may prescribe an external device to improve movement, such as a foot splint to improve walking.

- *Reduced balance* can be caused by problems with the brain's vestibular system, sensory losses, or weakness. Physical therapists are skilled in identifying the factors contributing to the balance problem and providing treatment. Education and promoting strategies to compensate for the problem. For example, using light when getting up at night can prevent the patient from falling since the vision provides additional information to the brain. A physical therapist should evaluate people with MS who have impaired balance to prevent the adoption of compensatory strategies that can lead to secondary problems like joint strain, increased fatigue, and muscle imbalance.

- *Tremor* can be a challenging symptom that affects functionality. They can occur in any limb and vary in frequency, amplitude, and duration. Tremors affect different aspects of daily living activities, such as writing, eating, and walking. Various treatments, such as repetitive patterning movements to improve coordination, adding weights to wrists to decrease the tremor's amplitude, and positioning education to increase the stability of the arm or leg, may be attempted.

- *Spasticity*, characterized by muscle spasms and stiffness, is a common symptom among individuals with MS. It is caused by changes in nerve impulses to muscles. Physical therapists guide individuals with MS and their caregivers on techniques such as stretching and positioning to alleviate spasms and prevent muscle shortening. In addition, medications such as baclofen or tizanidine may be prescribed to control spasticity, and physical therapists track the efficacy of these medications over time.

- *Pain* in MS can be caused by the areas of the central nervous system affected and is often referred to as neurogenic or neuropathic pain. This type of pain is treated with medication such as gabapentin. On the other hand, pain can also be caused by muscle spasms and joint strains and can be treated with physical rehabilitation. This therapy intervention can address the underlying causes of pain, where the therapist develops an individualized treatment plan to address them. For example, therapists evaluate the level of seating and postural support needed for individuals with limited mobility and provide guidance on pressure relief.

Figure 2.3: Physiotherapists work closely with patients to help them achieve individual goals [26]

Furthermore, [5] presents four stages of physical rehabilitation therapy in MS: *acute phase* immediately after a relapse or exacerbation, *stabilization phase* following the acute phase with a focus on maintaining the individual's current level of function, *maintenance phase* following stabilization focused on preventing deterioration, and *end-of-life phase* aiming to provide comfort and enhance the quality of life for individuals with progressive forms of MS.

Speech and swallowing therapy aims to improve the communication and swallowing abilities of MS patients. Speech and swallowing difficulties can occur at different stages of the disease depending on the location of the damage in the CNS. In [5], MSIF describes the course of the treatment. The therapy typically involves working with a speech-language pathologist (SLP) who will assess the individual's abilities and create a personalized treatment plan, i.e., therapy consists of an evaluation and treatment phase. During the evaluation phase, the SLP conducts an articulation test to assess the individual's ability to produce sounds correctly by asking them to say words and sentences in their native language. In addition, assessing the function of the lips, tongue, soft palate, throat, voice quality, and speech rhythm and fluency helps to identify which muscles are not functioning correctly and the specific nature of the abnormality. For example, when assessing swallowing dysfunction (dysphagia), a speech-language pathologist typically starts by asking the person about their experience and any difficulties they may have when eating or drinking. Additionally, the pathologist takes note of any specific eating habits, such as chin position and pushing hard when swallowing. After the evaluation, the SLP develops a treatment plan, usually including different measures. For example, speech exercises and techniques improve muscle control and strength in the face, jaw, and tongue.

Furthermore, SLP may teach the person techniques to enhance speech intelligibility, such as proper breath control, pitch, and speech rate. Treatments for dysphagia can include adjustments in posture, increasing sensitivity before swallowing, muscle control during swallowing, and modifying diet consistency to improve swallowing and reduce risks of food entering the airway.

The primary objective of **Occupational Therapy** (OT) is to help individuals with MS to perform daily activities and tasks, despite their physical, cognitive or emotional limitations. It is designed to help people maintain their independence and quality of life. The occupational therapist evaluates the limitations of the MS patient, and determine strategies for overcoming these limitations. Figure 2.4 illustrates life domains that are commonly addresses by OT. The specific treatment approach highly depends on the nature, i.e. type and stage of the disease. For example, at early stages of MS, the occupational therapist could help patients by providing strategies for managing fatigue, information on how to adjust their home and car to accommodate their needs, modifications to the workplace and job performance. If the disease progresses, the therapy might include learning compensation techniques, obtaining assistive devices and trying different options to meet short-term and long-term needs. Cognitive training can be a part of occupational therapy. MS can cause cognitive changes such as difficulty with attention, memory, problem-solving, and planning, which can affect a person's ability to perform daily activities. Occupational therapist can work with neuropsychologists and speech therapists to come up with strategies to help the person compensate for these difficulties. [5] emphasizes the importance of cognitive training and retraining for maintaining independence and keeping PwMS active in their daily activities.

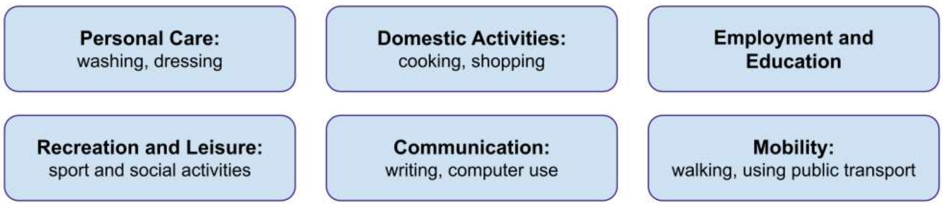


Figure 2.4: Life domains addressed by occupation therapy (done by the author based on reference paper [5])

MS patients are often involved in **vocational rehabilitation**. The aim is to help PwMS to make changes in their careers and to keep working as long as they wish to. It offers services, support, and training that allow people with disabilities to acquire, maintain and progress in jobs that align with their abilities, interests, and experience. With help of the counselor, a patient develops an individualized plans for their future career [5].

Counseling is the final rehabilitation strategy discussed in [5]. It is a form of psychological support that can help individuals and their families cope with the uncertainties and unpredictability of the illness. Every person with MS has to continuously adapt to changes that come with the disease, regardless of its type and course. This intervention can include a variety of mental health professionals, such as counselors, social workers, or psychologists. It is important to emphasize the significance of counseling following a diagnosis. In this phase, counselors provide patients with the required information, guidance, and support to comprehend their diagnosis and make decisions about their care, particularly concerning the prognosis and treatment options. Moreover, PwMS may experience significant and in some cases, long-lasting psychological symptoms. The prevention and management of these symptoms is another objective of counseling interventions. Psychological difficulties mainly include depression, anxiety, chronic fatigue, and stress reactions. Counseling can help patients manage these difficulties and develop coping strategies. However, understanding the disease is important not only for the individual with MS but also for the people around them. Counseling typically includes providing emotional and psychological support to the patient's family. For example, it can help family members to manage changes and shifts in family roles, cope with emotional impact and stress, and improve communication between them.

According to Baumhackl et al. [4], cognitive dysfunctions occur in 50-60% of PwMS, which are manifested by a reduction in concentration and attention, but can also lead to reduced retentiveness and memory lapses. Moreover, MS can negatively impact efficiency of information processing, executive functions and speed of processing. In their book *Österreichische Multiple Sklerose Bibliothek* (ÖMSB) [4], Baumhackl et al. emphasize the importance of **cognitive rehabilitation**. Cognitive rehabilitation aims to minimize cognitive deficits, increase patients' awareness and ability to take their cognitive impairments into account in their daily lives, and promote positive neurobiological changes. There are numerous research papers and books that discuss different cognitive rehabilitation approaches for MS, including:

- *Memory and attention training exercises* that involve activities designed to improve memory and attention, as well as executive functioning skills, such as planning, organizing, adaptable thinking and working memory.[27]

- *Computerized cognitive training programs* that include software applications and games to improve cognitive abilities such as processing speed, memory, and attention.[28]

- *Cognitive-bahavioral therapy* (e.g. keeping a diary), both PC and paper-pencil methods, can lead to improved performance. The strategy represents "deficit training", i.e. one practices exactly those performances that one finds difficult and documents the progress.[4]

- *Mindfulness and relaxation techniques* (e.g. yoga, meditation and relaxing music), that aim to improve mental focus and reduce stress, anxiety and fatigue which can improve overall cognitive function and patient's quality of life.[29]

The foundation of an effective rehabilitation program is the combination of the above described approaches, together with a number of other specialised disciplines, specifically tailored for each individual coping with MS. MSIF provides us with the information about the commonly reported rehabilitation interventions, both in centres and clinics, and in-home rehabilitation programs [5]. From the table 2.1, we can see that the majority of respondents reported using physical rehabilitation and occupational therapy, while less frequently accessing cognitive retraining, social or rehabilitative nursing and vocational rehabilitation. This suggests that the primary focus of rehabilitation programs is still mostly on the physical aspects of MS. Despite the potential benefits of cognitive training, it is not yet widely implemented in clinical practice.

Types of intervention	
Physical rehabilitation	73%
Occupational therapy	34%
Psychology	17%
Rehabilitation of bladder, bowel and sexual disorders	10%
Rehabilitation in speech, language and swallowing disorders	6%
Vocational rehabilitation	6%
Rehabilitation nursing	6%
Cognitive retraining	4%
Social nursing	3%

Table 2.1: Commonly reported rehabilitation intervention types reported by MSIF [5]

2.3 Serious Games

There has been a growing interest in using digital technologies for rehabilitation and healthcare in recent years. One area that has shown particular promise is using serious games for rehabilitation. In this chapter, we will explore the use of digital rehabilitation and serious games to improve health outcomes and enhance patient engagement in their care. First, we will explore serious games as the fundamental concept of this thesis. We will begin by defining the term "serious game" and explain its origin, classification, and area of application. Next, we will delve deeper into serious gaming, particularly in the

(a) Level 1: Roxxi is attacked by an enemy lymphoma cell in patient's lymph node, with a colony of cells lurking in the background.

(b) Level 2: Roxxi destroys an enemy cancer cell with her radiation gun while patrolling patient's spinal column.

Figure 2.5: Re-Mission [31]

context of healthcare. Finally, we will examine the related concept of exergames, a type of game specifically designed to promote physical activity and exercise.

2.3.1 History and Fundamentals

The first occurrences of serious games can be discussed since there are different opinions on the topic. The roots of serious gaming can even be found in ancient Greece. At that time, Plato believed that encouraging certain behaviors in a child's play could be used to direct the preferences that they will fulfill as adults. Looking back in the past, we can find various examples when games were not used solely for entertainment. However, in the digital context, the term "serious game", as used nowadays, was first mentioned in 2002 by founders of the Serious Game Initiative, David Rejeski and Ben Sawyer [30]. The proposed serious game "America's Army" was used to train army personnel in the US. Its goal was to acquire procedural skills and/or knowledge while keeping the players, i.e., army recruiters, captivated. A few years later, serious gaming was introduced into the healthcare field. Re-Mission [31] was one of the first serious games designed explicitly for healthcare purposes, and it was released in 2006. The game was developed by HopeLab, a nonprofit organization that creates games and other digital tools to improve the health and well-being of young people. The game aimed to provide an engaging and educational experience for patients to learn about their condition and treatment while also motivating them to stay on track with their medication regimen. Figure 2.5 shows the game scenario. A player character is Roxxi, an RX5-E nanobot, who is injected into the human body to fight specific types of cancer and related infections, such as non-Hodgkin lymphoma and leukemia, on a cellular level [32].

Michael et al. define serious games as *"games that do not have entertainment, enjoyment,* *or fun as their primary purpose"* [33]. The paper emphasizes that serious games should not exclude the entertainment factor; however, it is not the primary design objective. The goal is to go outside the context of pure entertainment and design games with educational character or games that would improve physical well-being. Furthermore, the paper provides a classification of serious games based on different criteria. For the purpose of this thesis, we will focus on the application domain. Serious gaming can be applied to a broad area of application, such as military and defense, marketing, education, training, and healthcare [33].

2.3.2 Serious Gaming in Healthcare

In chapters 2.3 and 2.3.1 we already mentioned an increasing application of serious games in healthcare, from training doctors and helping in rehabilitation to detecting diseases and monitoring patients' conditions. They are typically focused on two main target groups. The first type aims to educate healthcare professionals. This includes training and simulation games used by professional staff to gain experience, which will prepare them for real procedures. The second target group is patients. The games with health-related content aim to provide players with knowledge or habits to reduce risks, improve health or help them cope with health problems [34]. They should positively affect a patient's physical or mental health. Wattanasoontorn et al. [35] classify serious games for patients according to their use into five different categories which are:

- *Treatment* or *therapy games* designed to address health issues.
- *Rehabilitation games* used for faster or long-term recovery of patients after or during an illness.
- *Health monitoring games* that involve monitoring patients' bio-signals to keep track of their health status. Mostly use the application software with the help of the networking technology.
- *Detection games* focused on identifying and analyzing irregular symptoms of the patient.
- *Education* or *self-care awareness games* aiming to increase understanding about the disease or health problems and learning how to maintain or improve their health in relation to those problems.

In this thesis, we focus on the serious games used for rehabilitation. Specially designed games, with a set of physical and cognitive tasks, can motivate and increase patients' adherence to their treatment by making the training sessions more enjoyable. Serious games that support traditional rehabilitation could maximize the effectiveness of the entire process. Many researchers explored the use of serious gaming in rehabilitation across various conditions, from injuries [36][37] to chronic diseases [38][39][40]. One pioneering initiative in this field is the Rehab@Home European project [41], which is a game-based biomedical monitoring solution intended to provide an effective and engaging virtual rehabilitation environment for home-based rehabilitation. The project is focused on the rehabilitation of upper limb motor impairment in elderly people. The initial idea was to develop a solution to support post-stroke patients in their long-term rehabilitation. Stroke survivors are typically involved in long-term therapy that requires work with therapists. The first stage of rehabilitation usually occurs in a medical facility. Only 10% of patients can leave the hospital shortly after a stroke. Nevertheless, the patient's condition can improve over a long period of time, sometimes requiring years. Rehab@Home extensively investigated possible solutions for affordable, high-quality rehabilitation by adopting suitable technical aids at home and monitored personalized training. The very basic project idea is inspired by existing commercial platforms like Nintendo Wii^{TM}, Sony PlayStation Move^{TM} and Microsoft Kinect^{TM}. The research and development approaches used in the Rehab@Home project are also used in the scope of this thesis for conceptualizing the proposed serious game. They are focused primarily on users aiming to achieve the following outcomes [41]:

- In-depth knowledge of the rehabilitation operational context. This includes analysis of actual rehabilitation processes and medical protocols, robust requirements engineering process for identifying representative use and test scenarios, and target groups.
- Specification and design of home-based multipurpose rehabilitation platform. This means a Rehab@Home solution including standalone hardware components (sensors, actuators, communication modules, visualization and storage devices, etc.) and an open service-oriented architecture, where each standalone functionality represents a service provided by the solution (interaction management, visualization, data logging, etc.).
- Different levels of priority will categorize subsets of functionalities. The functionalities will be incrementally implemented according to their priority in the form of prototypes. The prototypes of different complexity will be used as solution demonstrators.
- The solution prototypes will be assessed at each iteration with real users, both patients and professionals. The evaluation is carried out based on suitable assessment protocol and use and test scenarios defined in the requirements engineering process.
- Scientific validation is used to review evidence confirming/disclaiming that the proposed rehabilitation platform helps to improve patient's health. The evidence is compared with alternative rehabilitation concepts from existing therapy, physiotherapy, and neurophysiology methods.
- The final step is to recognize and define the proposed solution's potential in real life. This includes a definition of an exploitation, development, and commercialization strategy.

Figure 2.6 presents several game scenarios designed in a scope of the Rehab@Home project.

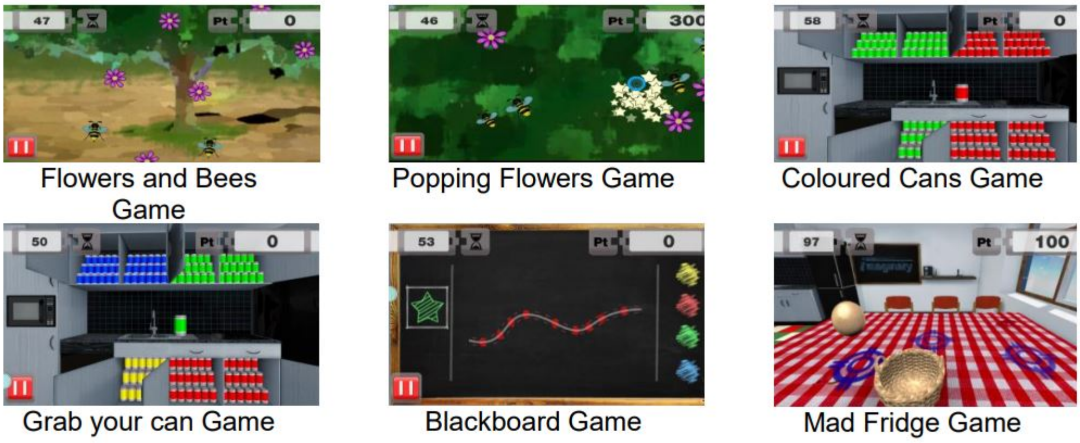


Figure 2.6: Rehab@Home different game scenarios [42]

2.3.3 Sensor-based Exergames

After discussing serious games, it is important to also consider the related concept of exergames. Oh et al. define exergames as *"video games that promote (either via using or requiring) players' physical movements (exertion) that is generally more than sedentary and includes strength, balance, and flexibility activities."* [43] While serious games are designed with a specific educational or therapeutic purpose in mind, exergames are primarily intended to provide a fun and engaging way to exercise in order to promote physical activity.

Exergames often incorporate sensors to capture the player's movements and give feedback on their performance. In figure 2.7, we can see a few sensors commonly used in exergaming, i.e., the Kinect for Xbox and Wii Balance Board. For instance, the use of Wii Balance Board in post-stroke rehabilitation was examined in a study by Garcia et al.[44], while another research by Ain et al. investigated the efficacy of Kinect for Xbox in upper limbs rehabilitation for chronic stroke patients [45]. In addition, various studies demonstrate the utilization of motion capture cameras like the Leap Motion Controller in exergames for upper limb rehabilitation of different conditions, such as Parkinson's disease [38] and stroke [46][47][48]. More about Leap Motion will be discussed in the following subchapter.

Our game will incorporate elements of both serious gaming and exergaming to create an immersive and engaging experience that can help patients adhere to their rehabilitation training. As a serious game, the designed game will include clearly defined goals and objectives directly relevant to upper limb rehabilitation. Providing an engaging and motivating environment can encourage patients to participate in frequent rehabilitation sessions, ultimately leading to improved rehabilitation outcomes. At the same time, the

(a) Kinect-sensor for Xbox One [49]

(b) Wii Balance Board [50]

Figure 2.7: Sensors used in exergames

game will also be an exergame, as it will use a Leap Motion sensor to track the patient's hands and finger movements and translate them into in-game actions. By incorporating the core concept of exergames, i.e., physical activity into the game, we aim to provide an entertaining and engaging way for patients to exercise their upper limbs, which can help increase commitment to their physical therapy.

2.4 Leap Motion Controller

This chapter will focus on the Leap Motion Controller as the hardware used for the serious game developed as a part of the thesis. We will discuss its specifications and application on the market.

The Leap Motion Controller from Ultraleap is a small, USB-powered device capable of tracking hand and finger movements with high accuracy and low latency [51]. It makes interaction with digital content natural and straightforward. Two infrared cameras and three infrared LEDs are positioned above the device, creating a "field of view". When the user places their hands or fingers within the field of view, the infrared LEDs project a grid of infrared light into that space. The cameras then capture the reflections of that light as it bounces off of objects, i.e., the user's hands and fingers. The resulting data is processed by an algorithm that recognizes and tracks individual fingers and their movements in three-dimensional space. Leap Motion software is able to identify and distinguish 27 hand elements, including bones and joints, and it can track them even when other parts of the hand obscure them. [51] This is achieved through a combination of machine learning and computer vision techniques. Leap Motion then projects captured movements on a computer screen; see figure 2.8. The device comes with software development kits (SDKs) and APIs that allow developers to integrate the hand-tracking data into their applications and games.

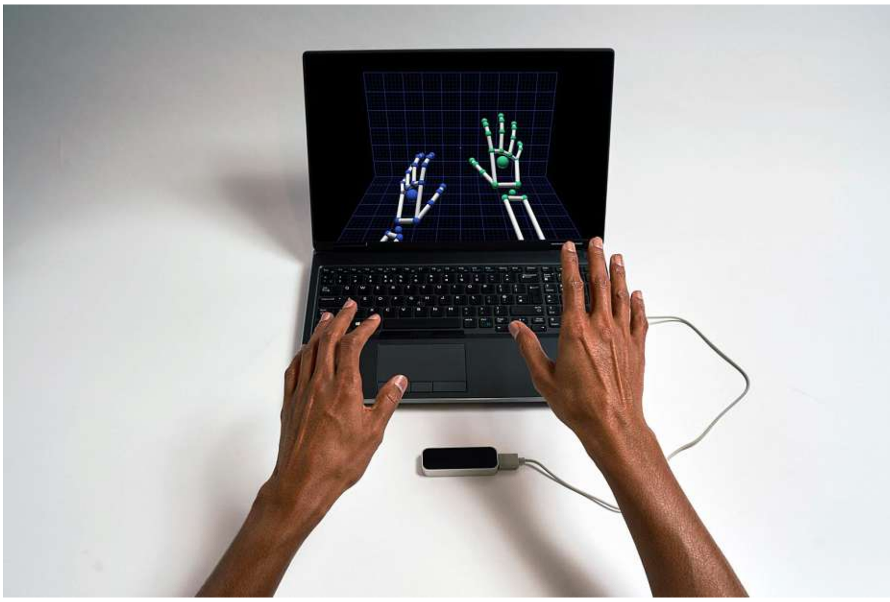


Figure 2.8: Leap Motion Controller [52]

The applications of Leap Motion Controller are diverse, including [52]:

- Touchless public interfaces (interactive kiosks, digital out-of-home, elevators)
- Healthcare (stroke rehabilitation, training, mirror, medical imaging, lazy eye treatment)
- Entertainment (location-based VR/AR experiences, arcades, amusement parks)
- Therapy and education (anatomic visualizations, hands-on learning)
- Personnel training (flight simulators, complex computer systems)
- Industrial design and engineering (automotive, assembly lines, facilities management)
- Robotics (telepresence, robotic controls, AI-assisted teaching)
- Remote collaboration (virtual whiteboards, 3D modelling)

Overall, the features and applications of the Leap Motion Controller align with the goals of the serious game, developed as part of this thesis, making it a suitable input device for the game. The Leap Motion Controller has already shown promise as a sensor for exergames designed to promote physical rehabilitation. Its high accuracy and low latency make it well-suited for tracking fine hand and finger movements, and its relatively low cost and ease of use make it an attractive option for researchers and developers in this field.

2.5 User-Centered Design

The aim of this thesis is to design an application for MS patients. During the entire process, the goal is to align our decisions with the distinct needs, requirements, and limitations of our target group. Therefore, the solution should be designed and iteratively prototyped based on the user-centered design approach, with a deep understanding of the end-users. This chapter covers the fundamentals of user-centered design, exploring its principles, advantages, and the ISO 9241-210 standard [53] that provides a comprehensive model for UCD principles and activities across the lifespan of computer-based interactive systems.

2.5.1 Fundamentals

User-centered design focuses primarily on the end user's needs, requirements, and limitations. In UCD, extensive attention is given to usability goals and user characteristics. The requirements are entirely based upon an explicit understanding of users since their feedback is incorporated throughout every stage of the design process. The advantage of this approach is that it tries to optimize the product around how the user needs or wants to use the product instead of forcing a specific behavior to adapt the user to the end product [54]. Both users and the product benefit from UCD. The product profits from continuous feedback, whereas the users are rewarded with a well-designed end product.

ISO 9241-210 standard proposes a model with requirements and recommendations for user-centred design principles and activities throughout the life cycle of computer-based interactive systems. The standard outlines six key principles of UCD [53]:

- The design is based upon an explicit understanding of users, tasks, and environments.
- Users are involved in the design process every step of the way. This is the crucial difference from other design approaches, where the users are first introduced to the product when the product is finalized.
- The design focuses on maximizing the whole user experience. Therefore, the underlying system should animate the user, and the design process should be geared towards maximizing usability and accessibility.
- The process is not linear and is characterized as a multi-stage iterative design process. More about this will be discussed in 2.5.2.
- At the end of each iterative stage, design is driven and refined by user-centered evaluation. Evaluation occurs even in the earliest stages of the design process. Several evaluation methods are used, such as usability testing, focus groups, surveys, cognitive walkthroughs, etc.

- The design team includes multi-disciplinary skills and perspectives. As a result, different specialists (e.g., developers and UX experts) work tightly together to design an optimal end system.

2.5.2 User-Centered Design Process

UCD is not a strictly defined method; it is a set of processes that put the user at the center of product design and development. Mao et al. [55] describe UCD as a practice of the following principles: *the active involvement of users for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach.* Each iteration is generally conducted in four phases:

1. Understanding and specifying the context of use
2. Defining user and organizational requirements
3. Producing design solution
4. Evaluation

These phases are illustrated in figure 2.9 based on ISO 9241-210 [53]. Activities are repeated until the resulting system meets specified requirements.

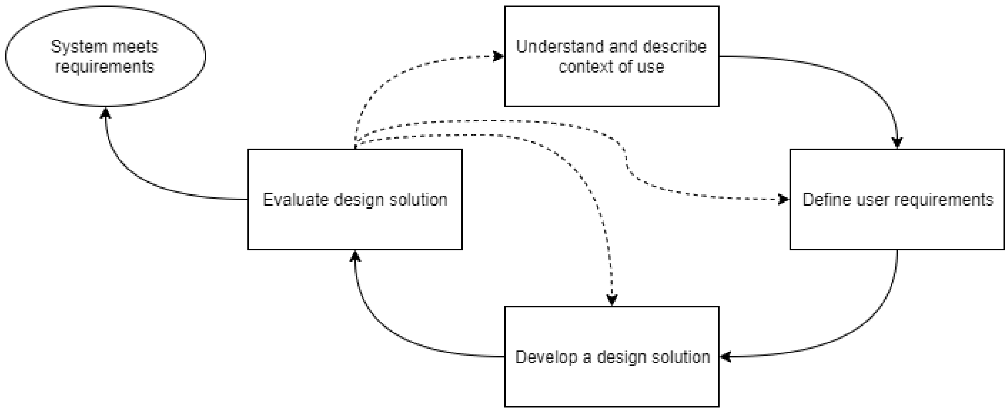


Figure 2.9: User-centered design phases [53]

Maguire et al. [56] provide more detail about each phase of UCD. Every system is developed in a particular context, therefore, in the initial phase we focus on specifying this context. The system under development is intended to be used by people with specific characteristics. They will have their goals and certain tasks they wish to perform. This phase aims to identify stakeholders and target groups as well as to define their goals and tasks. It results in defined users' expectations regarding satisfaction, efficiency, and effectiveness. For some systems, it is sufficient to identify stakeholders and arrange meetings with them to gather the required information. Alternative options for context analysis are interviews and surveys. For more complex systems, the process might require conducting a task analysis or different observational methods, such as field study.

We can now elicit user and organizational requirements based on the gathered information about the defined context. Requirements engineering has been increasingly recognized as to key to improved delivery of software and system projects [57]. More about the process itself will be discussed in the next chapter. Various studies [56][58] emphasize the importance of the requirements analysis. If not conducted correctly, it might have a decisive impact on the final product. Insufficient effort to determine user requirements and usability success criteria, or lack of user involvement during development, might lead to system failure. User requirements focus on specific workflows and tasks to be performed by a certain target group, i.e., describing use case scenarios in the specified context. This phase should result in defined success criteria and measurable benchmarks against which the emerging system design can be evaluated. Furthermore, it should indicate design goals and priorities for different requirements. Due to the iterative nature of UCD, the requirements set is constantly changing and evolving. It is revised at each iteration cycle. The newly specified requirements result from the evaluation of the current state of the design. However, they also serve as input and evaluation criteria for the subsequent process phase - developing design solutions [59] .

The next phase will start by developing the initial, simplified designs (sketches, low-fidelity prototypes), progressively increasing complexity until the final high-fidelity prototype is completed. There are various methods used in the implementation phase. Different techniques encourage the development of new ideas (brainstorming, thinking aloud, and parallel design), use of design guidelines and standards, and presenting the proposed solution (sketches, mock-ups, storyboarding, Wizard-of-Oz, and prototyping) [56]. At the end of each iteration, the state of the design is evaluated against the defined user and organizational objectives. The higher fidelity prototypes will be evaluated against more detailed requirements as the design progresses.

In the evaluation phase, the user is presented with the emerging system design. This step determines how far the user and organization requirements have been met and provides information for further system refinement. The evaluation results are used for detailing and adjusting requirements specifications. In UCD, the system is evaluated throughout the entire development process by performing usability tests. This method focuses on observing respective users interacting with the product while performing real tasks. Usability testing can be divided in two subcategories: *formative* and *summative* testing [60]. Formative testing is used while the system is still under development. It is part of the iterative process, aiming to diagnose and fix problems before production. The design can be refined based on the evaluation results. Summative testing is done in the latter stages of development when the system is nearly finished or finished. Its goal is to establish a baseline of metrics validating that the system meets the requirements.

2.6 Requirements Engineering

Requirement Engineering (RE) is the most important phase of the software development life cycle. In this process, the imprecise needs and requirements of the potential users are elicited and translated into formal specifications. These specifications then serve as a contract between the users and the developers. RE should ensure that the developed product meets users' expectations and help reduce errors in the early development stages [61].

2.6.1 Fundamentals

Requirements represent the basis for the efficient software development process. They establish the foundation for the project scope and time and cost constraints. Therefore, before providing a definition of requirements engineering, we will explain the term "requirement". The IEEE Standard Glossary of Software Engineering Terminology defines a requirement as *"a condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents"* [62].

We can distinguish between three types of requirements [63]:

- **Functional requirements** are requirements concerning the result of behavior that a system shall provide. In other words, they represent tasks a system should accomplish to provide operational capability. These requirements are usually defined by intended users and have to be consistent, unambiguous, and understandable.
- **Non-functional requirements** specify requirements to meet quality attributes that are not covered by functional requirements. Therefore, they are often classified as quality requirements. They indirectly influence the functionality of the underlying system. These requirements cover quality attributes such as security, reliability, performance, maintainability, scalability, and usability.
- **Constraints** are organizational or technological restrictions that limit the solution space beyond functional and non-functional requirements. Unlike the other two, these requirements are not implemented; they are rather controlled by external factors and cannot be influenced by team members.

All these requirements are considered in a requirements engineering process. There is no generally accepted definition of requirements engineering. As already stated, RE includes elicitation of individual user requirements and specifications of the same. Some definitions focus on eliciting the requirements, therefore, on the interaction with the users. Others pay more attention to the specification part, with the documentation of requirements in focus. However, in the recent literature, requirements engineering is most commonly defined in accordance to Pohl [64] as *"a systematic process of developing requirements* *through an iterative cooperative process of analyzing the problem, documenting the resulting observations in a variety of representation formats, and checking the accuracy of the understanding gained."*

This definition emphasizes the complexity of RE and raises many questions. According to Pohl, RE is a *systematic process*. In simple terms, systematic means that the process is a sequence of straightforward steps that lead to a conclusion. Since RE starts with many unknown factors and the steps cannot be clearly defined at the beginning of the process, how is RE systematic? Furthermore, RE is defined as *iterative co-operative process*. It is vital to decide when it is "enough", i.e., how many iterations will be needed and when do we known enough requirements have been gathered. Pohl describes the process as cooperative, therefore it is essential to establish which parties will be involved in the process and how they will communicate. We also need to answer questions addressing *documentation*. What representation formats and standards should be used, and how should the resulting requirements be documented? The last part of the definition *"checking the accuracy of the understanding gained"* also leads to questions. What does accuracy mean in this context? How can we make sure that all parties have the same understanding of the specified requirements? These are only some of the questions that need to be answered, and Pohl emphasizes that it is crucial to invest sufficient effort into doing so at the beginning of the RE process [64]. The next subchapter 2.6.2 will provide a more comprehensive discussion about the RE process.

2.6.2 Requirements Engineering Process

As discussed in the fundamentals (chapter 2.6.1), the requirements engineering process is a systematic approach incorporating various tasks. In this subchapter, we will explore those tasks and their activities in order to gain a comprehensive understanding of the process and its importance in software development. We will start by identifying four core tasks to be performed in the requirements engineering process, namely requirements *elicitation*, *negotiation*, *specification/documentation*, and *validation/verification* [64]. Figure 2.10 illustrates these tasks and their relationships, together with some potential actors.

Requirements engineering starts with the **elicitation** of requirements. This step focuses on gathering requirements from the stakeholders. The relevant knowledge is usually dispersed among various stakeholders, and it is essential to identify hidden system-relevant knowledge and make it explicit and understandable to all involved parties. RE is usually described as a cyclic process, and requirement elicitation is an activity that continues as development proceeds. The requirements are building up complexity and must be reorganized and revised during the process. Requirements elicitation can be performed through different conversational (e.g., interviews, workshops/focus groups, brainstorming), observational (e.g., observation, social and protocol analysis), analytic (e.g., documentation studies, card sorting), and synthetic (e.g., scenarios/passive storyboards, prototyping) techniques [65]. However, preferentially structured interviews are the most commonly used elicitation technique, and studies show that they appear to

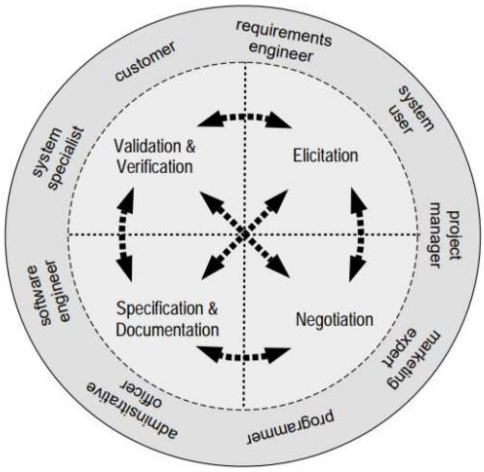


Figure 2.10: Four tasks in requirements engineering process [64]

be the most effective as well [66]. During the elicitation process, mistakes can happen if there is a lack of understanding between stakeholders. Various identified problems need to be considered when eliciting requirements. Some of these are: *missing* and *incomplete requirements*, *reluctant participation*, *misperception* and *disagreement* [67].

After elicitation, the goal is to establish an agreement on the requirements between involved stakeholders. This is done in the **negotiation** phase. The stakeholders have different backgrounds, goals, and expectations. Thus, they often have conflicting points of view. In order to make a development project succeed, they must overcome these differences and negotiate a common ground. The negotiation is performed in a step-by-step manner. The first step is to make all conflicts explicit and to eliminate purely emotional conflicts. This is typically done with the help of design collaboration support systems [68], which make conflict detection easier. Some of the detected conflicts can be solved semi-automatically. Only when the conflicts have been made explicit can we proceed to the second step, which is finding the relevant alternatives and argumentations. The next step is to ensure that we are making the "right" decision. When going beyond technical support, it is essential always to answer the question: *who* should be involved in *what* and *how*? It is crucial to involve the right stakeholder at the right time to prevent revising the conflict resolution decisions later. However, despite choosing the "right" decision, all decisions are still subject to revision, primarily due to better understanding in the latter phases of the development process.

The results of elicitation and negotiation are used as the input for the next task - **specification/documentation**. In this step, gathered requirements, which typically come in various formats, are transformed into formal specifications. All requirements are formalized in an artifact called Requirement Specification (RS). RS should be considered as a set of various models that:

1. Take viewpoints of different stakeholders into account
2. Include both intermediate and final results
3. Are traceable, unambiguous and consistent

RS can contain written and graphical models expressed to the stakeholders in various representation formats. For example, software engineers are presented with formal models, managers with graphical models and customers and users are submitted with specification documents written in a natural language. Formal Specification Languages (FSLs) and Knowledge Representation Languages (KRLs) typically assist in formal specification. Requirements composed by FSLs are more precise and unambiguous and can be consistently processed by computers for validation, communication, and management [69]. KRLs also enable automated reasoning of represented knowledge by providing well-defined formal semantics [64].

The last task in RE is **validation/verification**. Firstly, we need to explain the difference between these two terms. According to Boehm [70], validation is characterized as determining if we *"are building the right product"*. On the other hand, verification should determine if we *"are building the product right*. In RE, the validation task should check the consistency of the specified requirements with the customers' expectations. In contrast, the verification task should ensure that the specifications are consistent with the formally defined RS artifacts. Furthermore, Boehm distinguishes two types of validation/verification tasks, one focusing on the *internal*, other on the *external* consistency. The first group's tasks are usually performed with formal verifications, walk-throughs, and inspections. They are based on RS and do not require the involvement of customers and users since it is assumed that the stakeholders' goals were correctly understood. External validation is performed by asking users, customers and/or other stakeholders if the software meets their expectations. Different techniques are used in this step, such as interaction with stakeholders, prototyping, natural language paraphrasing, etc.

We stated that RE is an iterative process. Pohl [64] indicates that the relationships between tasks are not strictly circular, and the tasks do not necessarily happen in the order described above (see 2.10). The results of one task can initiate the execution of any other task in the process. For example, if conflicting requirements are detected during the validation/verification task, the negotiation tasks will be executed in order to solve these inconsistencies. In this case, additional information about requirements might be required, which will lead to the initiation of the elicitation task. In this paper, we provided a few techniques for each task for explanatory purposes. However, many other methods and techniques used in RE were not mentioned in the paper. Many of these approaches are not strictly bound to a single task. They instead serve different tasks, usually with different impacts.

2.7 User-Centered Design in Requirements Engineering

In previous subchapters, we presented fundamental principles of process in user-centered design and requirements engineering. The next step is to link them together and clarify how UCD methods can support RE throughout the development process.

Requirements engineering in the traditional waterfall model is straightforward. The analysis of requirements happens in the early stages of development. The process focuses on gathering all the requirements and preparing the requirements specification artifact upfront before proceeding to the design phase [71]. Pandey et al. emphasize various disadvantages of RE in waterfall. For example, the team sends a data collector to gather information about the target group. Data acquisition is typically made through structured or semi-structured guidelines (e.g., surveys and focus groups). Nevertheless, this information is usually insufficient to understand the target group and their context truly. Firstly, guidelines focus on particular observations and issues. As a result, they cannot discover issues that are not intended to be discovered by the development team. Furthermore, users cannot foresee all issues in advance. The issues they say at the beginning are usually not the issues they have.

On the other hand, the Agile manifesto [72] says, *"our highest priority is to satisfy the customer through early and continuous delivery of valuable software"*. As we can see, the agile approach is user-oriented and focuses directly on providing value for the customer. Even though not stated explicitly, it supports the basis of UCD. In the agile environment, the team manages the project by breaking it into multiple iterations, e.g., Sprints. Agile frameworks, such as Scrum, tend to include the expertise and competence of the involved stakeholder during the entire development life cycle. Due to incomplete or unknown factors, the complete and precise requirements specification is impossible in the first development phases. Therefore, the requirements specified at the particular stage are subject to change. User stories are the most commonly used method for gathering and verifying requirements in agile projects. They represent informal descriptions of requirements, written in a natural language from an end user's perspective. In Scrum, a prioritized collection of user stories is managed in the Product Backlog [73]. Flexibility and adjustability lie at the core of all agile approaches. Thus, a Backlog is never a finalized document but rather a living artifact, i.e., it can be modified, expanded, or shortened. It evolves with the product as new insights or impediments emerge to reflect user and project feedback changes.

In software development, various methods focus on direct interaction with users. In UCD, these methods are used to design a product that will drive better customer satisfaction. Different methods serve different purposes. Some are used to assist with requirements analysis and others in evaluating the state of the emerging design.

Questionnaires are a method to survey large groups of users. They can be used to elicit information in one of two ways: get statistical evidence or gather opinions and suggestions. The cost of conducting a study using questionnaires is very low, making it a logical choice for accumulating information on larger user populations. According to Mayhew et al. [74], questionnaires are commonly used in both the initial design phase and during iterative development. They are used to gain a deeper understanding of the users' needs and expectations before developing the initial concept. In the later iterative development phases, questionnaires are used to evaluate the state of the emerging design. They are typically structured as a set of closed questions where the user is offered a checklist of predetermined answers, or the user shares their opinion on a rating scale. The questions should only focus on the aspects relevant to the project. Cost-effectiveness is the most crucial strength of questionnaires. Moreover, they offer generalizability, reliability, and versatility. On the other hand, weaknesses of questionnaires include inflexibility and issues with depth. Closed questions have a high risk of misunderstanding, and the restricted inputs can stifle users' creativity.

Interviews are the most commonly used UCD method to learn about users' preferences and requirements. There are two types of interviews: *structured* and *unstructured* [75]. In structured interviews, the interviewer asks questions strictly following a standardized and premeditated list. On the other hand, an unstructured interview is non-directive in nature, and does not rely on premeditated questions in order to gather data. The interviewee is given as much freedom as possible when explaining. Unlike questionnaires, interviews provide some flexibility. The interviewer can rephrase misunderstood questions or ask a follow-up question if necessary. The interview can be adjusted during the process according to the interviewee's answers. However, the execution of an interview requires significantly more effort than a questionnaire. For example, the interviewer's presence is mandatory during the entire process, and the more detailed, free-form answers are harder to analyze and interpret.

Contextual inquiry is a field data gathering technique that forms the core of the contextual design. The empirical method aims at gaining a deep understanding of who the users really are and how they work daily. The process is straightforward: the intended users of a system are observed while working in their environments and asked about crucial steps to understand their motivation and strategy. Contextual inquiries are typically performed with four to eight participants. The method is based on four principles [76]:

- *Focus*: The inquiry requires a plan. The focus is defined based on a clear understanding of a purpose. It helps the researcher to stay on the right path of the discussion while not taking control away from the user.
- *Context*: The researcher has to spend appreciable time embedded into the user's work environment, i.e., the inquiry must take place in the context of use.
- *Partnership*: Establish a partnership between researcher and user to create a shared understanding. In this setting, the user is an expert, and the researcher is willing

to learn about the work. The goal is to engage the user in uncovering unarticulated aspects of it.

- *Interpretation*: Design is build upon interpretation of facts. Therefore, avoiding misunderstandings in interpretation is essential. The researcher must immediately try to reason gained knowledge about the user's work and share the interpretations with the user during the inquiry.

A **persona** is a fictional character created to represent an actual user. It is a means of summarizing the characteristics of the intended target group. The purpose of personas is to make the user more authentic and help design a user-oriented product. Target group profiles cover a range of characteristics, and the more detailed the persona description, the more effective they are as a design tool. In RE, personas can be a great help, e.g., prioritizing and illustrating use cases or assessing the priority of the requirements [77].

Prototyping methodology emerged out of a need to define specifications better. It includes building a demo version of a system that can be interpreted and evaluated by users. A prototype should only contain critical functionality sufficient to challenge certain assumptions and test them with users. They are not intended to be further developed for production. This method is proven very effective for identifying design problems and misunderstandings in the early stages of development. Iterative prototyping starts with the initial, simplified prototypes (e.g., sketches, low-fidelity prototypes), progressively gaining complexity as the design gets more advanced with each iteration [74]. Each iteration consists of two phases, creation and improvement of the design and the evaluation of the same. Low-fidelity prototypes (e.g., mock-ups) allow teams to explore different ideas and receive fast user feedback without too much effort since they are usually easy to create. As the development progresses, the level of the prototype's detail and effort also increases. The prototypes get more complex, representing so-called high-fidelity prototypes, as we approach final iterations. High-fidelity prototypes are, as close as possible, a true product representation that enables in-depth user testing of individual components and features. In his book on software engineering, Pressman presents four common types of prototyping [75]:

- *Rapid prototyping*: The objective is to quickly optimize and adjust the design and its functionality based on immediate user feedback using regularly updated prototypes and multiple short iteration cycles. Rapid prototyping includes three simple steps: prototyping, feedback, and improvement.

- *Evolutionary prototyping*: It goes beyond the traditional notion of a software prototype. It includes the simulation of the underlying system and its functionality. A prototype is initially developed based on the known requirements. The additional features can be later implemented when the requirements become clear to stakeholders until the final product emerges.

- *Incremental prototyping*: The focus is on the interaction between individual modules and components. Incremental prototyping includes building separate small prototypes in parallel. The first step is to evaluate the individual prototypes. Afterward, they are merged into a comprehensive system, and the system is then evaluated as a whole.

- *Extreme prototyping*: It is used in the web development domain. The first step is to create a basic prototype in HTML format. Then the data processing is simulated using a prototype services layer. Afterward, we implement and integrate services in the final prototype.

CHAPTER 3

State of the Art

In recent years, various studies explored serious gaming in the context of neurorehabilitation. The research in this field spreads across different neurological conditions (multiple sclerosis, stroke, Parkinson's disease, etc.), various technologies, and rehabilitation approaches. These games have been extensively studied in the context of rehabilitation and have demonstrated positive outcomes in terms of physical and cognitive improvements in patients. In the state of the art chapter, we have chosen to focus on specific serious games relevant to the topic of MS physical and cognitive rehabilitation. These games were selected based on several factors, including relevance to the topic, availability of research studies, targeted disease and type of rehabilitation, and hardware used in the game. To identify the games, we thoroughly reviewed the literature in the field of neurorehabilitation, serious gaming, and exergaming. We used sources of information such as IEEE, PubMed, Google Scholar, and ResearchGate to gather relevant and up-to-date information on the topic. Among others, relevant terms such as "multiple sclerosis", "multiple sclerosis rehabilitation", "neurorehabilitation", "serious games", "exergames", "Leap Motion", and "usability" were searched. After narrowing down the list of potential serious games, we selected five: Rehab@Home [41], StepAR [40], Rhythm-based serious game [78], Farm Life [38], and Weekend in Rome [79]. The selection aimed to ensure that we included games that approached the topic from different angles and perspectives to provide a comprehensive overview. Therefore, each selected game met some criteria mentioned above, i.e., some games focus on physical, others on cognitive rehabilitation; some are developed exclusively for PwMS; and some focus on upper limb rehabilitation with Leap Motion Controller. The analysis of these games will provide insights into the key features and design elements that make them effective for rehabilitation purposes, as well as the challenges and limitations of using serious games in this context. We will summarize the findings focusing on different aspects that will help us compare existing solutions against different parameters. Additionally, we will explain what distinguishes our serious game from the others in terms of its unique approach to addressing the challenges of MS rehabilitation. This comparative analysis will allow us to demonstrate the unique contributions of our game and to position it within the context of existing serious games for the rehabilitation.

3.1 StepAR

Amiri et al. [40] presented simple training exercises in a game series called StepAR. StepAR contains ten 2D exergames for walking training. The proposed solution uses a Microsoft Xbox Kinect and a video projector installed on top of a tripod (figure 3.1). A multidisciplinary team devised a set of exercises focusing on gait and balance, combining numerous implicit cognitive tasks. As shown in figure 3.2, the games were inspired by traditional physical rehabilitation, i.e., a combination of some physiotherapy exercises and a simple physical rehabilitation program called *"square-stepping exercise (SSE)"* [80]. SSE was designed by Japanese researchers aiming to improve walking ability, muscle strength of the lower limbs, balance, and reduce the risk of falling. The game was initially developed for PwMS while leaving room for adapting to different neurological conditions causing gait disturbances.

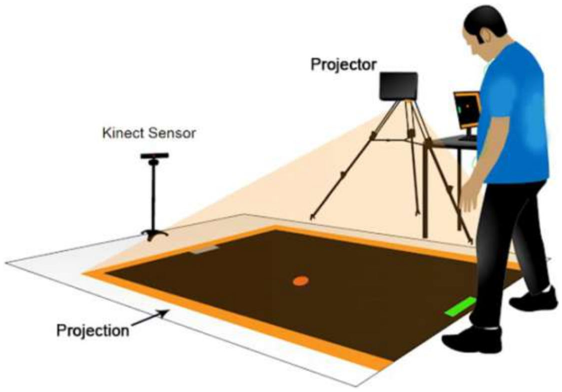


Figure 3.1: The general overwiev of the system [40]

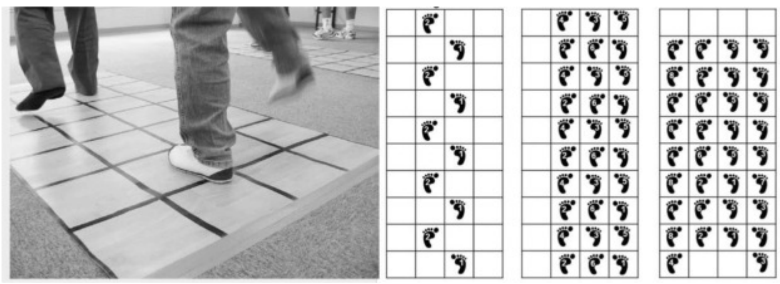


Figure 3.2: Square Stepping Exercise (SSE) (left) and difficulty levels (right) [40]

StepAR uses two design principles to ensure a realistic rehabilitation experience: *projection-mapping* and *dynamic difficulty adjustment (DDA)*.

Projection-mapping augmented reality (AR) technique should provide a better understanding of the relationship between movement kinematics and body perception, as the patient observes augmented reality directly from a natural field of view. This technique turns irregularly shaped objects into a projection screen using projection mapping [81].

According to [40], the game must provide a flexible and individualized training strategy to meet each patient's needs, i.e., establish an "optimal training zone." StepAR uses the DDA technique in exergames to provide adaptability. The algorithm adjusts the game difficulty automatically, based on the patient's performance, i.e., success and improvement. Patient's performance is measured concerning various parameters: the distance between targets, the devil's speed (floating obstacle), the number/frequency of devils, the game duration (the fixed time considered for completing each level), and the number of goals. Every patient starts the game at the initial level. Nevertheless, the system increases the difficulty level at each session if the player demonstrates significant development.

Figure 3.3: StepAR: Game on the floor [40]

Figure 3.3 displays the game scenario. The player starts with the walk test. This phase contains two levels. The markers' size and the area of the playing environment are determined before the start. The initial game can be played in two difficulty levels, determined by the feet distance (figure 3.2). The goal is to collect as many points as possible by stepping on the corresponding tag in a given time frame. The game ends when the timer runs out, and the next level begins while keeping the same difficulty level. After two repetitions, the difficulty level is adjusted based on the patient's performance. After finishing any further level, the acquired points and time needed to finish the game are displayed on the floor. Moreover, the player is also awarded various incentives (e.g., glory awards, access awards, sensory feedback awards).

3.2 Rhythm-based Serious Game

Shah et al. [78] propose a rhythm-based game for noninvasive fine motor rehabilitation. The work is not focused on a specific neurological condition; instead, its goal is to provide accessible gameplay that serves as a meaningful abstraction of basic rehabilitative hand motion therapy for people with different disorders and conditions by providing them with some level of adjustment. The developed rhythm-based serious game is intended to be used with the Leap Motion sensor. The controller is connected to a computer via USB and captures the movements of the impaired hand.

The game scenario is rather simple: music playing in the background, and notes, synchronized with the music, fall from the top of the screen. Figure 3.4 shows two types of notes: single and long notes. The player gains points while eliminating notes by making a specific hand gesture. Single notes require only brief gestures, while long notes require the player to hold a gesture for a few seconds. Unlike typical rhythm-based games, the proposed solution must function as a rehabilitation platform. The user must be able to form the right gesture at every note, even if he/she has a weak grip. Therefore, the pacing of the appearance of the notes is slowed down by setting the gap between notes to at least one screen height. As the user's functional abilities improve, the note sequences can be fastened to maintain a proper challenge level.

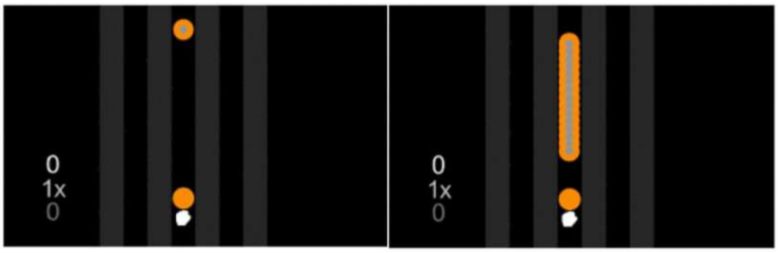


Figure 3.4: Single note (left), long note (right) [78]

3.3 Farm Life

Foletto et al. [38] designed a system of serious games inspired by nature and farm life for fine motor skills rehabilitation for Parkinson's disease patients. The team wanted to develop a system to maintain patients' rehabilitation training engagement. In order to make patients feel as natural as possible, the team used Leap Motion Controller to create natural interfaces. Farm Life is a set of three game prototypes that were developed based on the observed rehabilitation sessions at the Rehabilitation unit of Hospital Universitário de Santa Maria (HUSM). Furthermore, specialized therapists provided insights about day-to-day fine motor skill exercises. The theme of the prototypes was chosen to trigger elders' interest since they make up the majority of the target audience. Each game simulates a specific gesture and has a different metaphor. The correct interaction with the game is crucial; hence it has to make sense to the patient, i.e., the metaphor and the gesture must complement each other.

Game 1: Pinchicken

Pinchicken is a game that targets a patient's ability to perform a pinch gesture continuously. The game mechanics are relatively simple: the scene is composed of three egg nests, with eggs and chickens constantly falling on the ground (figure 3.5). The player has to pinch the fallen eggs and place them in the highlighted nest. The player is awarded 10 points if the egg is dropped in the correct nest. Additionally, visual and sound feedback is played in the background for motivation. On the other hand, if the egg was mistakenly dropped in the wrong nest, the visual and sound effects are played, but the player is not punished with negative points. According to [38], punishing players can negatively affect their motivation.

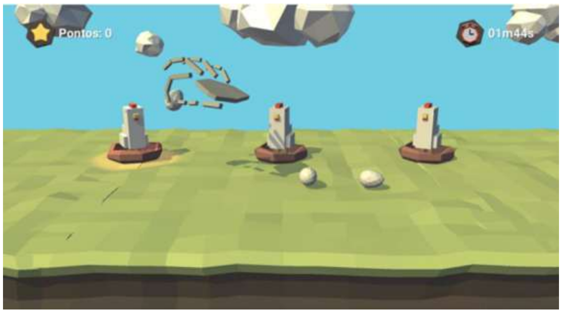


Figure 3.5: Pinchicken: Player should use the pinch gesture to grab eggs [38]

Game 2: Finger-Hero

Finger-Hero simulates an opposite thumb gesture. The game is inspired by the blockbuster game "Guitar-Hero." The game setting is displayed in figure 3.6: there are four lanes, each with a flower at the end. The flowers have different colors (green, red, blue, yellow) and are associated with a specific thumb opposite gesture (index, middle, ring, pinky). During the game, the bees randomly appear on the screen and move toward the specific flower in each respective lane. The objective is to perform the correct thumb opposite gesture when the bee reaches the flower. If successful, the player receives 10 points, and sound and visual effects are given. If the player misses, there is negative sound and visual feedback, but there are no negative points.

Game 3: Grabduzeedo

In Grabduzeedo, see figure 3.7, patients practice grab and release gestures. The goal of the game is to abduct sheep that appear on the platform on the right side of the screen. To do so, the player must control a spaceship that appears in the upper right

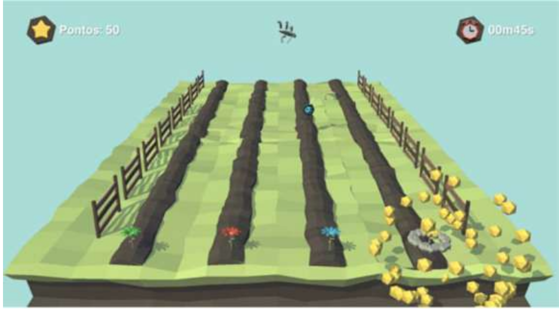


Figure 3.6: Finger-Hero: Player should use thumb opposition exercise to play the game [38]

corner at the game start. The spaceship's tractor beam is activated and deactivated by a simple grab-and-release gesture. The objective is to grab the sheep and move it to the left platform with fences. After successfully releasing the sheep on the platform, the player is awarded 10 points, together with visual and sound effects. Otherwise, only the effects are played in the background.

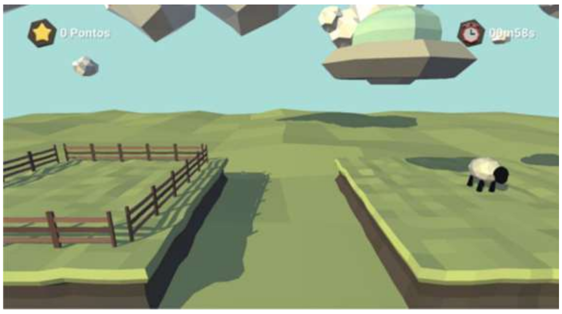


Figure 3.7: Grabduzeedo: Player should use the grab gesture to control the spaceship's tractor beam [38]

3.4 Weekend in Rome

Weekend in Rome is a design intended to be integrated into the MS rehabilitation system. Unlike the previously mentioned platforms, Gaspari et al. [79] present a serious game for cognitive training. The game is developed exclusively for the PwMS, as cognitive dysfunction unrarely appears in the early stages of the disease. The patients can experience cognitive impairments in, e.g., executive functioning, processing speed, memory, and attention. Planning is one of the main self-regulation skills related to executive functions, and it is exactly what the proposed design aims to improve. Weekend in Rome is a novel cognitive exercise where the patient has to plan a two-day vacation. The exercise was built using automated planning, a branch of artificial intelligence that focuses on the ability to plan a sequence of actions to reach a desired goal.

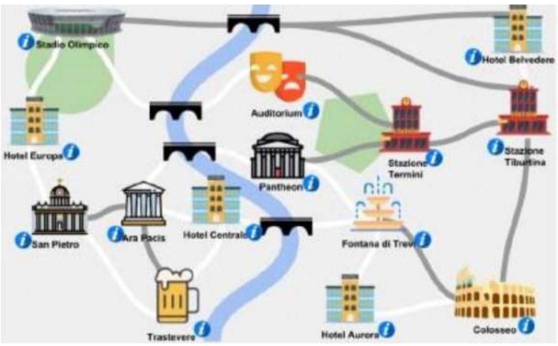


Figure 3.8: Map of Rome [79]

The game has the following structure: a patient has to plan a 48 hours trip to Italy's capital, starting from booking a train and hotel, progressing to different tasks that have to be accomplished during the trip. The team created a stylized map with a list of places and monuments to visit (e.g., the Trevi fountain, Saint Peters Basilica, the Colosseum, the Pantheon etc.), see figure 3.8. These locations are incorporated into the game as the player navigates through various visits, public events, and social occasions to achieve defined goals. Furthermore, the game includes other tasks, such as going to sleep, exercising, and having breakfast in the booked hotel. The goal of these tasks is to make the exercise more realistic. The patient has to orchestrate a sequence of these tasks, represented as atomic actions. The summarized list of actions is following:

- Book train
- Make hotel reservation
- Wait - action to skip ahead in time of one hour
- Travel - action to move around on the map by foot or by bus
- Go to sleep
- Have breakfast
- Do some activity - e.g. visit an exhibition or watch a football match
- Exercise

To make the game intuitive and easy to navigate, considerable attention was given to the user interface. Nevertheless, Weekend in Rome incorporates different auto-adaptive levels of difficulty that offer personalized training strategies for each patient and support their progress.

3.5 Summary

All researched applications are serious games for physical or cognitive rehabilitation. However, the approaches differ in many ways. In order to draw a comparison between the current state of the art and our game, we will focus on several aspects: disease, the technology used, the type of rehabilitation therapy, the level of customization that the game offers, and feedback mechanisms.

Analyzed serious games deal with different neurological disorders. They have in common that patients suffering from these diseases often experience similar symptoms, such as muscle weakness, poor coordination, loss of sensation, and cognitive impairments (e.g., processing speed, memory, and attention). However, these diseases affect different aspects of the nervous system and have their own associated characteristics, symptoms, and treatments. Rehab@Home is developed initially as a set of exercises to strengthen a patient's stroke-impaired limbs. Farm Life is intended for people who have Parkinson's disease. Parkinson's, like MS, attacks the central nervous system. They are both progressive and have similar symptoms, therefore can be easily mistaken for one another. However, there are differences that affect the patient's condition and treatment. For example, they start to affect people at different ages. Parkinson's disease usually affects people at age 60 or older, whereas MS starts earlier, typically in people between 20 and 40 years old. Therefore, Farm Life is designed with the elder generation in mind. The designers of the simple rhythm-based serious game did not focus on a specific neurological disorder. The game is more general and aims to support the rehabilitation of patients with similar symptoms. Finally, StepAR and Weekend in Rome are serious games designed for MS patients. Nevertheless, two games deal with entirely different impairments, one focusing on gait and balance other on cognitive dysfunctions.

Another considered aspect is the technology used. Weekend in Rome is developed for mobile devices and does not require any additional hardware. Mobile devices are popular gaming technology in neurological rehabilitation since they are highly accessible and easy to use. Rehab@Home and StepAR use Microsoft Xbox Kinect sensors as assisting hardware in creating augmented reality and making the gaming experience more realistic. Rhythm-based serious game and Farm Life are PC games that use Leap Motion Controller to capture hand movements and simulate physical exercises.

Discussed serious games handle two common types of neurorehabilitation, i.e., physical and cognitive therapy. Weekend in Rome is the only application focusing on defining and providing cognitive tasks for home rehabilitation. Other applications are intended for physical rehabilitation therapy. However, given that neurological diseases cause a range of symptoms, different applications deal with different impairments. For example, StepAR is designed for gain and balance training, i.e., to improve the way the person walks and the ability to maintain balance while standing or moving. Impairments of the upper limbs are the result of common symptoms of different neurological diseases. Rehab@Home, the rhythm-based serious game, and Farm Life are focused on those impairments, aiming to improve the patient's quality of life and independence.

Serious games can be more effective if they are tailored to the individual patient's needs and capacity. The rhythm-based serious game currently does not offer any customization capabilities. However, Shah et al. emphasize the importance of maintaining the right amount of difficulty to maintain the patient's interest in the game. In the paper, this is, however, described as an area of improvement and consideration for future work. Other selected STAR serious games offer some level of customization. Every game includes multiple levels to keep the player engaged and address different levels of disease severity. Moreover, Rehab@Home and Farm Life allow the therapist to adjust the difficulty and tailor the rehabilitation program according to the individual.

Feedback mechanisms are another aspect considered in the analysis. They are important because they provide information to the patient on their performance, progress, and improvement. Furthermore, feedback can motivate patients to continue with their therapy and help them understand their strengths and weaknesses, and to adjust and improve their overall skills. All discussed serious games provide real-time feedback on the player's performance. These include visual and auditory cues to indicate the correct positioning [41][40], and the accuracy and the speed of patient's movements [41][40][78][38]. Additionally, games that use sensors provide a real-time graphical representation of the movements that can help therapists analyze and adjust exercises accordingly. Each serious game described provides immediate scoring to help patients monitor their own progress. Rehab@Home and Farm Life offer progress tracking by therapists in a separate web application, allowing them to evaluate patients' performance over time and give their feedback accordingly.

A summarized comparison of the presented solutions and our game can be found in table 3.1. Accordingly, it is visible that there is no state of the art approach that satisfies following criteria:

1. Multiple sclerosis disease
2. Physical and cognitive rehabilitation
3. Appropriate level of customization
4. Suitable for daily training sessions

This thesis proposes a solution that combines best practices and elements used in the discussed solutions, such as providing real-time feedback on the player's performance and allowing for customization and adjustment of difficulty. However, it addresses the limitations of the discussed state of the art solutions and proposes several improvements. Firstly, it is disease-specific and exclusively designed for PwMS. It offers both physical

Serious Game	Hardware	Level of Customization	Feedback mechanism	Multiple exercises	Impairment	Disease
Rehab@Home [41]	Microsoft Kinect linked to a desktop computer	Rehabilitation program tailored to individuals, adjustable level of difficulty (by therapists)	Real-time feedback for patients; data is stored for analysis and progress tracking by therapists	Yes	Upper limbs	Stroke
StepAR [40]	Microsoft Kinect linked to a desktop computer	Customizable difficulty levels based on performance in previous levels; parameters such as distance, speed, obstacles, duration, and goals can be adjusted to modify difficulty	Real-time visual and auditory feedback; performance feedback at the end of each level	No	Gait	MS
Rhythm-based SG [78]	Leap Motion linked to a desktop computer	Currently static difficulty	Real-time visual feedback	No	Upper limbs	Not disease-specific
Farm Life [38]	Leap Motion linked to a desktop computer	Adjustment managed by therapists, i.e. time counter, spawn speed, gesture sensitivity, number of objects to be spawn	Real-time visual and auditory feedback; Web Application only accessible by therapists for insights and progress reports	Yes	Upper limbs	Parkinson disease
Weekend in Rome [79]	PC-based game	3 auto-adaptive levels of difficulty, i.e. 3 static maps of Rome	Performance metric feedback; "Hint" and "Verify" buttons for guidance and feedback on task execution	No	Cognitive	MS
Our game	Leap Motion linked to a desktop computer	Adjustable level of difficulty for both cognitive and physical tasks	Real-time visual and auditory feedback; long-term statistics on performance for patients and progress tracking by therapists	Yes	Upper limbs & cognitive	MS

Table 3.1: Comparison of our game and state of the art

exercise and cognitive stimulation since patients with MS often experience both. The proposed game takes into consideration the potential concerns of the target group, such as optical neuritis, fatigue, and other impairments commonly associated with MS. Unlike other discussed solutions, our serious game is specifically designed to address these concerns by incorporating features such as carefully selected colors, shapes, sizes, and shorter sessions and regular breaks to avoid exhaustion. This ensures that the game is enjoyable, safe, and effective for people with MS. Furthermore, the game offers adjustable levels of difficulty for both physical and cognitive tasks. One suggested approach for this customization involves using the Expanded Disability Status Scale (EDSS). EDSS is a method of quantifying disability in multiple sclerosis and monitoring changes in the level of disability over time [82]. This ensures easier analysis of performance metrics and a personalized and challenging experience for each patient. While implementing seven distinct levels for each game might exceed the scope of this prototype within the thesis, the full spectrum of MS stages will be considered in level design. Future work could consider the integration of all seven EDSS levels to offer a comprehensive experience for users. Furthermore, our application provides long-term statistics on the performance for patients, as well as progress tracking by therapists, which enables both parties to monitor progress. Additionally, our game includes multiple exercises, providing patients with various challenges to keep them engaged and motivated. The use of the Leap Motion Controller ensures accessibility since it is a small, low-cost, and easy-to-use device. This is important since the use of the application is intended for both rehabilitation centers and at-home rehabilitation without outside help.

CHAPTER 4

Results

This chapter presents the outcomes of research and implementation efforts, resulting in a high-fidelity prototype with two game scenarios for the rehabilitation of MS patients. Methods described in chapter 2.7 were applied to this thesis's concrete problem to assist requirements analysis and evaluate the emerging design. The work on the thesis started with the research phase, aimed at gathering relevant information and insights. This phase was accompanied by an extensive literature review and various methods such as brainstorming, questionnaires, qualitative interviews, and pencil sketches, with the obtained results serving as the basis for this thesis. The results of the research phase are presented in the following subchapter. This was followed by the implementation phase, an iterative requirements specification, and prototype development. Throughout the process, the prototype was continuously evaluated, where the results served as a starting point for requirements refinement in the subsequent iteration. Subchapter 4.2 provides an overview of the implementation phase, which was divided into multiple iterations. Each iteration is described in detail, starting with the initial iteration that involved designing high-level mockups derived from an extensive requirements engineering process based on the literature review and other methods used in the research phase. Mockups served as a blueprint for developing a prototype featuring two game scenarios. The development process spanned across two subsequent iterations, allowing for refinement of the requirements based on specialist's and patient's feedback. Both research phase and implementation phase were crucial for answering *RQ1* and *RQ2*. Finally, the prototype was evaluated to assess its usability, which involved engaging participants in a play session and afterwards conducting Game Experience Questionnaire [67] and System Usability Scale [8]. Selected questionnaires should help us answer *RQ3*. The evaluation results are also discussed in this chapter.

Table 4.1 summarizes the parties involved in the design process, i.e., specialists participating in interviews and discussions and patients and volunteers that assisted in initial questionnaires and usability testing.

Participant	Gender	Age	Role	Work	Phase
P1	f	60	Neurologist	Head of the MS Center at clinic in Vienna	RP
P2	m	29	Occupational Therapist	Self-employed	RP, IP
P3	f	35	MS patient	Project manager	RP, IP
P4	f	32	MS patient	Sales assistant	EP
P5	m	50	Volunteer	Software developer	EP
P6	m	31	Volunteer	Architect	EP
P7	f	21	Volunteer	Student	EP
P8	f	41	Volunteer	Accountant	EP

Table 4.1: Overview of the involved stakeholders

4.1 Research Phase

The research phase was structured into three distinct phases. It started with market research in a form of a questionnaire and initial brainstorming to assess the interest of MS patients in serious gaming for rehabilitation purposes. Then, structured interviews were held with specialists to understand the nature of the disease, therapy approaches, and their opinions on serious gaming in rehabilitation. The results were used for defining a set of game scenarios that will be considered for the thesis. Finally, as a part of the technology research, we explored suitable implementation approaches for developing a serious game with a Leap Motion Controller tailored to the needs of MS patients. We tried to identify the strengths and potential limitations of the controller. The research phase was pivotal for answering research questions defined in 1.2.

4.1.1 Sampling in Software Engineering Research

In a critical review of sampling in software engineering (SE) research, Baltes et al. [83] investigate and analyze the prevalent sampling strategies. The purpose of this paper is as follows: (1) *providing a detailed, SE-specific primer on sampling concerns and techniques;* (2) *investigating the state of sampling in SE research;* (3) *providing guidelines for improving sampling in SE research* [83]. The authors differentiate between *non-probability* and *probability* sampling and focus on the most applicable sampling approaches to SE research in both categories. Sampling techniques that do not involve randomness are categorized under non-probability sampling. The paper identifies that *purposive* and *convenience* sampling are the most commonly utilized non-probability sampling techniques, with a notable scarcity of probability sampling. Even though there is no best technique, since different sampling approaches are appropriate for different purposes in different circumstances, Baltes et al. suggest that SE research has a generalizability crisis due to a lack of probability sampling. Furthermore, the paper investigates misunderstandings and misuses of sampling terminology in the field, where representativeness and randomness often appear misunderstood. Lastly, [83] provides recommendations for researchers to improve the conduct and reporting of sampling for any empirical study, which will be considered in this thesis when conducting a questionnaire, identifying relevant stakeholders and evaluating our prototype. The suggested guidelines are as follows:

1. Clarify your philosophical position.
2. Explain the purpose of sampling.
3. Explain how your sample was selected.
4. Make sure your sampling strategy matches your goal, epistemology, and type of study.
5. Avoid defensiveness and overselling the representativeness of your sample.

4.1.2 Initial Phase

As seen in the methodology graph 1.1, following a comprehensive literature review, we decided to conduct a questionnaire with MS patients to gain a deeper understanding of our target group. Therefore, in the initial stages of the project, a questionnaire was created to gather valuable insights from MS patients regarding their symptoms, rehabilitation routines, and interest in serious gaming. The results gave us input important for answering research questions 1 and 2. The questionnaire was distributed to two MS support groups on Facebook, resulting in a total of 21 responses This sampling technique was chosen by practical considerations, acknowledging the challenges discussed in [83]. The practical inconvenience and absence of a well-defined sampling frame for the MS population made it challenging to apply probability sampling, i.e., making a random and representative participant selection. While recognizing the limitations of convenience sampling, particularly in terms of generalizability, this approach was suitable to gather preliminary insights and experiences from individuals directly affected by MS. Baltes et al. [83] indicate that there is nothing wrong with having a simple sampling algorithm as long as it is appropriate for the goals of the study. The questionnaire results support the previous research statement that a significant number of MS patients encounter challenges related to hand functionality, experiencing symptoms like tremors, spasms, and weakness. The findings also show that approximately 50% of respondents reported mild cognitive functioning issues. Another important aspect is that, even though not familiar with serious gaming, the majority of respondents had a positive opinion on the topic and would consider introducing serious games in their training. Figure 4.1 illustrates the demographic information of participants, whereas the complete list of questions and corresponding results can be found in Appendix B.

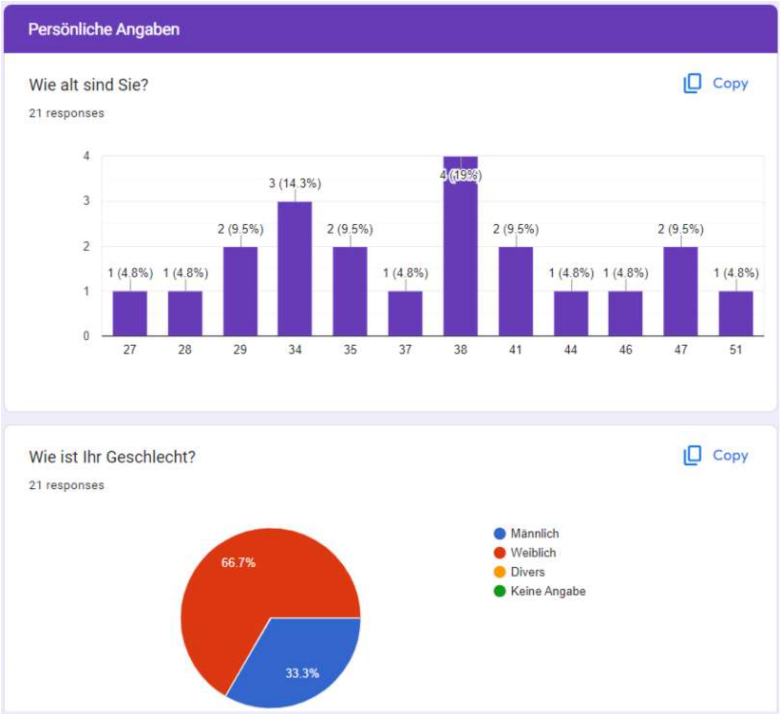


Figure 4.1: Demographic information of participants: Questionnaire results

Following the questionnaire, a semi-structured interview was conducted with two healthcare professionals. The same interview format was conducted with the neurologist and the occupational therapist. The objective of these interviews was to assist answering *RQ1* and *RQ2*, and to gain a deeper understanding of MS symptoms, their development, and explore the rehabilitation approaches from the perspective of professionals directly involved in patient care. The interview guide was prepared based on the derived knowledge from chapter 2 and state of the art research covered in chapter 3. The original German version and the translated English interview guide are included in Appendix A. The interviews, which lasted approximately one hour each, included a combination of specific questions and open-ended questions. We followed a structured approach but allowed room for brainstorming and open discussion. The participants are introduced in the following.

Neurologist (P1): Head of MS clinic based in Vienna specialized in neurology and multiple sclerosis.

Occupational therapist (P2): Self-employed occupational therapist, who supports individuals with neurological disabilities by providing various services, including training for everyday activities, cognitive exercises, and sensomotoric training.

Both interviews started by introducing the aim of this thesis to the neurologist/therapist and outlining the interview structure. Initially, we asked questions about MS, including its cognitive and physical symptoms and their frequency. In the second part, P1 and P2 were asked to provide insight into typical rehabilitation practices. Then, we gave a more detailed overview of the ideas for the prototype and delved into questions related to serious gaming. Participants were specifically asked about the feasibility of incorporating serious games into patients' rehabilitation practices based on their professional experience. Finally, they were asked about their general opinion and concerns regarding the idea. The participants were encouraged to share their thoughts and prioritize different requirements freely. Both therapists spoke candidly and provided valuable insights. The initial concept for this thesis was to develop a game primarily focused on fine motor training. However, both P1 and P2 emphasized the significance of cognitive training in MS patients. They suggested it would be a good idea to include cognitive tasks in game scenarios that exercise fine motor gestures. P2 explained which cognitive exercises have proven effective with their patients and suggested a cognitive gaming platform, NeuroNation, as a good starting point. Furthermore, P2 showed a few simple exercises that are often used for fine motor training, such as coin flipping. During the interview, there were some conflicting responses, particularly regarding the frequency and occurrence of various MS symptoms. P1 said that cognitive symptoms tend to manifest in the earlier stages of the disease, while physical impairments of limbs, like tremors and spasms, appear later. On the other hand, P2 shared their experience that patients initially come with motor difficulties and do not yet experience cognitive challenges. Nonetheless, both P1 and P2 agreed that, in their experience, most patients would be willing to introduce serious gaming into their routines. P2 mentioned that their current rehabilitation sessions already incorporate various games as part of the training. They also expressed that therapists are typically open to engaging patients in different types of training activities. The concrete ideas for the game prototype were not created at the time of the interviews. However, both interviewees shared a similar opinion of what requirements a game should satisfy and what should be considered before designing it to overcome possible limitations. The common opinion was that the game design must be simple, when possible, with natural interfaces and clear instructions that would support patients with cognitive impairments. Furthermore, P1 and P2 both said that fatigue is one of the most common symptoms of MS. Therefore, the gaming sessions must be kept short to achieve effective results. They both expressed the importance of the personalized levels, as already discussed in chapters 2 and 3. The interviews resulted in valuable input for the requirements elicitation. More about the specific requirements will be discussed in the following subchapter.

The next step was to facilitate knowledge from the literature review and conducted interviews, and to brainstorm ideas for 2-4 game scenarios. The initial step involved defining a set of potential gestures to be targeted by the games and developing simple tasks that would simulate these gestures using the Leap Motion natural interface. Four commonly practiced gestures were selected: thumb opposition, pinch, grab, and grasp. At this point, we decided to begin with commonly practiced gestures in traditional rehabilitation, without initially accounting for potential limitations arising from the translation of these exercises into Leap Motion-controlled games, also relevant for answering research question 2. Additionally, the goal was to incorporate some level of cognitive challenge into each scenario. Throughout the initial design phase, our focus was on creating games that were simple, short, and offered multiple difficulty levels, both physical and cognitive. At the end of this phase, a low-fidelity prototype was developed as a result of brainstorming processes. The prototypes were pencil sketches since the creation of such is fast and cheap. The purpose of these sketches was to evaluate and describe the initial idea and to discuss potential requirements. The sketches of four game scenarios are presented in figure 4.2. In this phase, we briefly described initial ideas that should be taken into consideration in subsequent design phases; they can be further refined and adjusted for the actual development if they are selected.

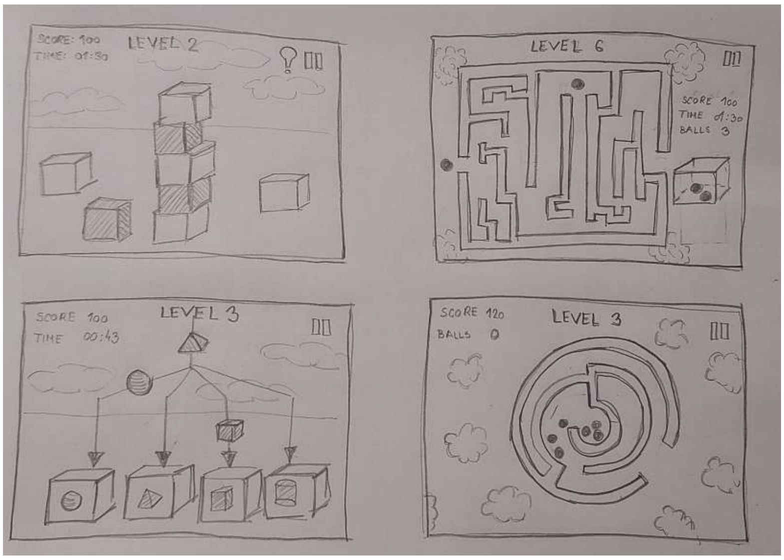


Figure 4.2: Pen and paper sketches of four game scenarios

Mindful Tower: Pinch Perfect

The focus in this game is on the pinch gesture, combined with cognitive activities involving memory and attention. The objective is for the player to construct a tower of blocks in various colors within a specified time frame, all while ensuring the tower remains stable without any blocks falling. Before starting the level, the player is shown the color pattern of the tower. The player needs to remember it before the game starts. Furthermore, the idea was to implement a hint feature to help the player during gameplay. The game offers different levels of challenge, including variations in tower height, the number of colors, the time allowed to remember the pattern, the allowed number of errors, and the time limit for building the tower. These levels can be categorized into two types: cognitive levels that focus on memorizing block patterns in different colors, and physical levels that consider the height of the tower or time constraints that force the player to move precisely but quickly. The reward strategy is simple: points are awarded for each successfully placed block, potentially varying based on the level. The player is awarded with extra points on each fifth block. At the game's end, players are rewarded with additional points for completing the task without errors or within the defined time limit. In the STAR chapter, we saw that negative points tend to have a negative impact on the player's motivation. Therefore, there are no negative points if the player wrongly places a block or if the blocks fall.

Maze Master: Grab Control

In this game scenario, the focus is on the gesture of grasp and release, along with cognitive activities involving reasoning and focus. The goal is to navigate multiple objects through a maze without touching the surfaces or obstacles, ultimately bringing them to the end of the maze and releasing them into a designated box. To make the game a little bit easier, the player is allowed to make a defined number of mistakes. The game offers different levels of challenge, including variations in maze complexity, i.e., the path length, the number of obstacles present, and the number of objects to be moved. The cognitive levels aim at the complexity of the maze, whereas physical levels consider the space or width available to move the objects through the maze and the number of objects. Players are rewarded based on the time required to successfully finish the challenge, i.e., to bring all objects to the box. Additionally, there are optional rewards or incentives that players can collect while playing. If the player successfully avoids hitting the maze border, they receive additional points. On the other hand, the player is not punished with negative points.

Thumb Tango: Opposition Challenge

The objective of this game is to exercise physical coordination involving thumb opposition and maintaining focus. The game scenario is simple: objects move along the lane, and the player must execute the correct thumb opposition gesture to place each object into the corresponding box. In the early levels, the objects and the boxes are coded with the same color, whereas in the advanced levels, the colors are mixed, requiring the player's concentration on both aspects simultaneously. The levels can be categorized into cognitive levels that introduce inconsistencies in colors and shapes and physical levels that increase the speed and frequency of falling objects. The player is rewarded with points for every successful movement without being punished with negative points if they miss. Furthermore, extra points can be earned if the players finish the level with all lives or if they accomplish specific goals, such as catching two objects within a certain time frame.

Ball Escape: Grasp of Steel

This game should address physical challenges related to hand weakness, grasp/grab, and dexterity while requiring good reasoning and focus. Inspired by Ball Maze, the player's objective is to release balls from the maze starting from the center by rotating the maze itself. The maze can have different shapes, i.e., circle, triangle, or square. As the game progresses, the levels can introduce various shapes, increased complexity, and a greater number of obstacles to overcome. Like in the above-described game scenarios, the levels can be categorized as cognitive and physical. Cognitive levels focus on the complexity of the maze layout, and physical levels require a steady hand and precise control since the maze gets more complex and the path narrows. At the end of each level, players are rewarded based on their completion time, additional points for missing obstacles, and optional incentives that they can collect during the gameplay. There are no negative points in this game, either.

As seen from the descriptions, all games are kept simple, as advised by P1 and P2. The initial designs were presented to P2 for review, where the evaluation primarily focused on assessing the game's suitability for MS rehabilitation from the point of view of an occupational therapist. Their feedback was highly positive, acknowledging the simplicity of the game designs, as advised previously. Furthermore, they appreciated the incorporated cognitive challenges, believing that even a minimal cognitive effort required could benefit patients. They emphasized that the final product should offer multiple games to accommodate the diverse MS symptoms. While they found every gesture exercise suitable for MS rehabilitation, they did express concerns about the execution of the game *"Maze Master"*. Their opinion was that moving objects through narrow mazes on a laptop screen might be too challenging, if possible. Regarding the games *"Ball Escape"* and *"Mindful Tower"*, they believed it could be suitable for many MS patients. In their experience, one of the common physical MS symptoms is intention tremor. Intention tremor is a rhythmic, oscillatory, and high amplitude tremor during a directed and purposeful motor movement, worsening before reaching the endpoint.[84] This means that the tremor develops and becomes more pronounced as the person tries to reach for something. Both *"Ball Escape"* and *Mindful Tower* require precision and controlled movement and presents a practical challenge in practicing hand steadiness and coordination to address the symptoms of intention tremor. Additionally, P2 suggested that the user interface presented in the sketches could be further simplified. By eliminating unnecessary backgrounds and details, we could improve the readability and keep the player focused on the game. Their feedback was strongly considered in the upcoming requirements engineering phase.

4.1.3 Leap Motion Controller and Unity

The integration of advanced technologies into serious games has opened up possibilities for innovative solutions in rehabilitation and cognitive training. This chapter explores Leap Motion, a state of the art hand-tracking technology, as a controller chosen for a serious game developed as a part of the thesis. As a foundation for the upcoming prototyping phase, we investigate the possibilities and limitations of Leap Motion in the context of Unity game development.

In chapter 2.4, we introduced the Leap Motion Controller and presented information about the hardware resulting from the literature review. In this phase, we wanted to gather more empirical results by evaluating the behavior of the controller across different scenarios, i.e., to evaluate the Ultraleap's Hand Tracking Software. In our research, we used a Leap Motion Controller 1 in combination with Ultraleap Tracking Software version 5.16.0. Since the application should include a game, the use of a game engine was considered. Ultralep provides support for Unity [85] and Unreal Engine [86]. Our evaluation criteria included ease of development, community support, and overall functionality. According to official documentation [87], in terms of hand tracking, there is currently more functionality available for Unity Modules than Unreal Plugin. The comprehensive documentation and community support further affirmed Unity's suitability for integrating Leap Motion into our prototype. The next step was to explore the integration of Leap Motion within the Unity framework. This step included downloading and setting up the developer tools plugins for Unity. It features Ultraleap's powerful Interaction Engine, which bridges the gap between the hand tracking data and the game engine physics. This makes it possible to interact with virtual objects in a natural and intuitive way. Then, we created a simple scene with a desktop rig provided by Leap Motion and a set of virtual hands to assess the hand-tracking software's performance with respect to the requirements for the thesis. Specifically, the focus was on assessing the precision of the gestures relevant for the four game scenarios introduced in the previous chapter; namely *pinch*, *thumb-opposition*, *grab*, and *grasp*. The games, along with their corresponding hand gestures, are summarized in table 4.2.

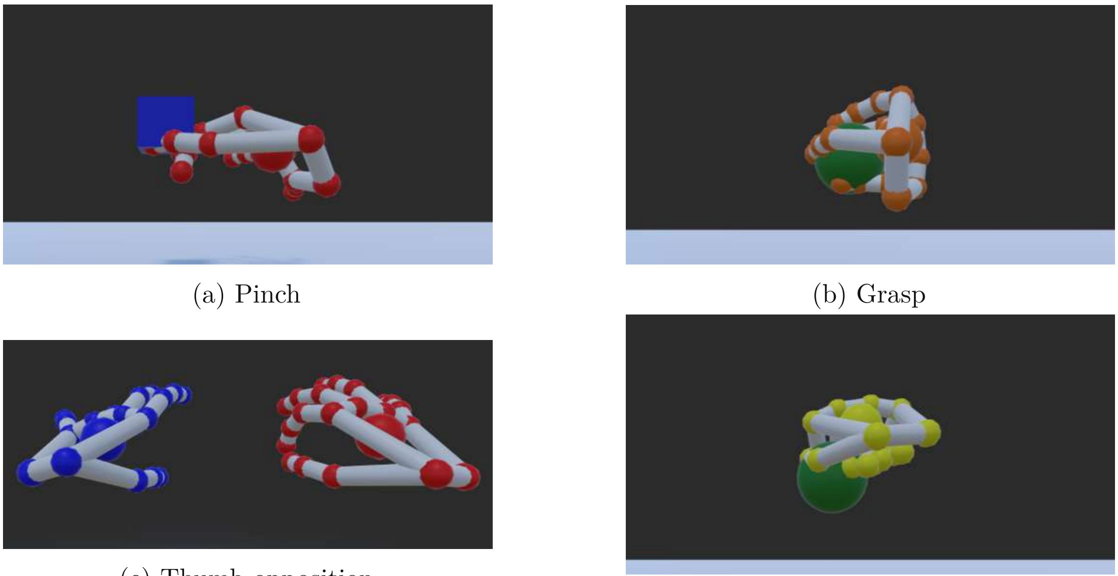
Game scenario	Hand gesture
Mindful Tower	Pinch
Maze Master	Grab
Thumb Tango	Thumb-opposition
Ball Escape	Grasp

Table 4.2: Proposed games and their corresponding gestures

Ultraleap Tracking Software supports three different tracking orientation modes [88]:

- *Desktop* - facing up from a table
- *Head-mounted* - fastened to a VR/AR headset
- *Screentop* - facing down towards the user

The orientation mode is set at the application level by the developer. In the scope of the thesis, our focus was on developing a desktop game as opposed to an Extended Reality (XR) game. Furthermore, the decision to first try the desktop orientation mode was driven by its ease of use for players. After setup, next step was to assess the precision and the user experience during the performance of the hand gestures specified in table 4.2. Figure 4.3 illustrates those gestures and simple interactions with objects.



(a) Pinch (b) Grasp

(c) Thumb-opposition (d) Grab

Figure 4.3: Hand gestures in desktop mode (captured by the author)

Our findings identified three potential limitations in Leap Motion's performance concerning the requirements for our serious game. Firstly, we encountered challenges in accurately tracking the thumb opposition gesture. The tracking results could have been more precise and consistent. Although the software could recognize thumb-index finger opposition, as seen in 4.3 (right hand), the tracking data for other fingers tends to be inaccurate. Contrary to expectations, we can see that the sensor could not register the thumb opposition with the middle finger of the left hand. According to official documentation, Ultraleap's Hand Tracking Software models the underlying structure of the hand at the level of the joints and bones. This means the software can accurately pinpoint the position of a finger or thumb, even if it is hidden from view [88]. However, our results did not align with this expectation. Therefore, we contacted Ultraleap's support on Discord. Our goal was to address the identified issues and explore potential solutions, whether through configuration adjustments or suggestions from the Ultraleap community. The team acknowledged that they are aware of some discrepancies when tracking in desktop mode. Their suggestion was to either switch to head-mounted mode, since this mode provides better accuracy (see figure 4.4), or to upgrade to a Leap Motion Controller 2, as they introduced tracking improvements with the latest version.

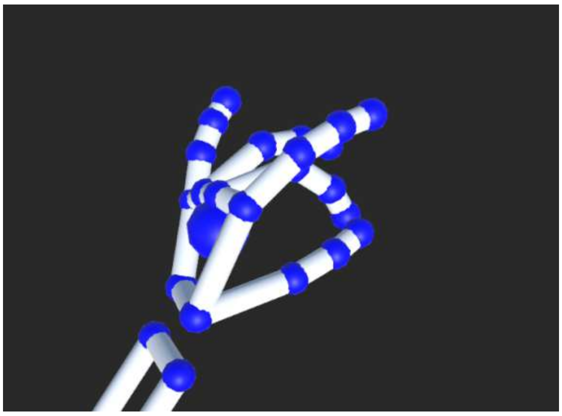


Figure 4.4: Thumb-opposition in head-mounted mode (captured by the author)

Secondly, we faced difficulties in differentiating between grab and grasp gestures. As we can see in figure 4.3, the controller was able to perform these gestures. However, distinguishing between objects became challenging during practical interaction with objects due to their similarity. Although this is not a direct limitation of Leap Motion, it led us to reconsider the necessity of having distinct game scenarios for each gesture.

The third concern raised was the interaction with objects in a 3D space without a VR headset. While a primary objective of the thesis is usability and natural interfaces for easy interaction, the user experience can be affected when trying to interact with objects in a 3D environment while hands are projected onto the desktop, especially when attempting to interact with multiple smaller objects that are positioned differently along the z axes. The lack of a tangible spatial reference point may feel unfamiliar to the player and require significant adjustment time. The interaction with the object is not overly difficult, but the gamified aspect and the stress factor during gameplay might negatively affect the spatial awareness of the player, which could lead to decreased user-friendliness.

Empirical testing of Leap Motion and Ultraleap Tracking Software in the context of traditional upper limb exercise helped us identify the technology's potential and limitations. This step greatly contributed to answering *RQ2*.

4.1.4 Findings

The comprehensive research phase was crucial for establishing the foundation of a thesis and identifying potential and limitations. Firstly, we defined four potential game scenarios based on prior research methods. We strongly incorporated feedback from P2 in the game selection and refinement process. This impacted our decision to reconsider the game *"Maze Master: Grab Control"* due to concerns about the possible difficulty for patients with MS, given its requirement for steady hands and high concentration. We also took the usability suggestions into account in the upcoming requirements specification. Furthermore, the outcome of Leap Motion's performance evaluation strongly impacted our decision-making. The concerns discussed in 4.1.3 made us rethink proposed game scenarios. Finally, the games chosen to proceed with are: *"Thumb Tango: Opposition Challenge"* and *"Mindful Tower: Pinch Perfect"*. P2 emphasized the importance of fine motor exercises. *"Mindful Tower"* and *"Thumb Tango"* are games that specifically target fine motor exercises and related gestures. We decided to implement *"Mindful Tower"*, with consideration of the concerns regarding the interaction with the objects in a 3D space. In the following phase, we will aim to design a game that is intuitive and user-friendly. The selection of *"Thumb Tango"* influenced our decision to use of the head-mounted mode, as the desktop mode did not yield satisfactory results in terms of accuracy. The findings from 4.1.3 prompted us to consider only one game between the *"Ball Escape"* and *"Maze Master"* due to the close similarity between the grab and grasp gestures. The opinion expressed by P2 regarding the *"Maze Master"* influenced our decision to exclude this game. We also decided not to implement *"Ball Escape"* as the part of this thesis, since we decided two games would be sufficient and that the other two games offer more adjustability in cognitive challenges. The results of the research phase are used for the input for the requirement elicitation, which is discussed in detail in the following subchapter.

4.2 Iterative Implementation

The implementation phase includes iterative requirements engineering, prototyping, and evaluation, structured into three iterations. The first iteration starts with requirements specification derived from the research phase. Based on the requirements list, we develop mockups for our application. These mockups are then subjected to evaluation with patients, and the outcome is taken into consideration for the subsequent iteration. In iteration two, we refine the set of requirements based on lessons learned. The second iteration also includes prototyping core features, i.e., game scenarios and menus. This involves the precise definition of the application workflow. Detailed workflow design specifies how users navigate menus, perform various actions, and interact with game scenarios. Just like in the first iteration, we evaluate the emerging state of the prototype, where the gained insights are used for the requirements refinement in the final iteration. During the third iteration, we make the last refinements to the requirements and prototype. In this phase, we incorporate final functionality into the prototype, including achievements and statistics, and tutorials. The completed prototype is then presented to a therapist for evaluation to ensure it aligns with the intended goals and user needs. Their feedback is last before formal assessment in the evaluation phase, discussed later in the scope of this thesis.

4.2.1 Iteration 1

The objective of the first iteration is to summarize the knowledge acquired in the research phase and define a comprehensive list of requirements that will serve as the foundation for the prototyping phase. Additionally, the first iteration involves creating mockups that will be used as a blueprint for developing the high-fidelity prototype of our serious game.

Requirements Specification

The first step in the RE process was to identify relevant stakeholders. The goal was to define decisions about business needs, goals, and objectives from their perspective. As discussed in chapter 2.7, the persona, as a user representation, is a valuable tool that can reduce effort by modeling the end users and being the primary source of information. In chapter 4.1.1, we cover different sampling techniques in software engineering based on the research of Baltes et al. [83]. In alignment with the principles of effective sampling discussed in this paper, the selection of stakeholders for our personas is grounded in practical considerations and the challenges posed by the MS population. As Baltes et al. emphasize in [83], the choice of sampling strategy should align with the goals of the study and the characteristics of the target group. In our case, the absence of a well-defined sampling frame for the MS population and the practical challenges associated with probability sampling led us to purposive selection of stakeholders. In our case, we identify two stakeholders: patients and occupational therapists. Patients are the end users who are going to interact with the software. While the therapist does not directly use the application, they guide the patient on its usage and assess the patient's suitability for using it. The demographic information for the defined personas is provided in table 4.3.

Name	Age	Occupation	Marital status	Location
Maria Katzer	41	Human resource consultant	Married	Vienna
Lisa Lackner	33	Occupational therapist	Single	Vienna

Table 4.3: Personas

Maria works as an HR consultant in Raiffeisen Landesbank. At the age of 26, she was diagnosed with MS. The first symptoms she experienced before her diagnosis were fatigue and changes in her vision. In recent years, she started experiencing numbness and weakness in the upper and lower limbs. She noticed that she can no longer easily use her smartphone and tablet or hold her coffee cup still due to weakness and tremors in her hands. Maria's favorite hobby is cooking. However, optical neuritis affected her vision, and she sometimes faces difficulties in the kitchen. Accurately measuring ingredients, reading recipe instructions, or safely handling hot objects can be challenging. Furthermore, she cannot carry the shopping bag as long as she used to, and it takes longer to focus on the necessary groceries. She also struggles with remembering and organizing her schedules, i.e., private and business appointments. To enhance her overall functional abilities, Maria contacted an occupational therapist. She is involved in fine motor and cognitive training sessions three times a week, one hour per session. Her occupational therapist suggested starting with everyday tasks such as cutting with scissors, folding clothes, and cooking. Her rehabilitation strategy targets both her physical and cognitive abilities. However, Maria is now motivated to explore new methods to bring something new to the rehabilitation sessions. Her occupational therapist suggested a serious game with multiple scenarios targeting the same hand and cognitive impairments as the traditional exercises.

Lisa is a self-employed occupational therapist located in Vienna. She finished her studies in occupation therapy in 2014 at the IMC FH Krems. Since then, she has been a dedicated occupational therapist specializing in neurological rehabilitation. In line with her motto, "back to everyday life," Lisa is focused on everyday training. She understands the unique challenges of MS patients and tries to tailor training sessions individually for each patient. Patients have different goals, and she tries to achieve them through sensorimotor and cognitive functional training. In her experience, patients tend to lose interest in rehabilitation if they are always asked to perform similar exercises. Therefore, Lisa uses a holistic approach in her one-to-one sessions, i.e., combining traditional exercises with innovative approaches to keep the patients involved in their therapy. She always keeps track of the patient's personalized progression. Besides formal exercising, her methods include simple everyday tasks, such as writing, folding clothes, and cooking. She also noticed that playing games with patients has a motivational impact on them. Lisa is dedicated to continuous learning to provide the best possible care for her patients. Recently, she gained more interest in games designed explicitly for neurorehabilitation. At the Annual Conference of the Austrian Society for Physical Medicine & Rehabilitation in 2022, she was introduced to a serious game called Mitii ("Move It To Improve It") [89]. The game aims to improve the balance and communication between brain and body. She liked the alternative approach to training. However, her work with patients is typically focused on fine motor training and activities of daily living. This specific game was not suitable, but Lisa would consider serious games that align with the goals of traditional exercises. She is interested in a game that addresses fine motor skills and cognitive abilities. Another important aspect is that the required equipment is affordable and accessible. Even though she wants to invest in her practice, her budget is limited.

The persona Maria is defined based on the interviews with P1 and P2, where they shared their knowledge of common symptoms and problems that MS patients experience daily. Furthermore, the results of the questionnaire with PwMS about their symptoms, training routines, and openness to introducing serious games in rehabilitation influenced the shaping of this persona. On the other hand, inspiration for occupational therapist Lisa came from an interview with P2. The interview taught us about different training approaches and limitations that therapists encounter. We could establish the initial set of requirements based on the information about Lisa and Maria. Our application should include games that integrate physical (R06) and cognitive tasks (R07). The UI should be designed with consideration of Maria's visual impairments (NFR02). Furthermore, Lisa's patients experience different symptoms, and their training routines vary; hence, providing multiple games (R04) and a level of customization within the games (R09) is important. She would also like to be able to track patients' individual performance. Therefore, it is important that the application provides statistics (R15). During the requirements engineering process, the questions to keep in mind were *what should the product do, how well should it do it and under which conditions should things be done*. The requirements elicited in this phase serve as a foundational step in answering *RQ1*, with further iterative refinement in the following phases.

After specifying a comprehensive list of functional requirements, we prioritize them according to their relevance to the application's context and the primary objectives of this thesis. Requirements with the highest priority are the most important ones to answer the research questions and make gameplay possible. Those with the lowest priority are not likely to be implemented in this work but may be considered for future work. Various factors influenced the prioritization process, including discussion with specialists, extensive literature review, and state of the art research. There were certain differences in the findings from the literature review, the opinions of experts, and the questionnaire results. However, the author made the final decision after analyzing the pros and cons. The requirements are prioritized based on a MoSCoW prioritization technique. The term MoSCoW itself is an acronym derived from the first letter of each of four prioritization categories [90]:

- *Must have* (M) - These are critical requirements that the project cannot complete without. The failure to deliver these requirements would result in the failure of the entire project.

- *Should have* (S) - Features that would be nice to have if at all possible. These are high-priority items that are not as time-sensitive as the Must-haves.

- *Could have* (C) - Features that would be nice to have if at all possible but slightly less advantageous than the Should-haves. Therefore, they can be included if time and resources permit.

- *Won't have* (W) - also known as *"wish list"* - these requirements are not unimportant, but they will definitely not be implemented in the current software project. They are agreed upon and recognized but are dropped for the project's current timeline.

Moving forward, we will focus on requirements categorized as *"Must have"*, *"Should have"*, and *"Could have"* to ensure essential functionality in our prototype. Two requirements addressing social aspects in the application, i.e., leaderboard (*R16*) and chat (*R17*), are categorized as *"Won't have"*. Despite potentially beneficial, these social components were evaluated as out of scope for this thesis. We want to keep the primary focus on the core functionalities and rehabilitation aspects outlined within the thesis, which is important for answering research questions 1 and 2. We present a complete list of requirements in tables 4.4 and 4.5, with the respective requirement ID, title, implementation priority, stakeholder who contributed to this requirement, and whether the requirement is included in the final prototype. In addition to the tabular list, we provide a detailed description of each requirement. This requirements list will be essential for the next phase, where we start with creating a low-fidelity prototype for our serious game.

Req ID	Title	Priority	Contribution	Included in protoype
R01	Login	C	Author	Yes
R02	Logout	C	Author	Yes
R03	Tutorials	S	P1, P2	Yes
R04	Two Game Scenarios	M	Author, P1, P2	Yes
R05	Gamification Elements	M	Author, P2	Yes
R06	Hand Gesture Tasks	M	Author, P1, P2	Yes
R07	Cognitive Challenges	M	P1, P2	Yes
R08	Levels	M	Author, P1, P2	Yes
R09	Personalization	M	Author, P1, P2	Yes
R10	Pause Level	S	P1	Yes
R11	Replay Level	S	Author	Yes
R12	In-Game Assistance	C	Author, P1, P2	Yes
R13	Sound and Visual Effects	S	P1, P2	Yes
R14	Game Finish	C	Author	Yes
R15	Statistics	M	P1, P2, Author	Yes
R16	Leaderboard	W	P1	No
R17	Chat	W	P1	No

Table 4.4: Functional requirements

- **R01 Login, R02 Logout**: The system should provide a straightforward login mechanism with username/password authentication. The user should also be able to log out and log in again with the same username/password combination. After login, the user should be able to play a game or track their progress in the statistics section. The logout mechanism should guarantee user privacy and data security. These requirements represent established best practices in application development and fundamental requirements for user experience and system security.

- **R03 Tutorials**: At the beginning of the first level in each game, the application should display a tutorial outlining game instructions. This tutorial serves to familiarize the player with the gameplay mechanics and controls. For this application, it was chosen to use a written form of tutorials. The game should only start when the user reads the instructions and agrees to proceed. To improve user experience, a checkbox option should be provided, allowing users to opt out of future tutorial displays after reviewing the instructions. This requirement emerged from initial interviews with P1 and P2.

- **R04 Two Game Scenarios**: The application should support integration of two game scenarios. Each scenario should be thoughtfully designed to achieve specific rehabilitation objectives while considering users' different needs and abilities. The development of these scenarios should promote engagement, progress tracking, and an increased user experience. The scenarios should differ in terms of motor skills requirements and cognitive challenges. This requirement originated from extensive brainstorming sessions about the objectives of the MS rehabilitation application. It has been carefully refined through a thorough literature review to ensure consistency with existing state of the art research in this area. Furthermore, active participation and input from stakeholders, particularly P1 and P2, contributed to the decision-making process. Practical evaluation of Leap Motion Controller helped to validate the feasibility and practicality of implementing two distinct game scenarios within the scope of this thesis. The final decision to implement exactly two games was made deliberately in order to create a strategic balance. Focus on a smaller number of scenarios ensures a manageable scope of development and allows for a more in-depth exploration of the chosen games: *"Thumb Tango"* and *"Mindful Tower"*. On the other hand, it fulfills the primary objectives of the thesis, helping us to answer *RQ1* and *RQ2*, and provides room for further development.

- **R05 Gamification Elements**: Besides two game scenarios, the application should provide other gamification elements. They are intended to stimulate motivation and drive continual engagement throughout the gaming sessions. Gamification elements should include rewarding players with badges for achieving milestones, using scoring systems to track progress, implementing levels to maintain active participation, and using timers to add an extra layer of engagement. This requirement originated from state of the art research, but the interview with P2 contributed to its specification.

- **R06 Hand Gesture Tasks**: Each game within the application should be designed to center around a specific hand gesture exercise inspired by conventional rehabilitation practices. This means that the player must correctly execute a specific hand gesture in order to complete a game task successfully. This requirement is important for answering first two research questions. It emerged from brainstorming sessions in the initial phases. It was further inspired by state of the art research on the use of sensor-based devices, such as Leap Motion Controller and Microsoft Kinect, in serious gaming for rehabilitation. The first step was to identify potential gestures relevant for patients with MS. This was done through a literature review and questionnaire with MS patients. Identified gestures were then discussed with P1 and P2 during interviews. We started with four common motor skills exercises, i.e., four gestures, that led to brainstorming four potential game scenarios. The selection process was discussed in the scope of the requirement R04, where we, after considering input from P2, decided to focus on two hand gestures, namely *thumb opposition* ("Thumb Tango") and *pinch* ("Mindful Tower").

- **R07 Cognitive Challenges**: Each game scenario should incorporate some level of cognitive challenge. The goal is to enhance cognitive abilities while engaging the player. Some examples of cognitive aspects in the games include concentration, memory, dual-tasking, reasoning, and problem-solving. The initial idea for the thesis did not involve an intentional focus on cognitive challenges. However, interviews with P1 and P2, along with the outcomes of patient questionnaires, where the results indicated cognitive processing impairments among the significant number of participants (see Appendix B), led us to rethink our idea. We decided to explore game scenarios that are not only centered around specific fine motor exercises but also require players to show focus and concentration and activate cognitive functions. This decision aimed at offering a more comprehensive approach to address both physical and cognitive challenges faced by MS patients. P2 supported presented game scenario ideas.

- **R08 Levels**: The games should have multiple levels that distinctly challenge players in cognitive and physical aspects. Progressively increased difficulty does not only aim to engage the player but also has rehabilitation purposes by encouraging incremental improvement of the patient's abilities. Physical levels should include a focus on motor skills, dexterity, precision, and speed in hand movements. On the other hand, cognitive levels should focus on challenges related to concentration, reasoning, and problem-solving. The initial inspiration for this requirement came from a literature review, but P1 and P2 also contributed. P1 expressed the opinion that difficulties should drastically vary from basic levels, suitable for patients with highly progressed MS, to complex levels for patients who still do not experience any of the targeted symptoms but are engaged in training to sustain well-being. Furthermore, P1 suggested creating the levels based on the Expanded Disability Status Scale. EDSS is a way of measuring how much someone is affected by MS. According to P1, every patient that is rated at EDSS level 0-7 should be able to play the game. This was strongly considered in the decision-making process. However, it goes beyond the scope of this thesis. It would be very difficult to precisely measure the symptoms for each level of the EDSS scale and interpret the findings regarding our game. In the end, we decided to implement three levels for each game that should support patients with varying levels of disability.

- **R09 Personalization**: The application should have personalized settings to tailor games for a better user experience. The player should be able to accommodate individual preferences and requirements, ensuring a more comfortable and effective rehabilitation experience. This would include different aspects, such as choosing the length of play sessions, selecting the exercising hand, and toggling the sound effects on and off. The importance of personalization is discussed in the STAR chapter 3. P1 and P2 highly contributed to clarifying this requirement.

- **R10 Pause Level**: The user should be able to pause a game at any time. This standard game feature is particularly important for MS patients, considering they often experience fatigue and difficulty maintaining concentration. The pause option should serve as a crucial accessibility feature, allowing players to manage their energy levels and enhance their overall gaming experience. Discussion with P1 about fatigue as a most common MS symptom and the requirements derived from that, i.e., the need for short sessions and/or pause option, contributed to the specification of this requirement.

- **R11 Replay Level**: The user should be able to replay the level, regardless of their performance. This aligns with this thesis's overall aim to develop an application for rehabilitation training. In this context, users should have the flexibility to continuously practice and repeat specific tasks to support their learning and improvement.

- **R12 In-Game Assistance**: The application should offer in-game assistance, commonly known as hints, while the user is playing the game. This requirement is supported by P1 and P2 and the fact that MS patients are susceptible to cognitive impairments, such as decreased concentration and processing speed. Hints should have different forms depending on the context of each game.

- **R13 Auditory and Visual Feedback**: Auditory and visual feedback should be integrated into the application to assist players and enhance the overall user experience. Both P1 and P2 agreed that auditory and visual elements could have a motivational impact on players. Effects should be strategically employed to provide meaningful feedback and maintain the user's focus. P2 emphasized the importance of auditory feedback, especially for patients with visual impairments. The integration of sound effects, such as feedback for successful actions or motivational cues, contributes to a more dynamic gaming experience and helps patients with vision problems navigate the game. Moreover, P1 suggested visual effects, such as celebratory fireworks upon completing a game. From their experience, visual effects can positively impact players and serve not only to entertain but also to motivate and reward them.

- **R14 Game Finish**: After finishing a game, the player should be presented with a score overview. If the current score exceeds their previous best, the application should offer the player an option to proceed to the next level, acknowledging their progress. This feature should be followed with motivational visual and auditory feedback. However, if the score does not surpass their best, the player can choose to either replay the level or leave. This should accompanied by a motivational message. This feature aims to motivate the player by acknowledging their achievements and providing clear indications for progression.

- **R15 Statistics**: Statistics should represent the user's individual progress tracking. A separate statistics section should be created for each game within the application for better readability. This section should include informative graphs illustrating the user's performance over time, focusing on levels and personalized settings. Furthermore, it should contain basic metrics, such as the number of completed games, best results, and other achievements. This requirement is relevant for both patients and therapists. The patient can monitor their own progress and improvements, but it is equally crucial for therapists to track patients' performance, analyze trends, and plan future training sessions more effectively. This requirement requirements emerged from a discussion with P1 and P2 and was later confirmed after defining personas.

- **R16 Leaderboard**: Leaderboard should enable patients to compare themselves with others and get insights into how many players are playing the game. The idea for this requirement comes from P1, who thinks leaderboards create a sense of community. Furthermore, according to literature and state of the art research, it appears that many games use this ranking system. Besides a sense of community, leaderboards create a sense of competition. This competitive element can motivate individuals to strive for improvement.

- **R17 Chat**: The application should integrate chat with other players. Just like a leaderboard, chat should create a sense of community and encourage social interaction and support among patients. The players should be able to exchange messages in a chat room before or after play sessions.

- **NFR01 - Gesture Detection**: One of the main objectives of the application is to provide players with a natural and engaging gaming experience. To achieve this, the application should respond promptly to players' gestures without significant latency. Minimizing latency should ensure immersive interaction with game objects. This requirement is derived from a combination of empirical testing of the Leap Motion Controller conducted by the author and insights gained from relevant research papers. According to [91], the latency that is tolerable by the human visual and

Req ID	Title	Category	Origin
NFR01	Gesture Detection	Responsiveness	Author
NFR02	User-friendly Interface	Usability	P1, P2, Author
NFR03	Leap Motion Controller	Compatibility	Author

Table 4.5: Non-functional requirements

nervous system is approximately 30-35ms. Leap Motion is a low-latency controller, with an average latency of 8ms [51], making it a suitable device for our serious game.

- **NFR02 - User-friendly Interface**: The game should have an intuitive and user-friendly interface to accommodate players with cognitive impairments. Both P1 and P2 emphasized the importance of user-friendly system interfaces for patients with neurological conditions. Given that MS patients often suffer from symptoms such as memory loss, difficulty concentrating, and reduced cognitive processing speed, ensuring user-friendliness becomes a key requirement. The application should have clear instructions, and every scene in the application should be accessible within three clicks.

  Approximately 50% of MS patients experience vision problems, often caused by a condition known as optic neuritis. Optic neuritis is characterized by an acute inflammatory demyelinating disorder of the optic nerve. [92] Its common effects may include blurred and reduced vision and changes in color perception. To address this challenge, P2 recommended the development of a high-contrast, monochrome user interface for our application. The use of a monochrome color scheme as a basis is considered the optimal choice as it increases visibility, legibility, and contrast. A monochrome scheme is applied to backgrounds, creating the foundational visual backdrop. In contrast, intensive colors are selectively reserved for specific elements, such as main game elements or highlighted text, to emphasize crucial aspects of the application. It is essential to use fonts large enough to avoid tiny hint texts and ensure that all text elements are easily readable. This requirement aligns with the objectives of creating a user-friendly interface for patients with vision impairments. Furthermore, UI should be kept minimalistic to avoid unnecessary details that might distract the player. Both P1 and P2 contributed to this requirement.

- **NFR05 - Leap Motion Controller**: The application should ensure compatibility and optimal performance with the Leap Motion controller and Ultraleap Hand Tracking software.

We want to note that requirements *R05*, *R06*, *R07*, *R08*, *R09*, and *R12* share a common objective for both game scenarios. However, the approach to achieve these requirements in each game will rely on individual games' unique design and mechanics. Therefore, in detail, specification of, e.g., gamification elements, physical and cognitive tasks, and personalization possibilities will be discussed in later phases - game-specific.

Low-fidelity Prototype

Following the comprehensive elicitation of requirements, the next step was to create a low-fidelity prototype. Figures 4.5, 4.6 and 4.7 show the results of this phase. These initial mockups, designed using Figma, represent the first version of our application's design. Besides the design, Figma's prototyping features allowed us to create interactive flows to explore how a user may interact with the design. Mockups were presented to an MS patient to get an initial idea of the application's look, feel, and functionality. The evaluated and refined version of the design will be used as a blueprint for implementing the high-fidelity prototype in the following two iterations.

The application begins with a login prompt (*R01*), where the user is asked to provide their login credentials to access the platform. After successful login, they are redirected to a start screen where they can choose to play one of two games, *"Thumb Tango"* or *"Mindful Tower"* (*R04*). Clicking on either game triggers a transition to the game menu, where they can either start a new game, adjust settings based on personal preferences (*R09*), or review game statistics (*R15*). The game menu should have the same functionality for both games, with minor differences in the UI design. If the player decides to start a game, they have to select between three levels tailored to different motoric challenges (*R08*), each progressively increasing difficulty. These steps are illustrated in figure 4.5.

Figure 4.6 presents the games. After level selection, a player is prompted with a tutorial (*R03*) explaining game rules, scoring mechanisms, and other essential information. Players are presented with an option to opt-out of future tutorial displays. The tutorial should provide players with the necessary knowledge to seamlessly transition into the gameplay, with a clear understanding of the game's rules and mechanics. At this point, the mockups serve as a basis for evaluating design simplicity, explaining basic game rules to MS patients, and evaluating their interests. From the gameplay designs (figure 4.6), we can see that the player is always presented with the current level, score, and remaining time, providing continuous information. We can also see that the color scheme used, i.e., a combination of monochrome background and vibrant game objects, aims to enhance user-friendliness (*NFR02*). The game scenario on the left represents the game "Thumb Tango," where players execute a thumb opposition gesture with a specific finger (*R06*) to direct balls toward the correct box along the lane. On the right, we can see "Mindful Tower," where the players have to reconstruct a tower shown to them earlier by continuously pinching (*R06*) one of four boxes in a specified color and moving them on the platform. We will explore further details of settings, including cognitive challenges (*R07*), controller mechanics (*R06*), and game duration, as well as hints (*R12*), and visual/audio effects (*R13*) in the next chapter. Furthermore, this chapter will cover the implementation details of gamification elements, such as scoring and achievements, carefully designed for both games (*R05*). These requirements are refined for the high-fidelity prototype's implementation in the next iteration. Moreover, players can pause the game at any point (*R10*). On pause, a popup dialog provides essential information such as the current score, remaining time, and level, ensuring that the player has a clear overview. Players can resume the game whenever they wish. As defined in *R14*, after the time expires, the game finishes with a *"Game Finish"* modal displaying the achieved score. This prompt should include a motivational message or visual effects aimed at encouraging the player (*R13*), along with a special indicator if the achieved score is the best so far. Finally, the player can proceed to the next level, replay the current one (*R11*), or exit the game and return to the game menu.

As already mentioned, besides initiating a new game, from the game menu, players can access settings or review game statistics (figure 4.7). The settings are similar for both games, allowing players to personalize their gaming experience. Requirement *R09* highlights the importance of personalization. This includes options such as selecting their preferred controller hand, toggling sound, adjusting cognitive challenges explicitly tailored for each game, and choosing game duration. Once the player confirms their settings by clicking the *"Done"* button, these preferences are saved and applied for the next play sessions. On the other hand, statistics provide insights into the player's gaming history, containing details like the number of games played, average and best scores, achievements, and a few graphs displaying play statistics over time (*R15*). Both aspects, settings and statistics, will be refined and discussed in detail in the upcoming iterations.

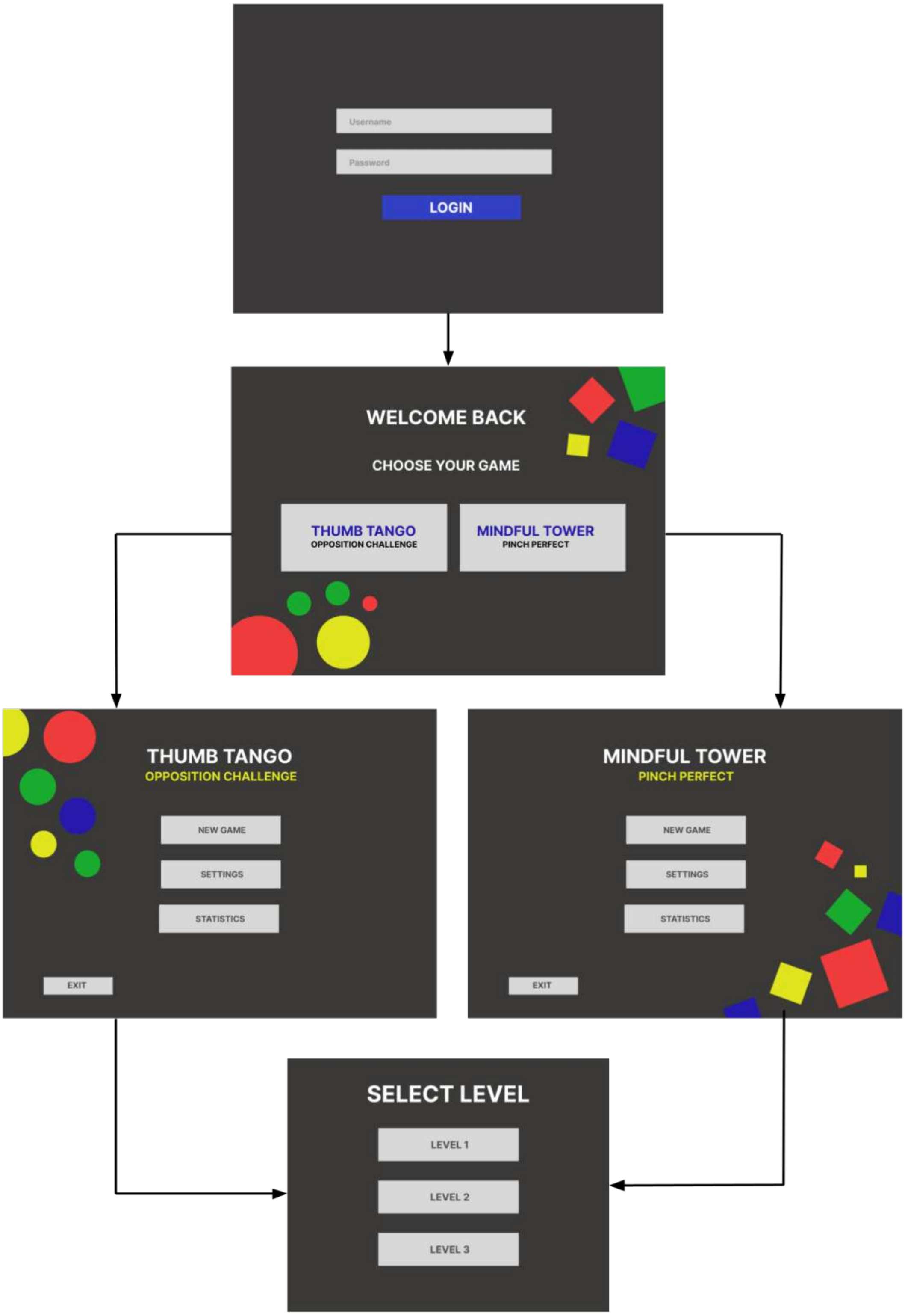


Figure 4.5: Menu interface

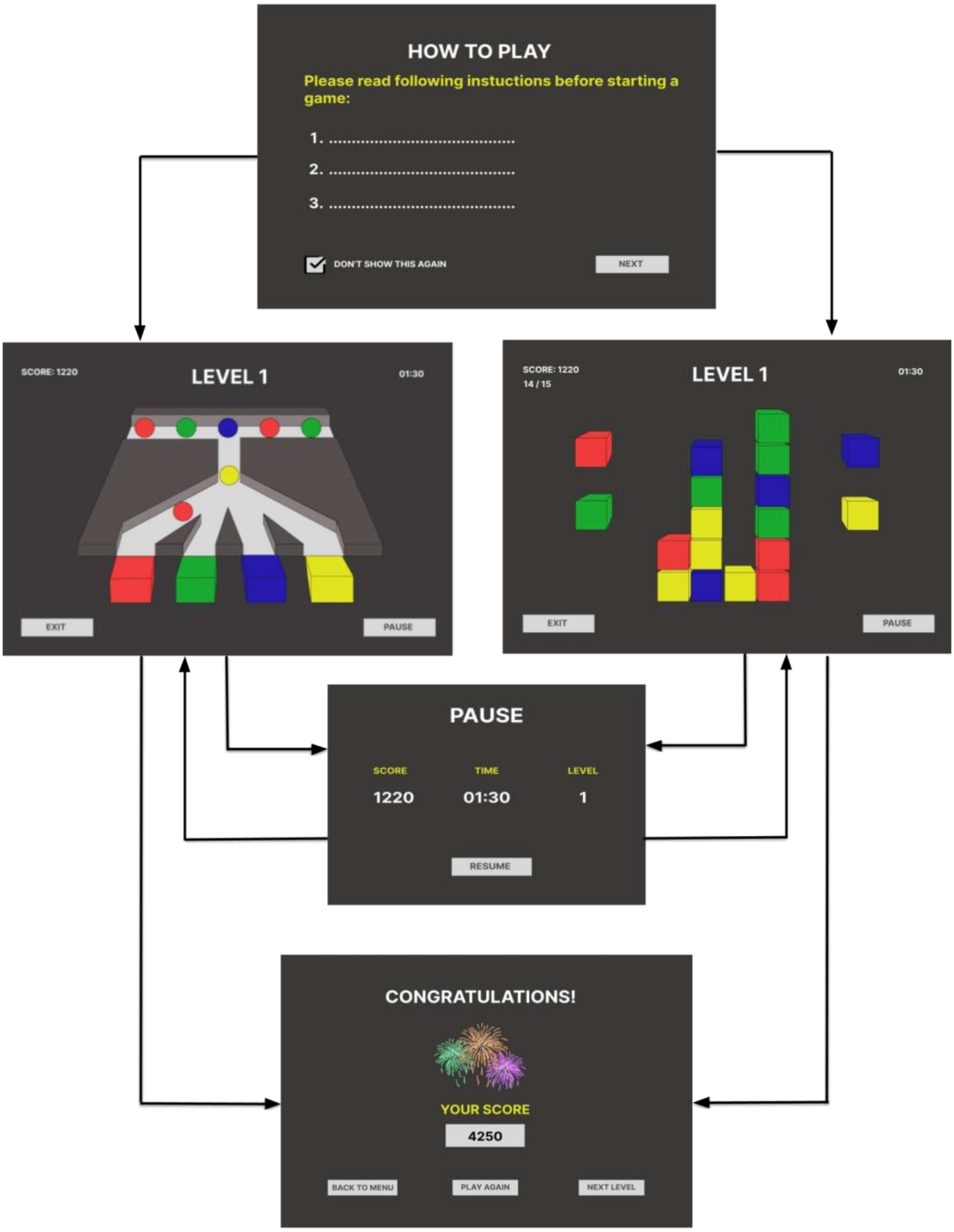


Figure 4.6: The games

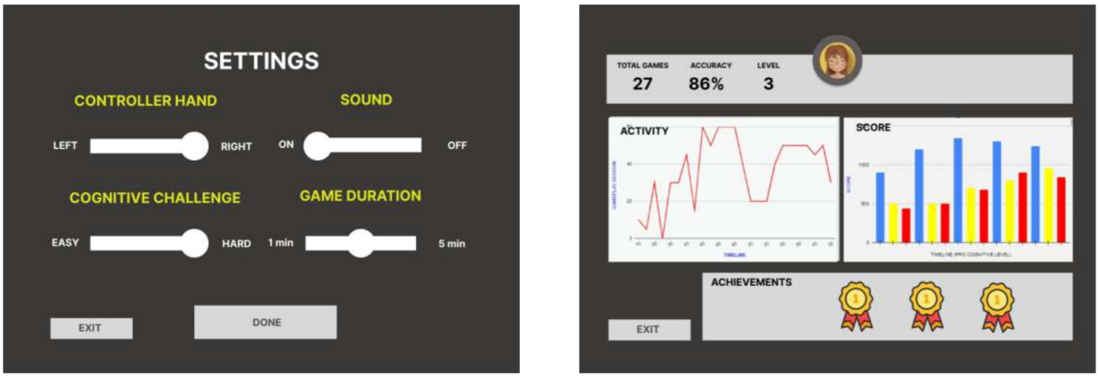


Figure 4.7: Settings and statistics

Patient P3 was involved in evaluating the mockups. In a 30-minute meeting, they were presented with the design concept and demonstrated the application's flow. The meeting was unstructured, and we encouraged P3 to openly share their opinion on both application design and the game ideas. Through this evaluation, we identified a few oversights, which contributed the iterative refinement of our understanding of the requirements, ultimately assisting in answering *RQ1*. Firstly, we noticed that the mockups are missing the logout feature (*R02*). This will be adjusted for the following iteration. The second topic of the discussion were the tutorials (*R03*). P3 acknowledged the significance of explicit instructions outlining user actions and the scoring system in the tutorial. However, while discussing the chosen written format for our prototype, they recommended either incorporating images to illustrate gestures and game steps with text instructions or using a short video instead of a written form. They agreed on the importance of clear understanding, whereas written steps alone tend to be overlooked and more complicated to understand. For instance, terms like "thumb-opposition" might not be immediately clear to players, and visual representation could significantly enhance usability to prevent any potential misunderstandings. Further feedback from P3 revealed an oversight in our initial requirements, specifically in requirement *R10*. While collaborating with P1, we established that players should be able to pause and resume gameplay at any point. However, according to our mockups, players can pause a level but cannot exit the application to resume their game later. P3 said that they would like to be able to exit the game and be able to return to it later at their convenience. Therefore, we adjusted the game menus for both games, allowing players to resume their previous gaming session in addition to starting a new game. The last thing that was addressed in the meeting was the game controller, i.e., Ultraleap hands. While these hands weren't explicitly featured in the mockups, we clarified to P3 that their hands would be projected onto the screen. They would directly interact with 3D objects or trigger specific actions based on captured gestures. During the discussion, we decided that the buttons available during playing, i.e., the *"Exit"* and *"Pause"* buttons, should not be conventional 2D buttons as in other scenes. Navigating these buttons using a mouse cursor while the Leap Motion captures hand movements could trigger undesired in-game actions, such as moving an unwanted box (*"Mindful Tower"*) or directing a ball to an incorrect box (*"Thumb Tango"*). Therefore, we decided to exit and pause the game by detecting a specific hand movement. Initially considering a simple swipe left or right gesture, we plan to finalize this decision after testing the gesture detection in the first implementation phase during the next iteration.

4.2.2 Iteration 2

Mockups from previous iteration were used as a blueprint for the high-fidelity prototyping in iteration 2. The prototype should satisfy the specified requirements, and build upon the technological foundations addressed in the previous chapters. The following subchapter starts by describing used technologies and our architectural decisions. Furthermore, we provide diagrams, to summarize the orchestration of game elements, user interfaces, and the seamless interaction of scripts. During second iteration, we established core application requirements, whereas the implementation details of the two proposed game scenarios are discussed in this chapter.

Architecture

As already discussed in chapter 4.1.3, we decided to implement our serious game using Unity, together with the programming language C#, and Leap Motion Controller as hardware and Ultraleap Hand Tracking software for hand tracking (*NFR03*). In the context of a Unity game using C#, the architecture typically revolves around GameObjects organized in Scenes as top-level containers. Each GameoObject has associated Components that control behaviors and interactions within the game. Besides the GameObjects controlled by the built-in Unity Components attached to them, like renderers or colliders, more complex gameplay features are implemented by creating custom Components using scripts. The simplified diagram of a typical Unity game architecture is illustrated in figure 4.8.

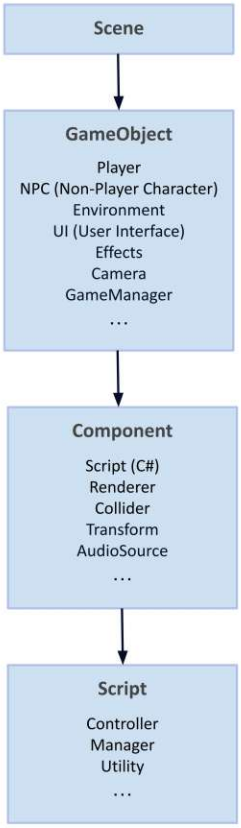


Figure 4.8: Typical Unity game architecture

Our prototype scripts are structured around the principles of separation of concerns. We categorized them into *controllers*, which handle individual GameObjects, user input, and player interactions, *managers* that manage game state and coordinate interactions between different components, and *utility classes* that provide reusable helper functions for various Components. The scripts are further organized into those that are globally used throughout the application and those that exclusively control the behavior of GameObjects in one of two games (figure 4.9)

Below is the complete list of global scripts used by both game scenarios:

- **GlobalManager** - *manager* - represent a central manager for global state, such as logged-in user, settings preferences, game parameters, and levels.
- **GlobalVariables** - *utility class* - holds global variables that can be accessed throughout the game.
- **LoginManager** - *manager* - manages the login and logout process.

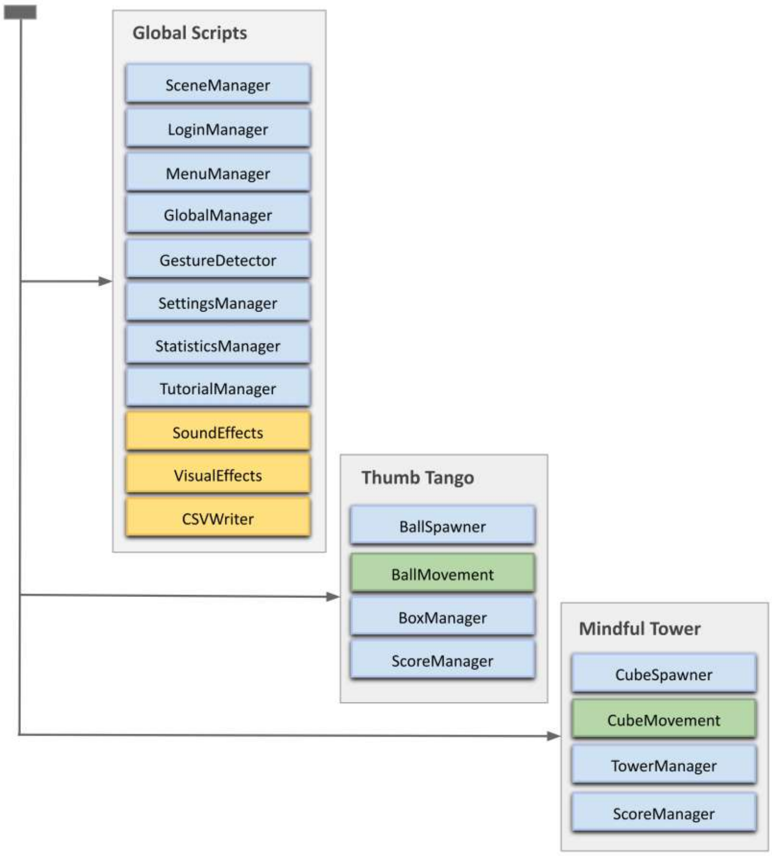


Figure 4.9: Relevant C# scripts in the application

- **SceneManager** - *manager* - handles the navigation across all scenes within the application.
- **MenuManager** - *manager* - the script is responsible for managing user interactions with objects in the main menu and menus for both games.
- **SoundEffects** - *utility class* - provides a service for playing sound effects to be reused across different parts of the game.
- **VisualEffects** - *utility class* - encapsulates a visual effects functionality to be used in other components.
- **StatisticsManager** - *manager* - responsible for handling and presenting game statistics and ensuring access to a detailed overview of a player's performance and progress over time.

- **TutorialManager** - *manager* - this script controls the content and navigation through tutorials in the introductory game phase.

- **GestureDetector** - *manager* - manages the hand models used for gesture detection and provides methods for detecting specific hand gestures (pinch gestures and thumb opposition gestures).

- **CSVWriter** - *utility class* - for this prototype, a CSV file simulates a database for storing essential data. This utility script manages operations related to CSV files for effective data handling.

We also listed all manager and controller scripts relevant in the game *"Thumb Tango"*:

- **BallSpawner** - *manager* - initiates the spawning of player objects, i.e., balls, and assigns necessary scripts to them.

- **BallMovement** - *controller* - controls the movement of individual balls by handling user inputs to influence the game state.

- **BoxManager** - *manager* - manages the behavior of four boxes in the game.

- **ScoreManager** - *manager* - a centralized script that handles game logic, including score and timer management, event triggering (sound and visual effects), and invoking of data management methods.

Lastly, we provide the list of all scripts that control GameObjects in the game *"Mindful Tower"*:

- **CubeSpawner** - *manager* - initiates new cubes on demand and assigns necessary scripts to them.

- **CubeMovement** - *controller* - controls the movement and behavior of individual cubes by handling user interaction.

- **TowerManager** - *manager* - manages the initialization of the tower examples, including setting up the color and shape mapping, and contains game logic to ensure the player is building a correct tower.

- **ScoreManager** - *manager* - the script has the same role as ScoreManager for the first game, containing essential game logic and scoring mechanisms.

The Game

During this iteration, we implemented core application features. This includes login (*R01*) and logout (*R02*), all game menus and navigation, and two game scenarios (*R04*). In the scope of this iteration, we also implemented visual and auditory effects (*R13*) that should assist users while playing. In the following subchapters, we give a detailed overview of the game logic for both scenarios. This will cover various elements, such as game rules and reward systems (*R05*), user preferences and configurable settings (*R09*), in-game assistance (*R12*), and complexities of different levels (*R07*, *R08*).

Thumb Tango: Opposition Challenge

The following game scenario is implemented during this iteration. The rules are rather simple: balls in four different colors move along the lane, which splits into four lanes at a certain point. At the end of each lane, there is a box in specific color. The player's hands are projected on the screen, and they must perform a correct thumb opposition gesture to send a ball toward the box with a matching color (*R06*). Four fingers, i.e., index, middle, ring, and little finger, are assigned to lanes from right to left. The player should only use one hand that is previously selected in the configuration. Gesture detection script triggers an action only if the fingers are completely opposed. If this is the case, and the ball is sent to the correct box. The awarding system is following (*R05*): on correct gesture, the player is awarded 100 points. Additionally, players can earn extra points for notable achievements. For instance, achieving a streak by correctly assigning ten balls in a row rewards them 500 points. Moreover, completing a game without any misses results in an additional award of 10000 points for the players. Initially, we decided against assigning negative points on misses to avoid any negative impact on players' motivation. However, while evaluating the mockups with P3, they suggested that incorporating a penalty might enhance engagement and encourage sustained concentration throughout the game session. We finally decided to find a middle ground between insights from the literature review, which leaned towards avoiding punishment, and the patient's feedback. This resulted in implementing negative points but in smaller quantity compared to positive points, specifically 30. Furthermore, the player cannot lose or go into negative point values. The duration of the game is also specified in advance in the settings (*R09*). The timer is shown in the upper right corner to indicate how much time the player has. The importance of visual and auditory effects was discussed in previous chapters. We decided to include both in this game, as specified in *R13*. Three sound effects indicate either an achievement, a miss, or a game end. Regarding visual effects, we decided to implement a glow feature that illuminates a box when a player executes a gesture. This feature is designed to help players identify the selected box, especially if they miss it during the gesture performance. Moreover, at the game's end, the player is shown either an illuminating motivational message or, in case of a best score, a fireworks animation. During the interviews, P1 and P2 emphasized the importance of small motivational details in the application. After a game is finished, the player can replay the level (*R11*) or proceed to the next one. In the scope of this prototype, we implemented three levels, where the speed of the balls increases in each subsequent level (*R08*). A key aspect of any serious game for rehabilitation is personalization. Therefore, players can adjust settings according to their personal preferences and goals (*R09*). We already mentioned that the player can choose a controller hand. The gestures of a non-selected hand are not registered during the game. We also mentioned that the game duration can be customized from 2 to 10 minutes. It is important to note that the player can pause and replay a game at any point. Furthermore, players can toggle sound on and off according to their preferences. The last customizable aspect is the cognitive level. The player can decide if they want to have a cognitive challenge in their game or just want to practice physical tasks. For the game *"Thumb Tango"* we implemented four levels (*R07*):

- **Calm and Colorful** - *easy* - Balls of various colors appear, and the player has to decide where they belong. They should match the color of one of the four boxes.
- **Shuffle Challenge** - *medium* - Boxes swap positions every 10 seconds. The player has to keep an eye on the changing order and assign the balls to the correct box.
- **Color Reveal Challenge** - *medium/hard* - At the start, balls continuously change colors. The player must act quickly as the true colors are revealed before the assignment.
- **Memory Challenge** - *hard* - At the start of the challenge, the colors of the boxes are shown to the player. However, they will quickly turn grey. The players must rely on their memory to assign incoming balls to the correct color box.

The game logic is straightforward and does not require in-game assistance. However, for the memory challenge, our prototype offers a hint. While the intended gameplay involves players relying on their memory of the box colors' order, the grayed-out boxes revert to their original colors when a player presses a non-controlling hand and turn grey on the release (*R12*).

Mindful Tower: Pinch Perfect

This game scenario includes a time-based challenge to construct as many towers of colorful blocks as possible within a specified time frame. Before each tower construction, a detailed representation of the goal tower is showcased for ten seconds, challenging players to reconstruct it accurately. The players have to pay attention to the tower shape and block colors. The game environment consists of a pedestal with initial markers for blocks. The towers are constructed from a maximum of four blocks in a row, where the height goes up to ten blocks vertically. Levitating boxes, distinguished by four colors (red, green, blue, and yellow), are placed in the 3D space and can be reached by the controller hand. Players move these blocks by pinching them and accurately placing them in the corresponding marked positions (*R06*). The block is only moved with a pinch gesture, whereas all other interactions with blocks are ignored. To add an element of precision, we implemented a threshold concerning the marker, allowing a small permissible difference in coordinates for the block placement. Awarding mechanics is similar as in previous game (*R05*). If the player successfully places a block in the correct color on the correct position, they are awarded 100 points, and the block becomes fixed, preventing further movement. This decision is influenced by the feedback of P3, emphasizing the significance of focusing on single pinch movements to avoid potential negative impacts from tremors that could disrupt an entire tower. This game also incorporated additional points for a streak, i.e., ten correctly placed blocks (500 points), and if the player completes the game without misses (10000 points). The negative points are implemented as in *"Thumb Tango"*, and the player is assigned 30 negative points for each miss. The user interface displays the timer in the upper right corner, while the left upper corner contains both the current score and the count of placed blocks relative to the total number of blocks (e.g., 7/14). After successfully constructing a tower, players proceed to build a new one if there is time left. Sound and visual effects are integrated similarly to the first game, with effects for streaks, misses, and game completion (*R13*). The game completion modals are reused in both games and include motivational visual effects. Illumination highlights blocks when a player is pinching a cube to emphasize the correct gesture. Furthermore, the same can be paused (*R10*) and replayed (*R11*) at any point. We designed three levels, where the tower's complexity increases and the blocks' size decreases with each subsequent level (*R08*). Customization options include choosing a controller hand, toggling sound, and defining game duration (2 to 10 minutes) (*R09*). Nonetheless, *"Mindful Tower"* also encompasses two cognitive levels (*R07*):

- **Pinch Precision Challenge** - *easy* - The goal tower is initially shown in a large format for 10 seconds, followed by a smaller representation in the upper right corner during gameplay, emphasizing the physical challenge over memory.
- **Memory Challenge** - *hard* - After the initial display of the goal tower, the player must reconstruct the tower entirely from memory. For this challenge, a hint feature is implemented: pressing the non-controlling hand reveals the large representation of the tower, dismissing it on hand release.

The prototype was evaluated with P3. Due to the circumstances, an in-person meeting with patient P3 was not feasible. However, in the online session, we presented the game. Even though the patient couldn't actively engage in a play session to provide detailed feedback on the look and feel of our prototype, we demonstrated both games and collected their feedback. One recommendation for enhancement was the color selection for the user interface, addressing the requirement *NFR02*. Certain titles were challenging to read due to the chosen color scheme. Additionally, in the gameplay, players use their hands to interact with objects. To ensure usability and prevent unintended gesture detection captured by the Leap Motion camera, we implemented swipe left and right for pause (*R10*) and exit, replacing the typical button clicks. However, during the evaluation with P3, we noticed that a simple swipe was occasionally insufficient, since this gesture was incorrectly detected when moving blocks in the *"Mindful Tower"* game. Therefore, we decided to strengthen the rules for swipe detection in the next iteration: players are now required to swipe left or right with two fingers to execute the desired action. Just like the evaluation in Iteration 1, insights of P3 contributed to requirement refinement, i.e., answering research question 1.

4.2.3 Iteration 3

In the previous iteration, we implemented a high-fidelity prototype of a serious game for motor and cognitive training based on the requirements set defined in chapter 4.2.1. In the third iteration, a few prototype adjustments were made based on the evaluation with P3. Then, our prototype was finalized with achievements (*R05*), statistics (*R15*), and tutorials (*R03*). The expert interviews revealed that patients often have little or no motivation to perform their exercises. The research in the serious gaming field supports the assumption that incorporating gamification elements, such as achievements and statistics, can significantly increase a patient's motivation. Requirements *R05* and *R15* originated from research on existing games and interviews with P1 and P2. However, P3 also contributed during the prototype evaluation and open discussion in the later phases. Moreover, the significance of providing clear instructions was a point in discussions with P1, P2, and P3. To address this, we incorporated tutorials for each game within the prototype. P3 contributed constructive suggestions for improvement, so we decided to include a short video illustrating pinch and thumb opposition gestures in addition to the written game instructions and maximize the comprehensibility of the explanations (*R03*). This chapter describes the implementation details.

Achievements

The goal of the achievements is to keep players motivated. Achievements are one of the most common gamification elements, and we used them to establish requirement *R05*. The achievement system is implemented equally for both games. After finishing a game, key metrics such as the total number of games played and the overall training session duration are incremented, adding a sense of progression. Furthermore, we carefully designed various achievements. As an initial accomplishment, players receive a *"First Game Played"* badge after completing their intial game. Also, the highest score is displayed, together with the medal: *"Bronze"*, *"Silver"*, *"Gold"* and *"Platinum"*. The specific score requirements for earning these medals are tailored for each game. Detailed score ranges for each medal can be found in table 4.6.

Several achievements are designed to reward consecutive successes during gameplay. Players receive achievements for consistently and accurately placing blocks or assigning balls to the correct lane. Noteworthy milestones for these achievements are set at 5, 10, and 15 streaks, offering players recognition and additional motivation. Players are rewarded with an additional badge for completing a game without any misses. Perseverance and constant training are key for any rehabilitation, so in discussion with P2, we decided that

Medal	Thumb Tango	Mindful Tower
Platinum	Score $\geq$ 50000	Score $\geq$ 25000
Gold	35000 $\leq$ Score $<$ 50000	17000 $\leq$ Score $<$ 25000
Silver	20000 $\leq$ Score $<$ 350000	10000 $\leq$ Score $<$ 17000
Bronze	Score $<$ 20000	Score $<$ 10000

Table 4.6: Achievements: Medal scoring

an achievement milestone for every ten days of continuous training could contribute to the patient's engagement. The players receive an achievement badge if they played for 10, 20, and so on consecutive days.

Statistics

Statistics are implemented to provide personalized progress tracking (*R15*), serving both patients and occupational therapists. Primarily, the patient should be able to track their performance over time, focusing on levels and personalized settings. Across all statistical charts, we implemented filters - such as time intervals, hand preferences, level specifications, and cognitive challenge settings - to offer more comprehensive insights. On the other hand, a therapist should also be able to track patient's training sessions and performance and maybe adapt their training routines based on the results. A few simple statistics metrics are displayed in the statistics section header, including the total number of games played, the average accuracy of the right and left hand, and the date since the user started playing. Furthermore, we created two statistics charts that are the same for both game scenarios, and one additional chart was created for game *"Thumb Tango"*. Table 4.7 provides an overview of the implemented charts for respective games.

Additionally, we intended to design some form of communication channel between patients and therapists, especially during in-home rehabilitation. Therefore, we implemented a practical solution. In the context of our thesis and prototype, we decided on a straightforward functionality: the ability to download an Excel file with all the statistical data by clicking a button. The patient can use the file and share it with the therapist as needed. It should help therapists track patient's progress even when the application is not accessible. A simple Excel download would be sufficient for the current scope, with a potential for reevaluation in future work.

Chart Title	Description	Type
Precision Development	Shows how the average number of correctly performed opposition gestures per minute develops daily. The user can specify a time interval, exercising hand, game level, and cognitive challenge.	Line chart
Exercising Session Duration	Shows the overall daily exercising session duration in minutes, i.e. summarizes the duration of all the games played in one day. The user can specify a time interval and exercising hand.	Bar chart
Individual Finger Precision	Takes all incorrectly performed opposition gestures, i.e., wrongly assigned balls, into account and shows the percentage of misses for individual fingers.	Pie chart

(a) Thumb Tango

Chart Title	Description	Type
Precision Development	Shows how the average number of correctly placed blocks, i.e., performed pinch gestures, per minute develops daily. The user can specify a time interval, exercising hand, game level, and cognitive challenge.	Line chart
Exercising Session Duration	Shows the overall daily exercising session duration in minutes, i.e. summarizes the duration of all the games played in one day. The user can specify a time interval and exercising hand.	Bar chart

(b) Mindful Tower

Table 4.7: Statistics charts (*R15*)

Tutorials

Recognizing the significance of clear instructions, especially for patients with cognitive impairments, and since both games are based on engaging interactions, we finalized our prototype by implementing tutorials as specified in requirement *R03*. These tutorials consist of written instructions and a short video showing how to perform the gesture properly. The goal is to communicate essential aspects such as game rules, proper gesture performance, the awarding system, and in-game assistance. The tutorials appear at the beginning of the first level, ensuring that users receive guidance right when they are introduced to the game. However, the user has the flexibility to opt out of future displays after reviewing the instructions by checking the checkbox in the corner.

Finalized Prototype

The final prototype is illustrated with an example of user flow. Upon entry, the User is prompted with a login mask (*R01*). After successful login, the User is directed to a start screen, from which they can decide to engage in one of two games: *"Thumb Tango"* or *"Mindful Tower"* (*R04*). Both menus are depicted in figure 4.10.

Figure 4.10: Login and start screen

The User chooses to start with *"Thumb Tango"* and clicks the left button on the start screen, and they are forwarded to the game menu illustrated in figure 4.11, where they can either initiate a new game or resume a previous one if they paused their last session (*R10*). If the User wants to start a new game, they have the flexibility to always choose between three levels (*R08*), regardless of their prior performance and achievements. In that way, the User is allowed to tailor exercise sessions according to their preferences and requirements without restrictions from the application (*R11*). This time, the User has no unfinished sessions, so they initiate a new game. After selecting the third level from the *"Level Select"* modal, the game starts, and the User is prompted with a tutorial providing game instructions. After reading the instructions and watching a short video, the User clicks the opt-out checkbox to prevent the tutorial from future display and proceeds to the game (*R03*). These steps are shown in figure 4.11.

Figure 4.11: Thumb Tango: Menu and tutorial

The game details can be found in chapter 4.2.2 and will not be covered here. The User starts exercising with their right hand, but after a few minutes of playing, their hand starts to tremor, and they take a short break by swiping right and pausing the game session (*R10*). Later, the User decides to resume and finish the game. During the game, the User notices various game sound effects and box lightning effects that help them maintain focus (*R13*). The User notices a short bell sound a few times, indicating that they achieved two streaks of 10, for which they were awarded a new achievement badge (*R05*). Furthermore, the User achieved to beat their previous highest score, and is rewarded with a *"Gold"* achievement badge (*R05*). The *"Game Finish"* modal displays achieved score and a small firework effect for motivation (*R05*, *R13*, *R14*). The entire gameplay is presented in figure 4.12.

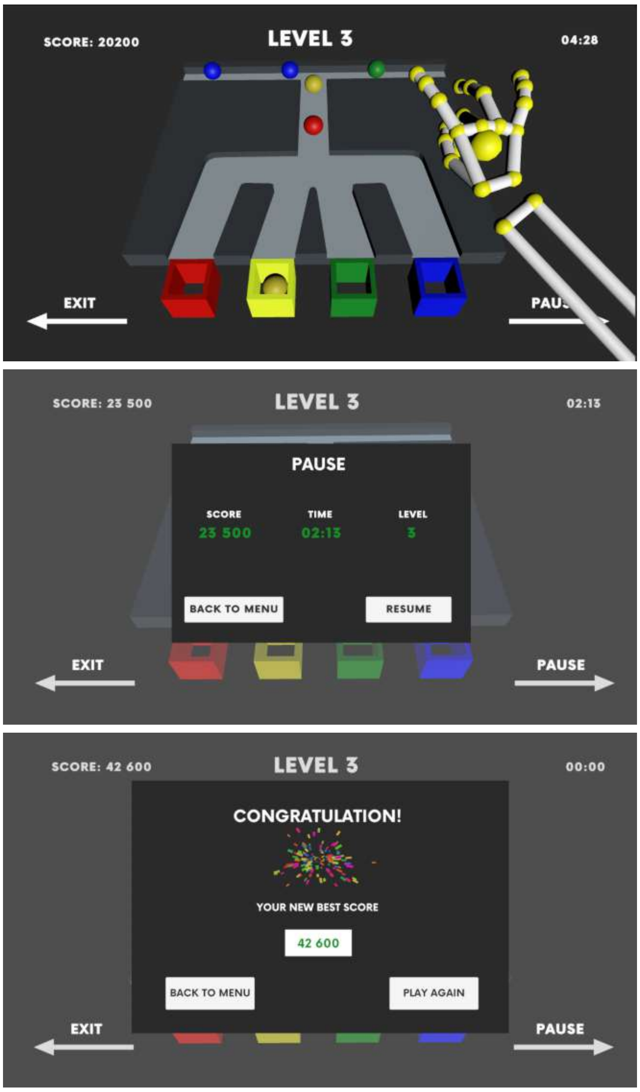


Figure 4.12: Thumb Tango: Opposition Challenge

From the *"Game Finish"* modal, the User returns to the game menu and adjusts the settings for future play sessions (*R09*). In the setting menu (figure 4.13), they switch cognitive challenge to *"Shuffle Challenge"* and change the game duration to 10 minutes. After saving the changes, the User checks new achievements in the statistics menu. As expected, new achievements are added to the achievement panel (*R05*), and the User also sees progress in the statistics graphs (*R15*). All achievements and statistics are presented in figure 4.14.

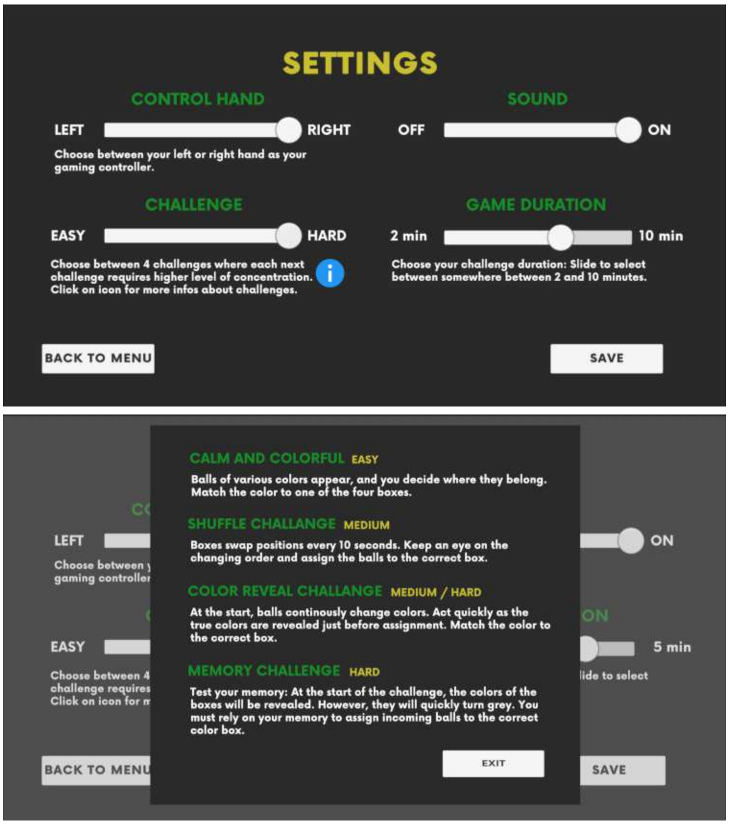


Figure 4.13: Thumb Tango: Settings

Figure 4.14: Thumb Tango: Achievements and statistics

After completing the first game, the User wants to have a short exercise by playing the second game. In the start screen (figure 4.10), they click on the *"Mindful Tower"* button. Last time, the User made some adjustments in settings, so now they want to check if all personalization aspects are set correctly. In the settings menu, the User switches back to the right hand as a controller hand, saves the changes, and returns to the game menu. Settings and main menu for *"Mindful Tower"* are depicted in figure 4.15.

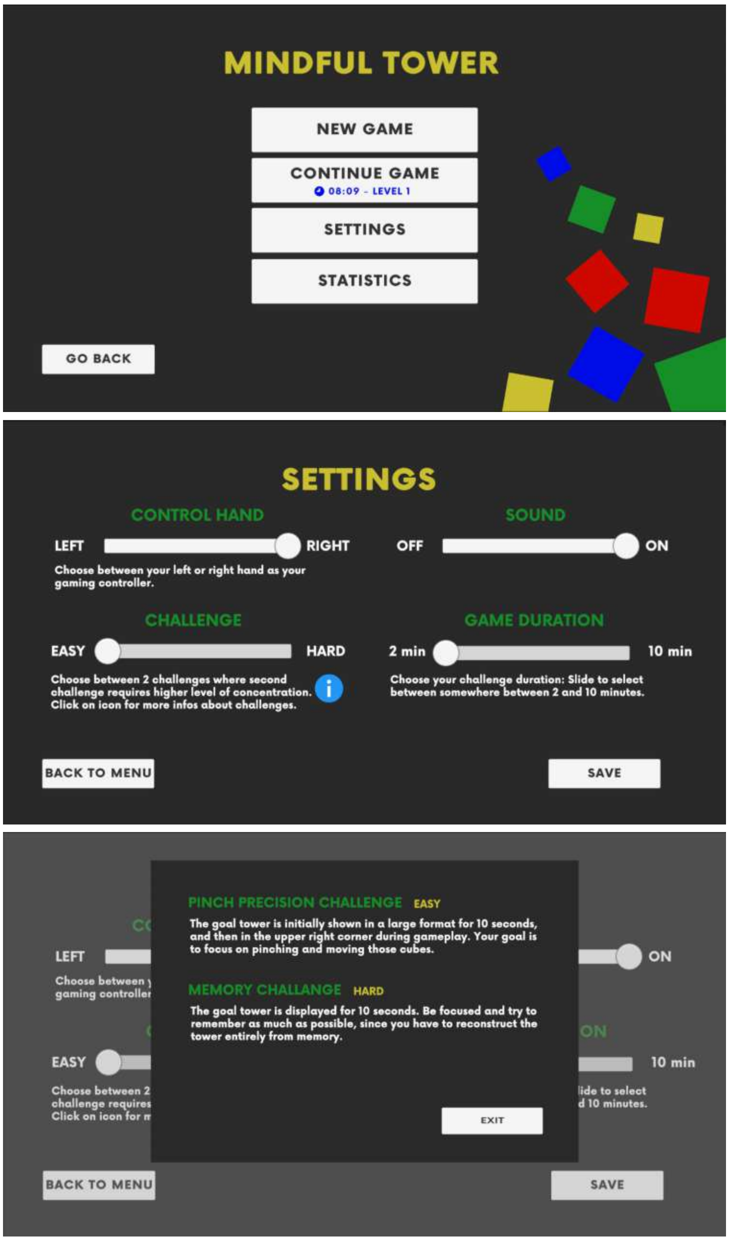


Figure 4.15: Mindful Tower: Menu and settings

This time, the User decides to resume the previous game. More about the game *"Mindful Tower"* is described in chapter 4.2.2. The User plays a *"Memory Challenge"* (*R07*), where they should build as many towers as possible from memory. However, at some point, the User reaches for a hint by pressing their left, i.e., a non-controlling hand, to see the goal tower once again (*R12*). After eight minutes, six built towers, and a few hints, the User completes the level. This time, the User couldn't outdo their previous best score, so the *"Game Finish"* now displays a score and a motivational message (figure 4.16). Finally, the User logs out from the application (*R02*) until the next exercise session (figure 4.18).

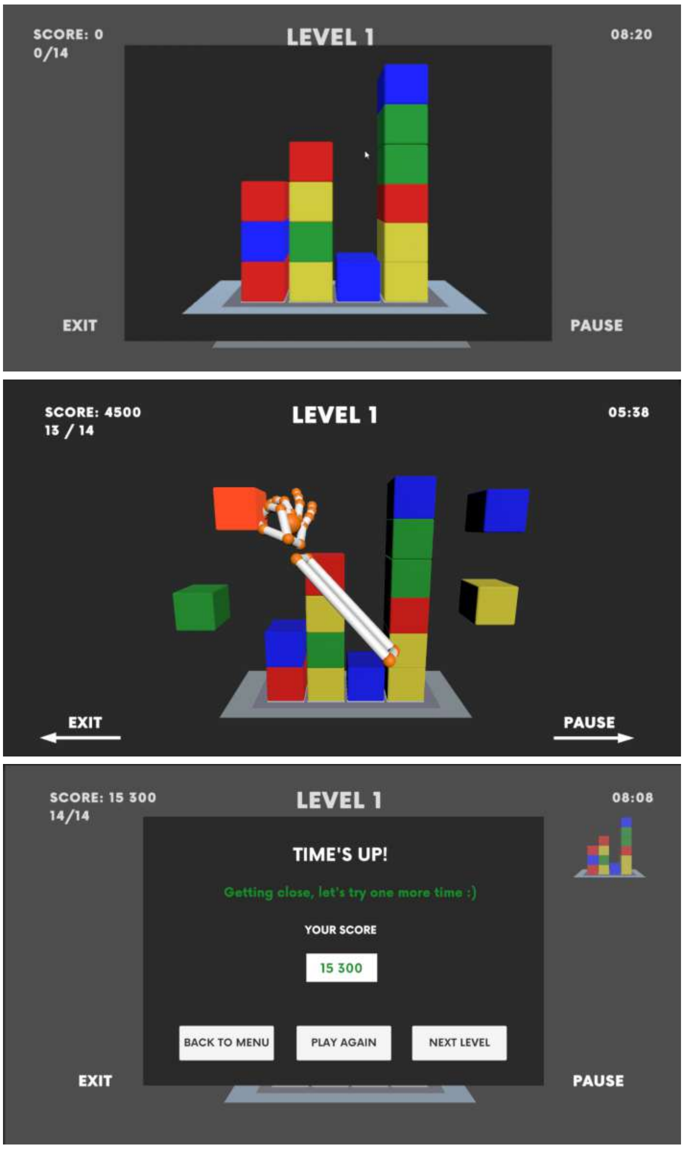


Figure 4.16: Mindful Tower: Pinch Perfect

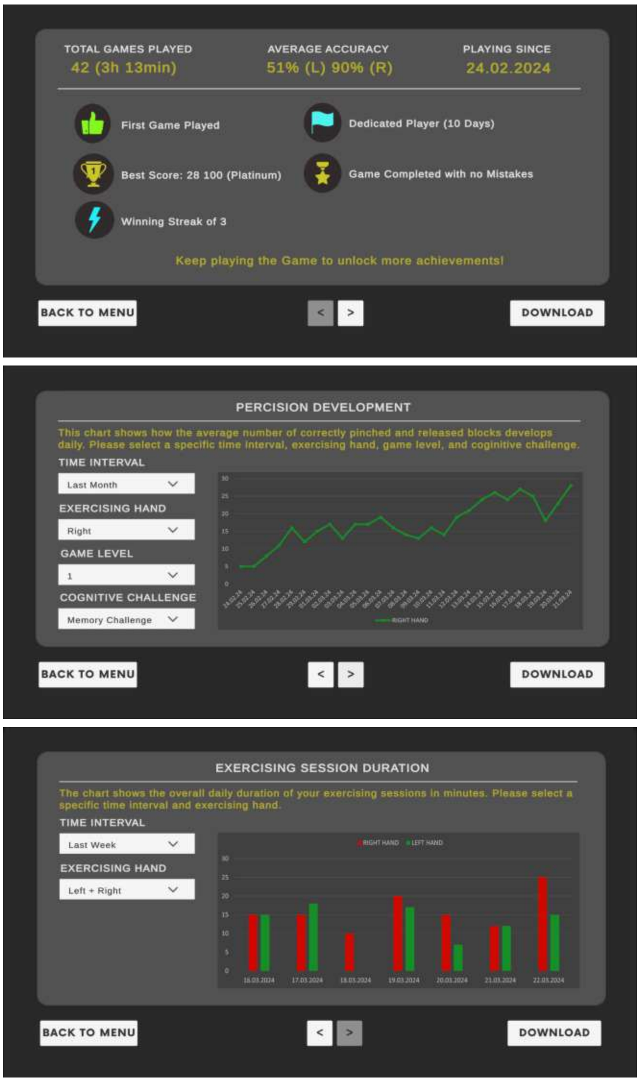


Figure 4.17: Mindful Tower: Achievements and statistics

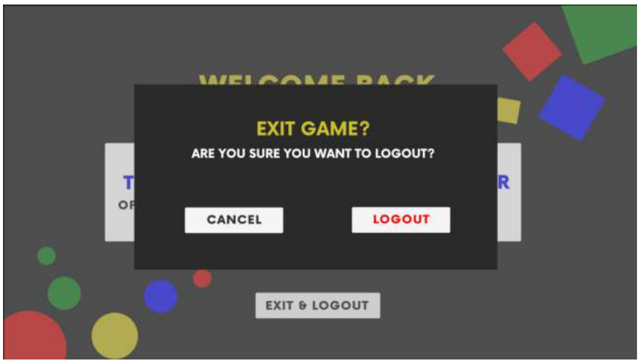


Figure 4.18: Logout

After completing our prototype, we wanted to get a feedback from the occupational therapist before presenting it to the volunteers in the evaluation phase. Therefore, we arranged an unstructured meeting with P2 to get their opinion on whether our solution satisfies the requirements for a serious game designed for upper limb and cognitive training of PwMS. During the meeting, we focused on various aspects, including game scenarios, the statistics section, UI design, among others. Furthermore, we discussed potential evolution of the prototype, a topic that will be discussed in detail in the final discussion chapter. Overall, P3 provided positive feedback, encouraging further research in this area. They said they would recommend such an application to their patients.

4.3 Evaluation

Considering that *RQ3* aims to identify if the developed serious game captivate and engage players, we decided to evaluate players' experience while playing. Game Experience Questionnaire was used as instrument to measure different factors of a player's engagement and skills in playing. On the other hand, we conducted usability testing to evaluate application overall usability, based on the System Usability Scale questionnaire. In this chapter we present you the results of the final prototype evaluation.

Five participants were involved in the evaluation process. We did not have access to a group of MS patients, therefore only one participant is suffering MS (P4), the rest of them are volunteers. The participants P4, P5, P6, P7, P8 engaged in the test session and completed the questionnaires, as presented in table 4.1. Although we had to apply convenience non-probability sampling for selecting participants due to the given circumstances (see chapter 4.1.1), we tried to keep the participant group diverse, considering criteria such as age, gender, and occupation. The participants are between 21 and 50 years old. P7 is a student while others are working. Participant P4 is a 32-year-old woman diagnosed with relapsing-remitting multiple sclerosis, experiencing mild symptoms that primarily affect her balance, upper limbs, and occasional fatigue. For each one of them we organized individual test session in a structured format. Initially, in the first 5 minutes the participants did not receive any instructions but were asked to familiarize themselves with the application. Then we told them to play each game for 10-15 minutes and encouraged them to adjust settings based on their preferences (*R09*), and to try different physical levels (*R08*) and cognitive challenges (*R07*). Our goal was to give special attention to application usability (*NFR02*) and whether the users understand the games. Therefore, P4, P5 and P6 were provided with a tutorial at beginning of each game, as described in *R03*. In contrast, P7 and P8 were instructed to play the games without prior guidance. The game *"Mindful Tower"* proved more intuitive, requiring less guidance for participants to understand the rules. On the other hand, *"Thumb Tango"* presented a slightly steeper learning curve, but after a few attempts and missed balls, they mastered the game rules. Eventually, all participants completely understood the goal of the games after carefully reading all instructions, including explanations of cognitive levels and gesture tasks, and details about the rewarding system.

Feedback from participants on the games was generally positive, expressing that both the application and the games themselves were intuitive and fun. However, a few of them (P4, P6, P7) expressed that they would like to have a larger selection of games to play. Furthermore, P6 suggested improvements to the achievement feature (*R05*), recommending in-game pop-ups and more detailed information on achievements in the tutorial. They said that when they are typically playing a video game, they like to have knowledge on possible achievements to create specific goals during gameplay. In the our prototype, only a limited number of achievements were presented in the tutorial, leaving room for improvement in providing a richer and more engaging achievement system. Moreover, P8 noticed that the application does not provide details about the levels. In the configuration, the player can read about different cognitive challenges, whereas the explanation of how the games change as the level progresses is not specified in settings, the level selection menu, or the tutorial. This is definitely something that we could improve. After the test session, all participants were asked to fill out two questionnaires: Game Experience Questionnaire and System Usability Scale.

4.3.1 Game Experience Questionnaire

The Game Experience Questionnaire (GEQ), including its variants, is a widely applied tool used by games researchers. Developed by IJsselsteijn et al. [93], this questionnaire is designed to measure participants' subjective experiences during digital gameplay. GEQ has a modular structure and consists of:

1. The **core module**, which is a heart of GEQ, that measures players experience across seven components, i.e., *challenge*, *competence*, *flow*, *immersion*, *tension*, as well as *positive* and *negative affect*. To ensure robust measure, 3-6 items were created for each factor, with high internal consistency.

2. The **social presence module**, which investigates psychological and behavioural engagement of player with co-players. This module is only relevant when a player interacts with other social entities, such as in-game characters, or engages with other players in online or co-located multiplayer settings.

3. The **post-game module** assesses how players felt after they had stopped playing. The goal of this module it to uncover any after effects, such as returning to reality, fatigue, pride or guilt.

For the purposes of our evaluation, we focused on the GEQ core module. The participants had to rate 33 items on the *Likert scale* ranging from 0 (*"not at all"*) to 4 (*"extremely"*). These ratings reflect their feelings while playing the games *"Thumb Tango"* and *"Mindful Tower"*. Both games were evaluated as a whole in a single questionnaire. In the following section, we present a complete list of core module items, where the original version of GEQ is provided in Appendix C.

1. I felt content.
2. I felt skilful.
3. I was interested in the game's story.
4. I thought it was fun.
5. I was fully occupied with the game.
6. I felt happy.
7. It gave me a bad mood.
8. I thought about other things.
9. I found it tiresome.
10. I felt competent.
11. I thought it was hard.
12. It was aesthetically pleasing.
13. I forgot everything around me.
14. I felt good.
15. I was good at it.
16. I felt bored.
17. I felt successful.
18. I felt imaginative.
19. I felt that I could explore things.
20. I enjoyed it.
21. I was fast at reaching the game's targets.
22. I felt annoyed.
23. I felt pressured.
24. I felt irritable.
25. I lost track of time.
26. I felt challenged.
27. I found it impressive.

28. I was deeply concentrated in the game.
29. I felt frustrated.
30. It felt like a rich experience.
31. I lost connection with the outside world.
32. I felt time pressure.

For a clear understanding of which item corresponds to which of the seven mentioned components, and for easier interpretation of our results, we provide an overview of components and their respective items in table 4.8.

Component	Items
Competence	2, 10, 15, 17, 21
Sensory and Imaginative Immersion	3, 12, 18, 19, 27, 30
Flow	5, 13, 25, 28, 31
Tension	22, 24, 29
Challenge	11, 23, 26, 32, 33
Negative affect	7, 8, 9, 16
Positive affect	1, 4, 6, 14, 20

Table 4.8: Game Experience Questionnaire: Components and their items

The scoring mechanism is rather simple: for each of the seven components, the score is determined by averaging the values of its corresponding items, as outlined in table 4.8. Similar to the individual items, the overall scores range from 0 to 4. The outcomes of the GEQ assessment for our serious games are detailed in table 4.9. The results distinguish between individual participants and the average score for every component.

Component	P4	P5	P6	P7	P8	Average
Competence	3.4	3.0	3.8	2.8	2.2	**3.04**
Sensory and Imaginative Immersion	3.0	2.8	3.17	2.83	2.0	**2.76**
Flow	3.2	3.0	2.0	3.0	2.4	**2.72**
Tension	0.0	0.33	0.33	0.0	0.0	**0.13**
Challenge	3.2	2.6	2.6	3.4	1.8	**2.72**
Negative affect	0.25	0.25	0.5	0.0	0.0	**0.2**
Positive affect	3.8	3.2	3.0	3.5	2.8	**3.26**

Table 4.9: Game Experience Questionnaire: Results

Interpreting the GEQ results provides valuable insights into participants' perceptions of the proposed serious game across different components. Our interpretation of the results for each component is as follows:

- **Competence** - participants generally rated this component with an average score of 3.04, which means that they felt *"fairly"* competent. This suggests that users felt a sense of accomplishment and proficiency while interacting with our serious games. We have to note that in order to get more reliable results, the competence factor should be assessed with MS patients since they are intended as end users, with the games being tailored with respect to the MS symptoms and potential impairments. However, P4 gave a score that goes in favor of the assumption that the designed games are suitable for MS patients.

- **Sensory and imaginative immersion** - this is a general, not MS-specific aspect of the game. Immersion received an overall score of 2.76. While participants evaluated immersive experience between *"moderate"* and *"fairly"* immersive, there might be room for improvement to enhance the sensory and imaginative aspects of the game.

- **Flow** - with an average score of 2.72, the flow component indicates that participants experienced a balanced and engaging flow during gameplay, suggesting that the games maintained an optimal level of challenge and skill for the participants. However, the score also indicates enhancement potential.

- **Tension** - with a score of 0.13, the lowest of all components, the GEQ results show that the games did not induce significant tension in participants. While some tension can contribute to engagement, it seems that the games were perceived as more relaxing than stressful. Considering that the application is intended for rehabilitation, this is considered a good score.

- **Challenge** - challenge received an average score of 2.72, indicating that participants found an appropriate level of challenge in the games. Balancing challenge is crucial for maintaining players' engagement and motivation, which is the primary goal and motivation for our thesis. Nevertheless, the evaluation with actual patients coping with challenges caused by MS might bring us more accurate results. Their unique circumstances might contribute to increased challenge levels in our games.
- **Negative affect** - this component scored low among participants, with an average of 0.2. This suggests that the games did not cause significant negative emotional responses, contributing to a positive overall experience.
- **Positive affect** - in contrast to the previous component, the positive affect component was assessed with the highest score from all, between *"fairly"* and *"extremely"*. The average score of 3.26 indicates that the participants generally experienced positive emotions during gameplay. This is a positive indicator that the game has the potential to generate enjoyment and satisfaction, which is the aim of this thesis.

Overall, the results show that the rating for each component was in the positive spectrum. Each rating contributes to answering research question 3, whether the proposed games engage players and positively impact ones motivation. However, further assessment with a group of MS patients would offer more comprehensive insights. Nevertheless, these findings provide a good overview of how is our serious game perceived and highlight areas for potential improvement in the future.

4.3.2 System Usability Scale

System Usability Scale (SUS) is a simple, reliable tool for measuring the usability of a system. This questionnaire is a *Likert scale* consisting of 10 questions, with five response options from *"strongly agree"* to *"strongly disagree"*. The original version of the SUS questionnaire is presented in Appendix C. The participants are asked to answer the following questions [8]:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.

8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

SUS yields a score in the range of 0 to 100. Even though interpreting scoring can be complex, based on research, a SUS score above 68 would be considered above average. Figure 4.19 illustrates a way for interpreting SUS results suggested by [94].

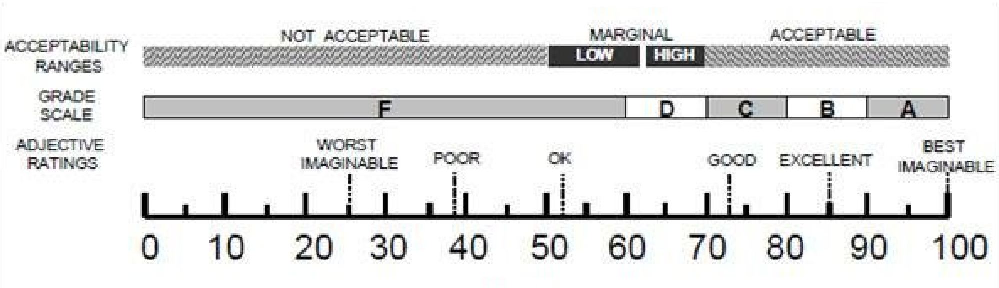


Figure 4.19: Grade rankings of System Usability Scale scores from [94]

If we look at the adjective ratings from figure 4.19, any score below 51 is considered *"unacceptable"*. A SUS score ranging from 52 to 72 is considered *"ok"*, between 73 and 84 is labeled as *"good"*, and a score exceeding 85 is considered *"excellent"*. If the application achieves a perfect score of 100, it is categorized as *"best imaginable"*, indicating that the system has no usability issues. The calculation process involves summarizing score contributions from each item, with each item's contribution ranging from 0 to 4. For items 1, 3, 5, 7, and 9, the score contribution is obtained by subtracting one from the scale position. For items 2, 4, 6, 8, and 10, the score contribution is derived by subtracting the scale position from 5. The overall value is calculated by multiplying the sum of scores by 2.5. The evaluation of our prototype through usability testing resulted in scores presented in table 4.10. The table contains individual scores for each participant and the average SUS score.

	P4	P5	P6	P7	P8	Average
Score	85.0	77.5	90.0	92.5	77.5	**84.5**

Table 4.10: System Usability Scale: Results

The provided scores indicate that P5 and P8 assessed the usability of our application as *"good"*, while the ratings from P4, P6, and P8 would classify it as *"excellent"*. The average score results in a SUS score of 84.5, which is considered a good score on the SUS scale according to [94].

CHAPTER 5

Discussion

At the beginning of this process, we identified three research questions as objectives. In the scope of this thesis, we designed and implemented a prototype for a serious game for the upper limb and cognitive rehabilitation of MS patients. Furthermore, the prototype was evaluated in a game session with volunteers, followed by two questionnaires, one addressing the gaming experience and the second the usability of the application. In this chapter, we discuss the research questions and their respective outcomes.

5.1 Research Question 1

What are the requirements for a serious game focused on cognitive and upper limb rehabilitation in individuals with multiple sclerosis, identified with specialists and MS patients?

The key challenge of any rehabilitation is maintaining motivation. MS patients are often involved in long-term therapy, targeting their cognitive skills and physical well-being. Many authors have explored alternative ways of exercising that could increase patient's engagement in their rehabilitation [37][38][40][78][79]. We also wanted to investigate this topic, so we started our thesis with a literature review discussed in chapter 2. In this phase we revealed various theories and studies that contributed to the initial requirements for a serious game for MS rehabilitation. We learned about the nature of MS and the symptoms and challenges that PwMS experience. We investigated different rehabilitation approaches, including both traditional and digital. Furthermore, we decided to apply a user-centered design approach, which included generating an understanding of the application context, specifying requirements, providing a design solution, and finally evaluating it, all in collaboration with MS patients and specialists. The literature review also included reviewing state of the art solutions in serious gaming for rehabilitation purposes covered in chapter 3. Based on the literature review findings, the initial requirements emerged and formed a basis for the ideas that were later presented to the specialists in one-to-one interviews.

Requirements specification started with the mentioned interviews. We used the same interview guide as a guideline for the questions for the neurologist and the occupational therapist. The interviews were semi-structured and lasted approximately one hour each, where one was held in person and the other via Skype. Our initial idea for the games was to keep focus on physical rehabilitation. However, both interviewees emphasized the requirement for cognitive tasks. Other common requirements that emerged included the need for customizable difficulty levels and settings, various hand gestures, simple and intuitive user interfaces, in-detail instructions, short exercise sessions, and engaging gameplay mechanics that motivate continuous participation. We came up with four game designs based on the interviews and previous theoretical research. Then, we presented paper sketches of these games to the occupational therapist and reviewed them in another meeting. Moreover, the precision of the Ultaleap tracking software concerning gestures selected for the games was practically evaluated. This step influenced our further decision making. Based on the sketches feedback and findings, we decided to proceed with two games: *"Thumb Tango"* and *"Mindful Tower"*. At this point, we decided to use personas as an assisting tool in requirements elicitation. We defined two personas, i.e., relevant stakeholders for our application: an MS patient and an occupational therapist, which were inspired by the previous interviews and meetings. Personas helped us to formally elicit 17 functional and 3 non-functional requirements for our serious game. Resulting requirements are presented in the tables 4.4 and 4.5. This was already the final, roughly defined set of requirements, in which we further developed and refined the details of the individual requirements in the following phases.

After the initial requirements were elicited, we wanted to get the opinion of our end users. Mockups were designed as part of the first iteration (see chapter 4.2.1) to elaborate the requirements for our serious game in a 30-minute unstructured meeting with an MS patient. After going through the application flow, we uncovered some oversights in our execution of the requirements. However, the requirement set did not change. In the next iterations, we implemented a high-fidelity prototype, where we evaluated the prototype and refined the requirements with the MS patient at the end of each iteration. Similarly to our first meeting, when we evaluated mockups, we usually revealed some improvement potential for individual requirements by keeping the requirements list as it was.

During the requirements specification and refinement, the emphasis was always on usability (*NFR02*), personalization (*R09*), physical (*R06*) and cognitive tasks (*R07*) game levels (*R08*), clear instructions (*R03*), and progress tracking (*R15*). The entire list of requirements can be found in chapter 4.2.1. The defined requirements concern the application, physical and cognitive tasks for two game scenarios, and gamification elements that are contained in the prototype. Initially, two additional requirements, namely leaderboard (*R16*) and chat (*R17*), were identified from the literature review and the interview with the neurologist. However, during the prioritization phase, we decided that these requirements fell outside the scope of this thesis. This might be considered a weak point of our prototype, as they are known to enhance the sense of community and overall motivation. These requirements can be reconsidered for future work, and we will address this aspect in the following chapter.

5.2 Research Question 2

Which traditional exercises should a game for fine motor training for PwMS imitate and are there any limitations of the Leap Motion Controller in translating these exercises into a game?

In addressing this research question, we started with a comprehensive exploration of traditional exercises suitable for fine motor training in PwMS. We based our findings on the literature review and insights from the occupational therapist. In the literature review, we investigated the stages of physical rehabilitation therapy in MS and which fine motor exercises target MS-specific impairments. On the other hand, the state of the art research explored which exercises are typically addressed in serious games that utilize Leap Motion Controller [38][78]. These exercises commonly involve interactions with smaller objects, such as pinching, moving, grabbing and releasing them, or performing specific movements with fingers. The findings from the literature review are covered in detail in chapters 2 and 3.

Our next goal was to summarize the acquired knowledge and, based on this, to organize an interview with an occupational therapist to obtain information about their practical experience working with patients with multiple sclerosis. The interview guide contained questions about the symptoms targeting hands and their rehabilitation approaches. On top of it, we encouraged the occupational therapist to freely share their experiences, ideas, and opinions outside of the question scope if they consider it valuable. They emphasized that the exercising approach highly depends on the patient, their goals and wishes. However, they said that commonly used exercises may be straightforward, like coin flipping, thumb-opposition exercises like turning a key with different fingers, hand gripping by squeezing a stress ball, pinching small objects like beads or buttons, or attempting to grab or grasp objects from a distance to counteract tremors and shakiness. On the other hand, an exercise session can include performing everyday tasks or activities, such as cutting and preparing food, playing cards, writing, or buttoning and zipping. In the scope of our thesis, we decided to focus on the simple hand gestures that can be accurately detected and interpreted by the Leap Motion Controller and to ensure that the patients can perform these repetitive exercises correctly in a potentially more enjoyable setting than during the traditional training sessions. At this point, we decided to proceed with four gestures: pinch, grab, grasp, and thumb-opposition, and to try to incorporate them into simple game tasks. To translate these exercises into a gamified context, we evaluated the capabilities and limitations of the Leap Motion Controller (version 1) used with Ultraleap Tracking Software (version 5.16.0) to detect hand gestures. Our evaluation centered on assessing the precision and user experience associated with performing hand gestures relevant to the identified traditional exercises. In this chapter, we summarize the findings relevant for this research question; the details can be found in chapter 4.1.3.

In the first setting, we used the Ultraleap *desktop* mode, where the controller is facing up from the table, and the hand movements are captured from below. Our findings uncovered several limitations in Leap Motion's performance, particularly concerning the precision of tracking the thumb opposition gesture in this mode. We had to contact Ultraleap's support to explore potential solutions, which revealed that they are aware of lower accuracy in the *desktop* mode. They offered us two suggestions: switch to Leap Motion 2 or use *head-mounted* mode, which we chose to do. This decision affected the overall usability of our application by requiring an additional piece of equipment, i.e., the need for players to wear the Leap Motion Controller on their heads to engage in gameplay. We made this trade-off to prioritize accurate tracking. Furthermore, providing players with more movement freedom could lead to a more immersive gaming experience. However, for future work, we could consider using a newer version of the Leap Motion Controller to asses the tracking accuracy improvements suggested by the official Ultraleap team. More on the topic will be discussed in the following chapter.

Additionally, we encountered some challenges distinguishing between grab and grasp gestures, making us reconsider the necessity for distinct game scenarios for each gesture. Interacting with large objects would not be a problem, but our game designs require interacting with smaller objects, which could lead to misinterpreting the gestures.

The last thing that raised usability concerns is interaction with objects in a 3D space without a VR headset, as players may experience difficulties in spatial awareness and object manipulation due to the lack of tangible spatial reference points. Therefore, we decided to design our games without unnecessary depth layers. In the case of our final games, *"Thumb Tango"* does not require direct interaction with objects, whereas in *"Mindful Tower"*, we changed our initial design where the boxed were scattered all around, to place them all at the same position along z-axis so the player can get a better feeling of their position.

Although we identified a few limitations, we still think that the Leap Motion Controller can be a useful tool for digital rehabilitation. In the scope of this thesis, we only implemented two games, i.e., exercises, meaning that there is more room to explore additional gestures and exercises to enhance the rehabilitation experience.

5.3 Research Question 3

Does the developed serious game captivate and engage players according to Game Experience Questionnaire?

Throughout this thesis, our primary goal was to design a serious game that would make the exercise sessions more enjoyable to increase patients' adherence to their rehabilitation while maintaining the efficiency of the traditional exercises. Research question 3 aims to determine if the developed serious game could contribute to the player's motivation. In order to answer this, we presented our final prototype and evaluated players' experiences during gameplay. A detailed discussion about the evaluation phase can be found in chapter 4.3. We could not access a larger number of actual patients to test the application. Hence, one MS patient and four independent volunteers were approached to participate in the evaluation. Each participant engaged in the individual test session, during which they familiarized themselves with the application and played both games for 10-15 minutes. Feedback was provided on the overall usability and understanding of the games. All participants expressed positive feedback in the open discussion after playing, stating that they found the games intuitive and enjoyable. A few suggested improvements, such as more details on the achievements and game instructions explaining levels. Furthermore, several participants expressed a desire for multiple game scenarios to prevent monotony from setting in with a single game. This consideration could impact the long-term engagement of MS patients and, therefore, should be considered in future work. However, in the scope of this thesis, we focus on a few exercises and investigate the potential of the Leap Motion Controller.

After the game sessions, we wanted to quantitatively measure how the end users perceived our serious game. Therefore, we asked all participants to answer the Game Experience Questionnaire (GEQ). GEQ is a standardized questionnaire used to measure player engagement and skills concerning seven components: *competence*, *immersion*, *flow*, *tension*, *challenge*, *negative* and *positive affect*. The participants assessed questions on a scale from 0 to 4, where each question was assigned to a single component. Finally, we collected the average score for each component. The results show that the participants generally rated competence (3.04), immersion (2.76), flow (2.72), and challenge (2.72) positively, indicating a sense of accomplishment, engagement, and positive emotions during gameplay. Two components addressing negative emotions, i.e., tension and negative affect, received low scores of 0.13 and 0.2, respectively. These scores suggest that the games do not cause significant negative feelings in players, contributing to the overall positive gaming experience. On the other hand, positive affect was rated with the highest score from all components, 3.26, which means that the games have the potential to positively impact players' motivation in the long run.

In conclusion, while the results indicate positive perceptions of the developed serious game, we must emphasize the importance of testing the application on actual MS patients to get more comprehensive insights. Some aspects of the game, such as challenge and competence, could be differently perceived by people suffering cognitive or upper limb impairments. From our results, we can see that the assessment of one MS patient does not significantly deviate from other participants. However, MS does not equally affect all people, and the symptoms can drastically vary depending on different factors, such as the type and stage of the disease. Further assessment with a larger group of MS patients over a longer time period would be necessary for reliably evaluating if the game is suitable for MS rehabilitation and whether it positively affects motivation. We will discuss potential approaches in the outlook chapter. Nevertheless, our findings show that the serious game is perceived as engaging, and provide a solid foundation for future game improvements and iterations to better meet patient' needs and preferences.

CHAPTER 6

Conclusion and Outlook

This thesis aimed to design a serious game for the rehabilitation of multiple sclerosis patients. The game should allow patients to exercise fine motor and cognitive skills by providing a tool to guide their everyday exercise sessions. Additionally, the application should ensure high personalization and statistics for long-term progress tracking. This chapter summarizes the results of this thesis. We also give an outlook into the future, which describes possible continuations of this work.

6.1 Conclusion

This thesis proposes a serious game utilizing a Leap Motion Controller for upper limb and cognitive rehabilitation for multiple sclerosis. The research shows a growing trend of digital rehabilitation for different conditions, ranging from acute injuries to chronic neurological diseases. The questionnaire we conducted with MS patients showed interest in incorporating serious gaming into their everyday exercise sessions. Moreover, it is evident from the interviews with specialists that they already use different games in therapy and would most likely suggest a digital approach as an assisting tool to traditional rehabilitation. In their opinion, patients are usually open to alternative approaches and would benefit from being able to perform their rehabilitation exercises digitally. Therefore, we designed an application that integrates gamification elements to encourage training sessions that patients enjoy more than repetitive exercises.

Our solution includes two game scenarios: *"Thumb Tango: Opposition Challenge"* and *"Mindful Tower: Pinch Perfect"*. Each game focuses on a fine motor physical task, with customizable cognitive tasks that challenge the player's concentration and memory. The most significant feature of our application is the flexibility of the proposed games to define a specific therapy approach that is easy to customize to the patient's particularities. Additionally, we would like to emphasize the importance of integrated long-term statistics.

Tracking an individual's progress over time is beneficial to both the patient and the occupational therapist. Another relevant characteristic, in addition to the capability to exercise, is the simplicity of use, which makes it suitable for in-home rehabilitation without necessary assistance.

The usability of digital applications used for health purposes is essential as it enables patients to use these applications independently. Furthermore, enjoyment is the most important since it directly influences player motivation and long-term adherence in therapy. Therefore, to evaluate whether the application has the potential to impart in the real world, five participants evaluated our prototype in a test session followed by a usability and game experience questionnaire.

6.2 Outlook

The outcomes of the diploma thesis highlight the potential of our serious game. Nonetheless, during different stages of this process, we experienced a few obstacles and identified improvement potential for our application. As a conclusion of this thesis, we discuss future work suggestions to address these limitations and further enhance the effectiveness and usability of our serious game.

We evaluated the final prototype in a gaming session with the help of the Game Experience Questionnaire. Based on the evaluated gaming experience, the use of the LMC based digital games for rehabilitation purposes has been favorably accepted. However, a few factors need to be considered when interpreting these results. Firstly, the number of participants and the lack of MS patients in the sample group are not sufficiently representative to give validity to the obtained results. Secondly, to get reliable results, the participants would have to use the application for a prolonged period because a single session is insufficient. One session is an encouraging indicator that the participants have understood and accepted the game. However, their current perception might depend on their mood or the fact that the games are new and interesting. In order to evaluate if this serious game contributes to the improvement of the health condition of MS patients and if this game generates greater motivation and endurance during training than traditional rehabilitation, we suggest a control group trial with MS patients. The trial would include randomizing MS patients into two groups: one that uses our serious game and one that does not. Baseline and post-intervention assessments should be conducted to measure outcomes, and data should be analyzed to determine game effectiveness.

Furthermore, with Leap Motion Controller 1, we had significant problems with the accuracy of the tracking results in the *desktop* mode. Therefore, we had to switch to the *head-mounted* mode offered by Ultraleap's Hand Tracking Software. This change enabled us to keep the initial game designs. The official Ultraleap support personnel indicated that the Leap Motion Controller 2 release significantly improved the tracking accuracy.

Hence, we would like to test these improvements in the next prototyping iteration, adjust our application, and revert to the *desktop* mode.

While researching the Leap Motion Controller, we discovered Ultraleap's TouchFree interface. The TouchFree application runs invisibly on top of any existing screen and user interface. It detects a user's hand in mid-air and converts it to an on-screen cursor [95]. This feature can be integrated into the Unity codebase, and it could be interesting to investigate it in the context of our serious game. We could improve the immersive experience of our application by implementing touchless control over the user interfaces. This can be applied to menus, buttons, sliders, and other interactive elements in applications and games. Moreover, we could explore its capabilities with respect to exercises and activities in upper limbs therapy, such as drawing or writing, that could be translated into a game.

The serious games implemented in this work are a versatile tool in rehabilitation processes since different functional and cognitive impairments can be treated according to the configuration defined by the patient or the therapist. However, multiple evaluation participants expressed that they would like to have more games. From the interview with the occupational therapist, we also saw that they use many exercises in their practice, even in a single session. Addressing participants' desire for more game scenarios could enhance long-term engagement. Future iterations could include additional exercises targeting different fine motor skills, such as precision grasping or finger dexterity exercises.

Another aspect of future work should be refining the user interface and feedback mechanisms. Incorporating participant evaluation feedback, particularly regarding the clarity of instructions and the presentation of achievements, could improve the overall user experience. This may involve redesigning tutorials, providing real-time feedback during gameplay, and enhancing the achievement system. Another idea is to implement adjustable volume and font size in the settings to satisfy the patient's individual needs, especially for those with visual disturbances. Furthermore, we would integrate social features that were presented in the requirements elicitation, namely leaderboard and chat, but were considered out of scope in the iterations of this thesis. The research shows that social support enhances motivation by fostering a sense of community among players and encouraging competition.

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Appendix A

Interview Guide - Translated to English

Date:
Name:
Age:
Job title:

1. How do you currently approach the rehabilitation process for patients with multiple sclerosis? Are there any limitations?

2. In your experience, how engaged are patients in rehabilitation? What factors contribute to their decision-making with regard to rehabilitation?

3. What are the most common cognitive challenges that patients with multiple sclerosis face and how often do these occur?

4. Are there any specific cognitive skills or areas that you think are particularly important to target during cognitive rehabilitation?

5. Are there any traditional games or activities that you have found to be effective for improving cognitive function?

6. What are the most common upper limb (hands and fingers) symptoms that patients with MS experience and how often do these symptoms occur?

7. What traditional rehabilitation methods and exercises are typically used to address these symptoms in patients with MS?

8. In your experience, how much do the severity levels of symptoms (both physical and cognitive) vary among MS patients? Are there certain factors that contribute to these differences?

9. Are you familiar with Serious Games?

10. In your opinion, how important is patient motivation in rehabilitation? Do you think a serious game could improve patients' engagement and motivation?

[Presentation of our idea for Serious Game]

11. Do you think patients would be interested in playing this type of game? 12. What do you think cognitive games for MS patients should do differently than normal cognitive games (e.g., chess, Sudoku, puzzles)?

13. Do you believe that games that combine cognitive and physical tasks could be beneficial for MS patients? In your opinion, is it feasible to incorporate both types of tasks in a game or is it too difficult for patients? What potential benefits and challenges do you see in such games?

14. What features do you think would be most beneficial and important for patients with MS in a serious game for rehabilitation?

a. Are there any MS-specific limitations that need to be considered in the design of the game (e.g., colours, shapes, and sizes due to visual impairments)?

b. Do you think patients could benefit from a high degree of personalization of the game (e.g. different levels for cognitive and physical tasks)?

c. Do you have any ideas about what kind of feedback and challenge might be most motivating for players?

15. Are there any concerns you have regarding the use of a serious game in rehabilitation for patients with MS?

16. Are there any specific outcomes or measures of success you would like to see from a serious game for rehabilitation in patients with MS?

17. What do you think about the idea?

[Open discussion]

Interview Guide - Original

Datum:
Name:
Alter:
Berufsbezeichnung:

1. Wie gehen Sie derzeit den Rehabilitationsprozess für Patienten mit MS an? Gibt es irgendwelche Beschränkungen?

2. Wie groß ist Ihrer Erfahrung nach das Engagement der Patienten in der Rehabilitation? Welche Faktoren tragen zu ihrer Entscheidungsfindung in Bezug auf die Rehabilitation bei?

3. Welche sind die häufigsten kognitiven Herausforderungen, mit denen Patienten mit Multipler Sklerose konfrontiert sind, und wie häufig treten diese auf?

4. Gibt es bestimmte kognitive Fähigkeiten oder Bereiche, die Ihrer Meinung nach bei der kognitiven Rehabilitation besonders berücksichtigt werden sollten?

5. Gibt es traditionelle Spiele oder Aktivitäten, die sich Ihrer Meinung nach zur Verbesserung der kognitiven Funktionen als wirksam erwiesen haben?

6. Welche Symptome der oberen Extremitäten (Hände und Finger) treten bei MS-Patienten am häufigsten auf und wie oft treten diese Symptome auf?

7. Welche traditionellen Rehabilitationsmethoden und Übungen werden üblicherweise eingesetzt, um diese Symptome bei MS-Patienten zu behandeln?

8. Wie stark variiert Ihrer Erfahrung nach der Schweregrad der Symptome (sowohl körperlich als auch kognitiv) bei MS-Patienten? Gibt es bestimmte Faktoren, die zu diesen Unterschieden beitragen?

9. Kennen Sie Serious Games?

10. Wie wichtig ist Ihrer Erfahrung nach die Motivation der Patienten in der Rehabilitation? Glauben Sie, dass ein Serious Game das Engagement der Patienten verbessern kann?

[Erläuterung der Idee für unseres Serious Game]

11. Glauben Sie, dass die Patienten an dieser Art von Spiel interessiert wären?

12. Was sollten Ihrer Meinung nach kognitive Spiele für MS-Patienten anders machen als normale kognitive Spiele (z. B. Schach, Sudoku, Puzzles)?

13. Glauben Sie, dass Spiele, die kognitive und körperliche Aufgaben kombinieren, für MS-Patienten von Vorteil sein könnten? Ist es Ihrer Meinung nach machbar, beide Arten von Aufgaben in ein Spiel einzubauen, oder ist es zu schwierig für die Patienten? Welche potenziellen Vorteile und Herausforderungen sehen Sie in solchen Spielen?

14. Welche Features wären Ihrer Meinung nach für Patienten mit MS in einem Serious Game für die Rehabilitation wichtig und am nützlichsten?

a. Gibt es irgendwelche MS-spezifischen Einschränkungen, die beim Design des Spiels berücksichtigt werden müssen (z. B. Farben, Formen und Größen aufgrund von Sehstörungen)?

b. Glauben Sie, dass Patienten von einem hohen Maß an Personalisierung des Spiels profitieren könnten (verschiedene Levels für kognitive und physische Aufgaben)?

c. Haben Sie eine Idee, welche Art von Feedback und Challenges für die Spieler am motivierendsten sein könnte?

15. Haben Sie Bedenken hinsichtlich des Einsatzes eines Serious Game in der Rehabilitation von Patienten mit MS?

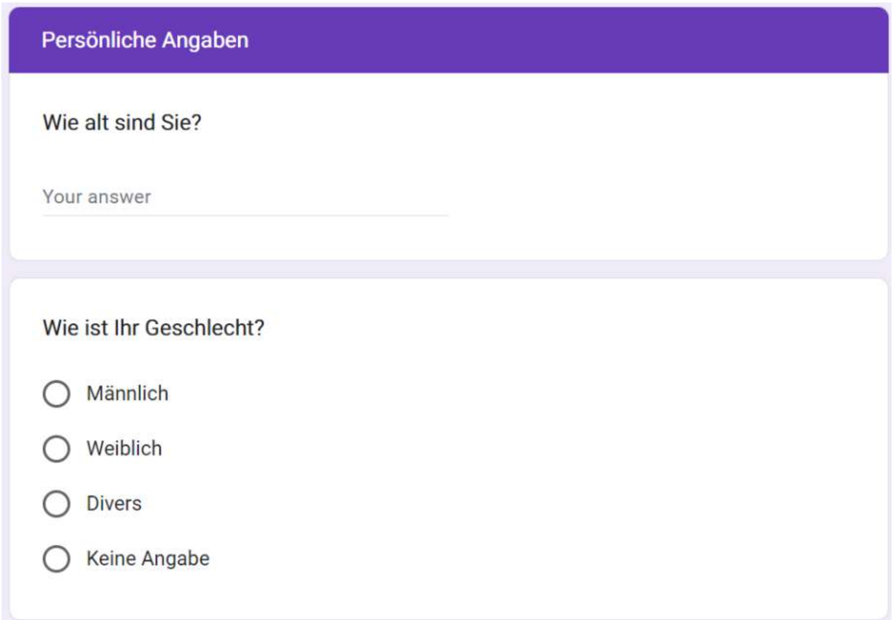
16. Gibt es bestimmte Ergebnisse oder Erfolgsmessungen, die Sie sich von einem Serious Game für die Rehabilitation von MS-Patienten wünschen würden?

17. Was denken Sie von der Idee?

[Offene Diskussion und Ideen]

Appendix B

Questionnaire - Original



Persönliche Angaben

Wie alt sind Sie?

Your answer

Wie ist Ihr Geschlecht?

- Männlich
- Weiblich
- Divers
- Keine Angabe

MS-bezogene Fragen

Wie würden Sie das Ausmaß der folgenden Symptome in Ihren oberen Extremitäten bewerten

1 - Keine Symptome
2 - Leicht
3 - Mäßig
4 - Schwer

Haben Sie Schwächegefühle?

1 ○ 2 ○ 3 ○ 4 ○

Wenn ja, wo?

○ Rechter Arm
○ Linker Arm
○ Beide

Haben Sie Spasmen (Muskelverspannungen)?

1 ○ 2 ○ 3 ○ 4 ○

Wenn ja, wo?

- ○ Rechter Arm
- ○ Linker Arm
- ○ Beide

Leiden Sie unter Zittern oder Tremor?

1	2	3	4
○	○	○	○

Wenn ja, wo?

- ○ Rechter Arm
- ○ Linker Arm
- ○ Beide

Haben Sie Empfindungsprobleme (Schmerzen, Taubheitsgefühl, Kribbeln, verstärkter Tastsinn)?

1	2	3	4
○	○	○	○

Wenn ja, bitte unten einkreisen:

Schmerzen

- ◯ Rechter Arm
- ◯ Linker Arm
- ◯ Beide

Taubheitsgefühl

- ◯ Rechter Arm
- ◯ Linker Arm
- ◯ Beide

Kribbeln

- ◯ Rechter Arm
- ◯ Linker Arm
- ◯ Beide

Verstärkter Tastsinn

- ◯ Rechter Arm
- ◯ Linker Arm
- ◯ Beide

Haben Sie Schwierigkeiten mit dem Gedächtnis?

- ◯ 1 - Nein
- ◯ 2 - Sie müssen zusätzliche Maßnahmen ergreifen, um Zeitpläne und Termine einzuhalten
- ◯ 3 - Sie haben Schwierigkeiten beim Multitasking, bei der Problemlösung und beim Kurzzeitgedächtnis
- ◯ 4 - Sie sind nicht in der Lage, Finanzen, Termine oder Medikamente zu verwalten

Rehabilitation

Sind Sie derzeit in der körperlichen Rehabilitation für die oberen Extremitäten tätig?

- ◯ Ja
- ◯ Nein

In welchem Rahmen nehmen Sie an Rehabilitationstrainings teil? (Sie können mehrere Antworten auswählen)

- ☐ Rehabilitationszentrum/Krankenhaus
- ☐ Heim
- ☐ Other: ____________

Wenn Sie nur an formellen Rehabilitationstraining teilnehmen (z. B. unter Aufsicht in einem Rehabilitationszentrum), wie zuversichtlich sind Sie, dass Sie Ihre Rehabilitationsübungen und -aktivitäten für die oberen Extremitäten selbständig fortsetzen können?

	1	2	3	4	5	
Überhaupt nicht selbstsicher	◯	◯	◯	◯	◯	Sehr selbstsicher

Haben Sie in der Vergangenheit an einer Rehabilitationsmaßnahme für Ihre oberen Extremitäten teilgenommen?

- ◯ Ja
- ◯ Nein

Wenn ja, welche Art von Rehabilitation haben Sie erhalten?

- ☐ Mobility Training (z. B. Flexion/Extension des Handgelenks, Flexion/Extension der Finger, Flexion/Extension der Schulter)
- ☐ Kräftigungs- und Widerstandsübungen (z. B. Griffstärkung, Schulterpresse, Handgelenkscurls)
- ☐ Training der Feinmotorik (z. B. Aktivitäten an der Stecktafel, Aufheben von Münzen, Schreiben und Zeichnen)
- ☐ Aufgabenspezifisches Training (z. B. Gläser öffnen, nach Gegenständen greifen oder Werkzeuge benutzen)
- ☐ Virtual Reality Training
- ☐ Other: ____________

Bitte antworten Sie, wenn Sie eine der folgenden Technologien in Ihrer Rehabilitation verwendet haben. (Sie können mehrere Antworten auswählen)

- ☐ Ich habe noch nie eine unterstützende Technologie in meiner Rehabilitation verwendet
- ☐ App auf dem Telefon, Laptop oder Tablet
- ☐ Am Körper zu tragende Geräte, z. B. FitBit, Smart Watch, Schrittzähler
- ☐ Sensorbasierte Technologien für die körperliche Rehabilitation, z. B. Kinect, Leap Motion Controller
- ☐ Other: ____________

Wenn ja, wie würden Sie Ihre Erfahrungen mit den verwendeten Technologien bewerten?

	1	2	3	4	5	
Sehr unzufrieden	○	○	○	○	○	Sehr zufrieden

Wenn Sie derzeit an einer Rehabilitationsmaßnahme für die oberen Extremitäten teilnehmen, wie oft haben Sie Ihre Trainingseinheiten? Bitte geben Sie die Anzahl der Trainingseinheiten pro Woche an.

- ○ weniger als 1
- ○ 1-2
- ○ 3-4
- ○ 5-7
- ○ mehr als 7

Wie lange dauern die Reha-Trainingseinheiten durchschnittlich (in Minuten)?

Your answer

Bewerten Sie, ob Sie seit Beginn der Rehabilitation eine Verbesserung der Funktion Ihrer oberen Extremitäten festgestellt haben.

	1	2	3	4	5	
Keine Verbesserung	○	○	○	○	○	Herausragende Verbesserung

Serious Games

Ist Ihnen der Begriff "Serious Game" bekannt?

- ◯ Ja
- ◯ Nein

Haben Sie jemals Serious Games als unterstützendes Hilfsmittel in Ihrer Rehabilitation verwendet?

- ◯ Ja
- ◯ Nein

Falls ja, welche?

Your answer

Würden Sie in Erwägung ziehen, ein Serious Game in Ihr tägliches Rehabilitationstraining aufzunehmen?

	1	2	3	4	5	
Nein	◯	◯	◯	◯	◯	Definitiv ja

Glauben Sie, dass die Verwendung eines Serious Game mehr Spaß macht als herkömmliche Formen der körperlichen Rehabilitation?

- ◯ Ja
- ◯ Nein
- ◯ Bin nicht sicher

Welche Faktoren würden Ihre Entscheidung für den Einsatz von Serious Games in Ihrer körperlichen Rehabilitation stark beeinflussen? (Sie können mehrere Antworten auswählen)

- ☐ Das Spiel sollte so gestaltet sein, dass es Spaß macht und zum Spielen anregt
- ☐ Das Spiel sollte für ein breites Spektrum von Benutzern zugänglich sein
- ☐ Das Spiel sollte geeignete Schwierigkeitsgrade enthalten, um den Spieler ausreichend zu fordern und ihn bei der Stange zu halten
- ☐ Das Spiel sollte klare und einfach zu befolgende Anweisungen für jede Übung oder Bewegung enthalten
- ☐ Die Ziele des Spiels sollten dem Spieler zu Beginn des Spiels klar mitgeteilt werden
- ☐ Das Spiel sollte Funktionen enthalten, die die Motivation des Spielers aufrechterhalten, z. B. Fortschrittskontrolle, Belohnungen oder soziale Funktionen, die es dem Spieler ermöglichen, sich mit anderen zu messen oder zusammenzuarbeiten
- ☐ Das Spiel sollte eine Vielzahl von Übungen und Bewegungen enthalten, um Langeweile zu vermeiden und sicherzustellen, dass der Spieler an verschiedenen Körperbereichen arbeitet
- ☐ Das Spiel sollte mit den Geräten und Technologien kompatibel sein, zu denen der Spieler Zugang hat, z. B. mit Smartphones, Tablets oder Virtual-Reality-Headsets
- ☐ Other: ____________________

Haben Sie Bedenken hinsichtlich der Sicherheit oder Wirksamkeit von Serious Games als Mittel zur körperlichen Rehabilitation?

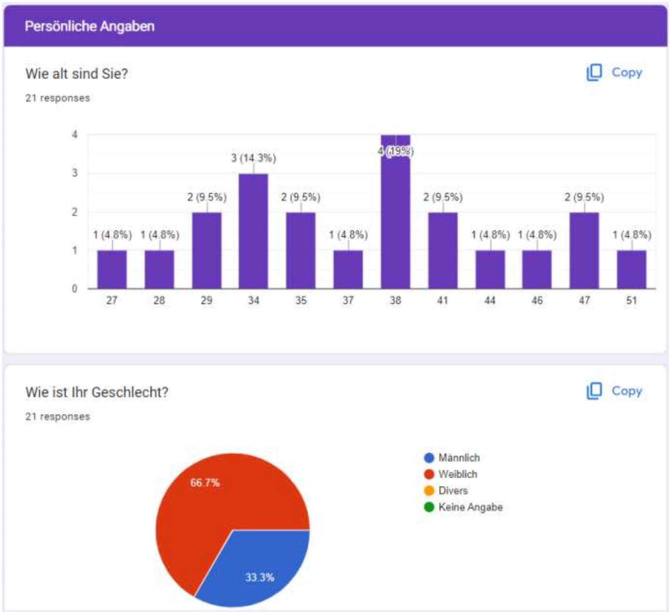
- ◯ Ja
- ◯ Nein
- ◯ Bin nicht sicher

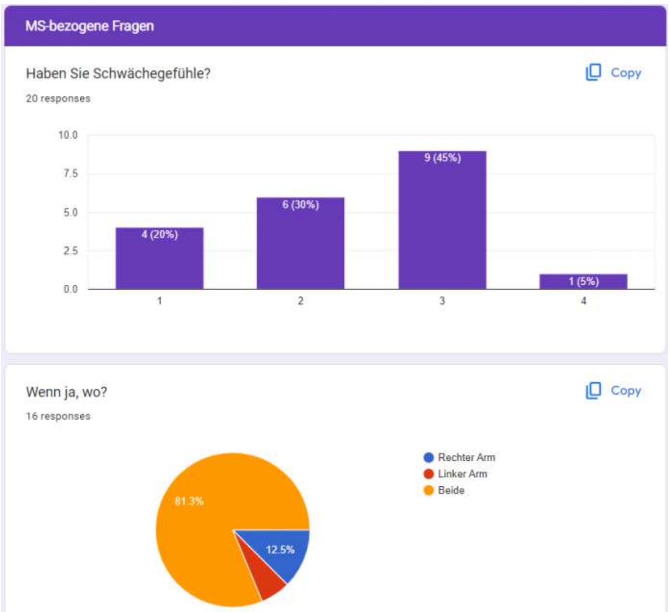
Was halten Sie von dem folgenden Workflow?

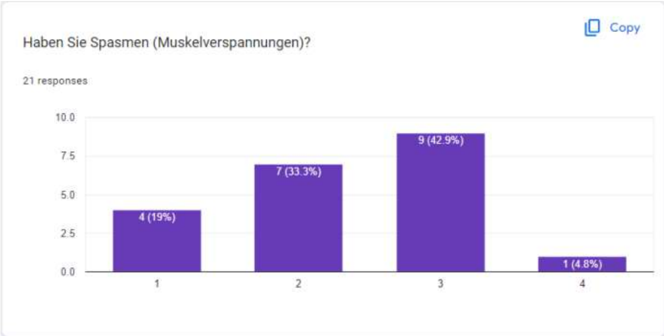
1. Der Therapeut/Arzt erstellt ein bestimmtes Level/eine bestimmte Übung im Spiel
2. Das Level/die Übung wird Ihnen zugewiesen
3. Sie spielen das Spiel/machen die Übung
4. Die Ergebnisse (z.B. Spielzeit) der Übungen werden an den Therapeuten/Arzt übermittelt
5. Der Therapeut/Arzt kann die Levels/Übungen anhand der Ergebnisse anpassen

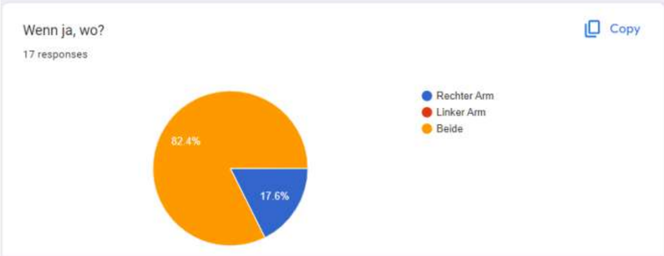
Your answer

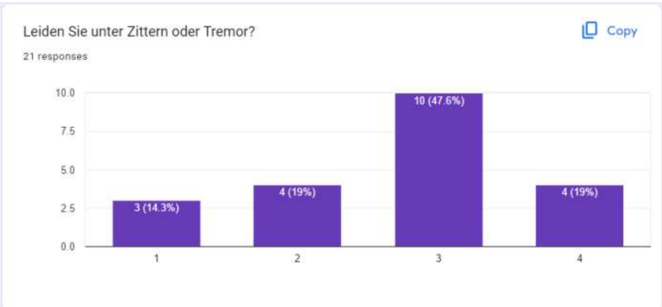
Questionnaire - Results

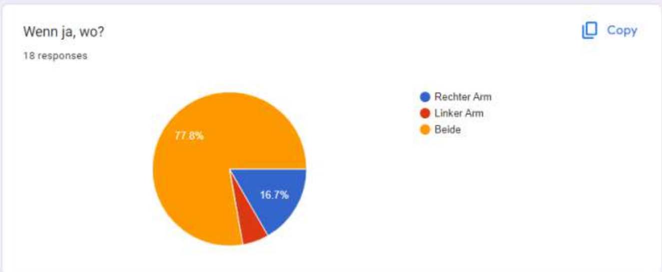




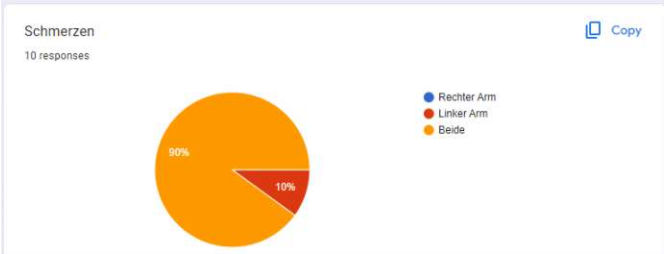

Haben Sie Spasmen (Muskelverspannungen)?
21 responses
Copy
10.0
7.5
5.0
2.5
0.0
4 (19%)
7 (33.3%)
9 (42.9%)
1 (4.8%)
1
2
3
4

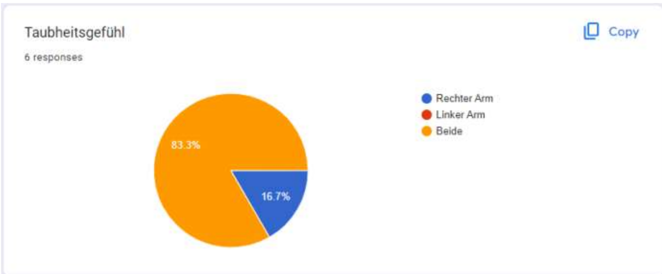

Wenn ja, wo?
17 responses
Copy
Rechter Arm
Linker Arm
Beide
82.4%
17.6%

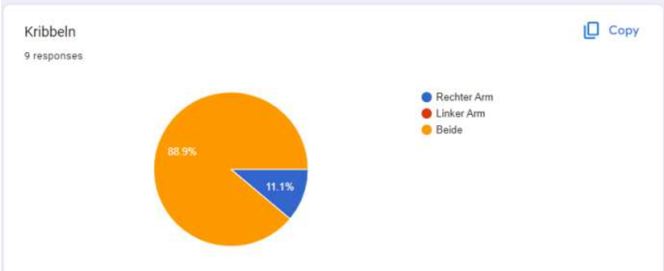

Leiden Sie unter Zittern oder Tremor?
21 responses
Copy
10.0
7.5
5.0
2.5
0.0
3 (14.3%)
4 (19%)
10 (47.6%)
4 (19%)
1
2
3
4

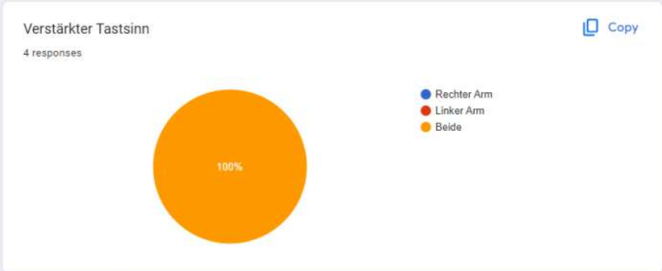

Wenn ja, wo?
18 responses
Copy
Rechter Arm
Linker Arm
Beide
77.8%
16.7%

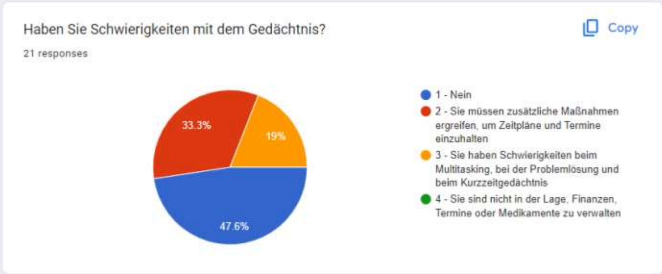
Wenn ja, bitte unten einkreisen:

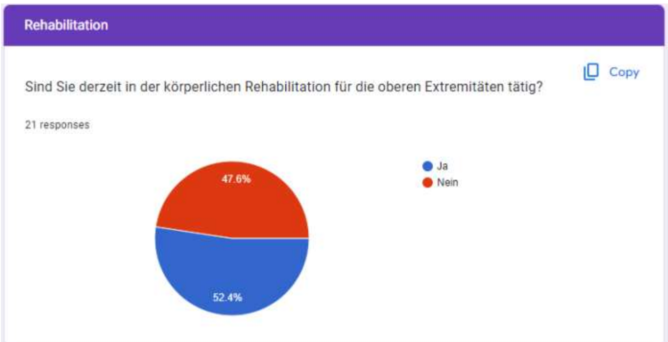


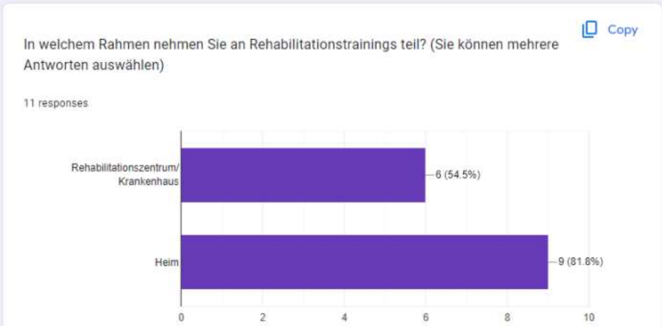


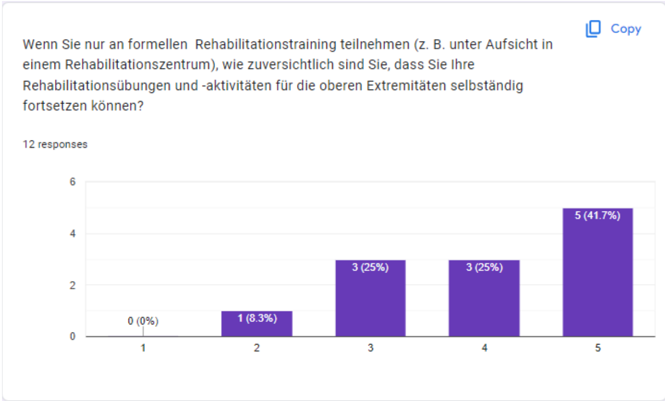


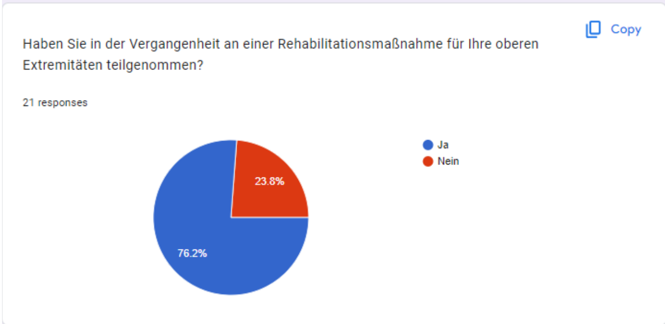

Verstärkter Tastsinn
Copy
4 responses
100%
Rechter Arm
Linker Arm
Beide

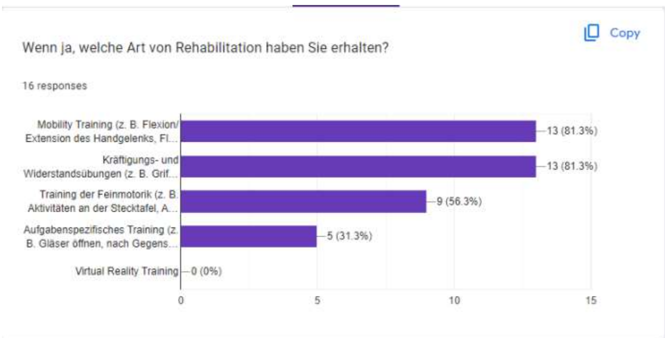

Haben Sie Schwierigkeiten mit dem Gedächtnis?
Copy
21 responses
33.3%
19%
47.6%
1 - Nein
2 - Sie müssen zusätzliche Maßnahmen ergreifen, um Zeitpläne und Termine einzuhalten
3 - Sie haben Schwierigkeiten beim Multitasking, bei der Problemlösung und beim Kurzzeitgedächtnis
4 - Sie sind nicht in der Lage, Finanzen, Termine oder Medikamente zu verwalten

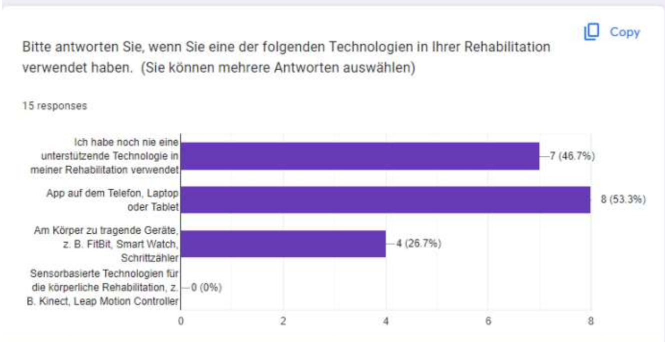

Rehabilitation
Copy
Sind Sie derzeit in der körperlichen Rehabilitation für die oberen Extremitäten tätig?
21 responses
47.6%
52.4%
Ja
Nein

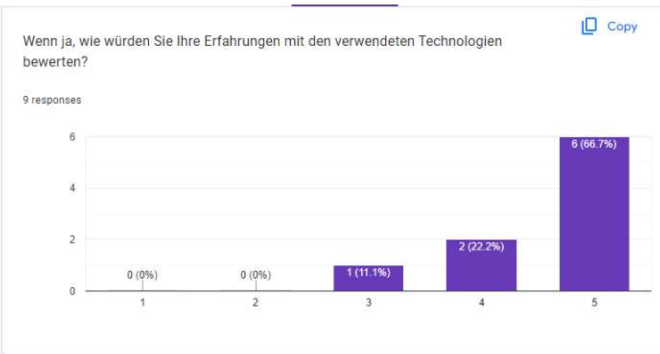

In welchem Rahmen nehmen Sie an Rehabilitationstrainings teil? (Sie können mehrere Antworten auswählen)
Copy
11 responses
Rehabilitationszentrum/ Krankenhaus
6 (54.5%)
Heim
9 (81.8%)
0
2
4
6
8
10


Copy
Wenn Sie nur an formellen Rehabilitationstraining teilnehmen (z. B. unter Aufsicht in einem Rehabilitationszentrum), wie zuversichtlich sind Sie, dass Sie Ihre Rehabilitationsübungen und -aktivitäten für die oberen Extremitäten selbständig fortsetzen können?
12 responses
6
4
2
0
0 (0%)
1 (8.3%)
3 (25%)
3 (25%)
5 (41.7%)
1
2
3
4
5

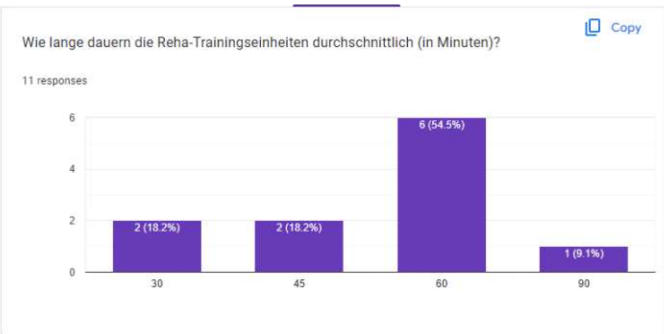

Copy
Haben Sie in der Vergangenheit an einer Rehabilitationsmaßnahme für Ihre oberen Extremitäten teilgenommen?
21 responses
23.8%
76.2%
Ja
Nein

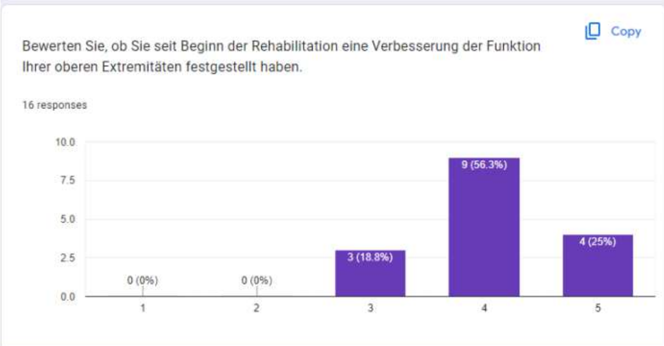

Copy
Wenn ja, welche Art von Rehabilitation haben Sie erhalten?
16 responses
Mobility Training (z. B. Flexion/ Extension des Handgelenks, Fl...
13 (81.3%)
Kräftigungs- und Widerstandsübungen (z. B. Grif...
13 (81.3%)
Training der Feinmotorik (z. B. Aktivitäten an der Stecktafel, A...
9 (56.3%)
Aufgabenspezifisches Training (z. B. Gläser öffnen, nach Gegens...
5 (31.3%)
Virtual Reality Training
0 (0%)
0
5
10
15

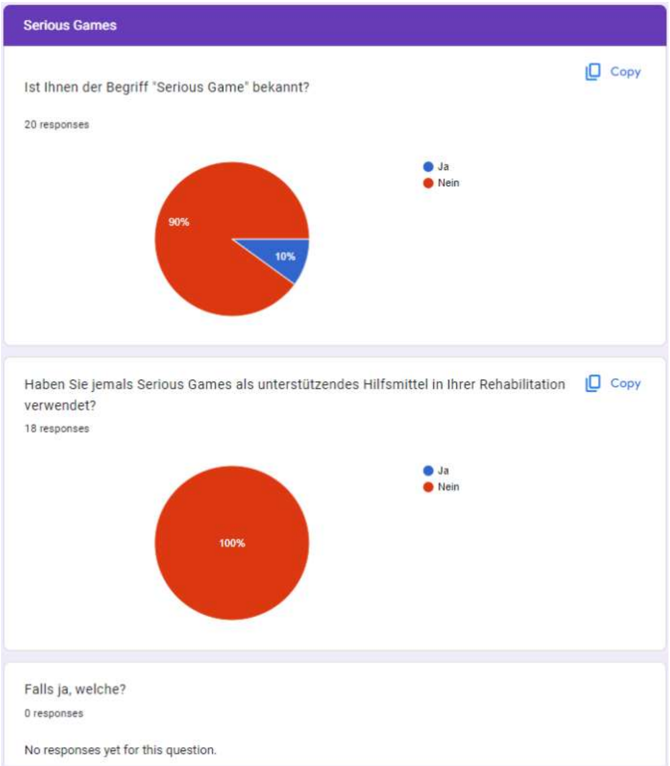

Copy
Bitte antworten Sie, wenn Sie eine der folgenden Technologien in Ihrer Rehabilitation verwendet haben. (Sie können mehrere Antworten auswählen)
15 responses
Ich habe noch nie eine unterstützende Technologie in meiner Rehabilitation verwendet
7 (46.7%)
App auf dem Telefon, Laptop oder Tablet
8 (53.3%)
Am Körper zu tragende Geräte, z. B. FitBit, Smart Watch, Schrittzähler
4 (26.7%)
Sensorbasierte Technologien für die körperliche Rehabilitation, z. B. Kinect, Leap Motion Controller
0 (0%)
0
2
4
6
8

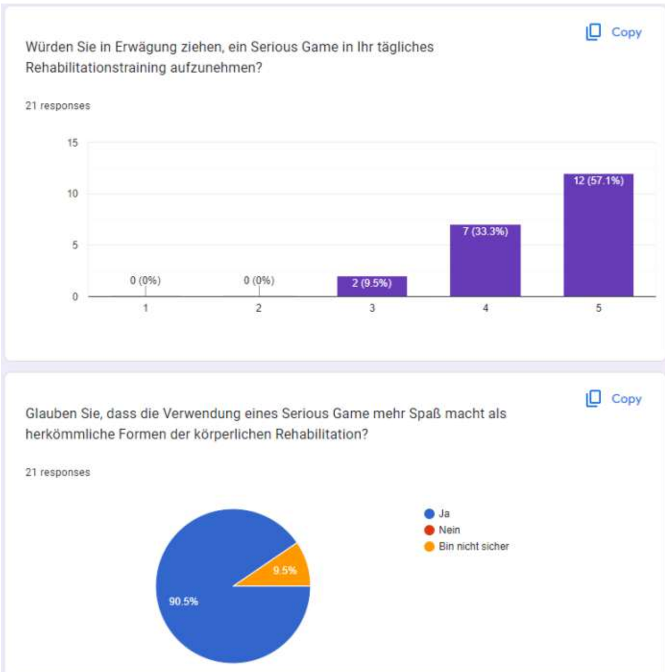

Copy
Wenn ja, wie würden Sie Ihre Erfahrungen mit den verwendeten Technologien bewerten?
9 responses
6
4
2
0
0 (0%)
0 (0%)
1 (11.1%)
2 (22.2%)
6 (66.7%)
1
2
3
4
5


Copy
Wenn Sie derzeit an einer Rehabilitationsmaßnahme für die oberen Extremitäten teilnehmen, wie oft haben Sie Ihre Trainingseinheiten? Bitte geben Sie die Anzahl der Trainingseinheiten pro Woche an.
11 responses
18.2%
72.7%
9.1%
weniger als 1
1-2
3-4
5-7
mehr als 7


Copy
Wie lange dauern die Reha-Trainingseinheiten durchschnittlich (in Minuten)?
11 responses
6
4
2
0
2 (18.2%)
2 (18.2%)
6 (54.5%)
1 (9.1%)
30
45
60
90


Copy
Bewerten Sie, ob Sie seit Beginn der Rehabilitation eine Verbesserung der Funktion Ihrer oberen Extremitäten festgestellt haben.
16 responses
10.0
7.5
5.0
2.5
0.0
0 (0%)
0 (0%)
3 (18.8%)
9 (56.3%)
4 (25%)
1
2
3
4
5

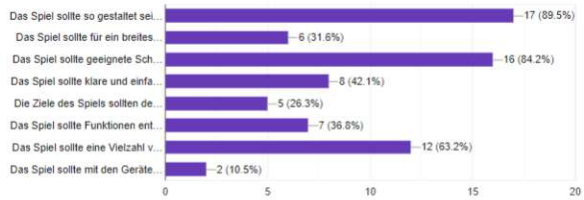

Serious Games
Copy
Ist Ihnen der Begriff "Serious Game" bekannt?
20 responses
Ja
Nein
90%
10%
Copy
Haben Sie jemals Serious Games als unterstützendes Hilfsmittel in Ihrer Rehabilitation verwendet?
18 responses
Ja
Nein
100%
Falls ja, welche?
0 responses
No responses yet for this question.


Copy
Würden Sie in Erwägung ziehen, ein Serious Game in Ihr tägliches Rehabilitationstraining aufzunehmen?
21 responses
15
10
5
0
0 (0%)
0 (0%)
2 (9.5%)
7 (33.3%)
12 (57.1%)
1
2
3
4
5
Copy
Glauben Sie, dass die Verwendung eines Serious Game mehr Spaß macht als herkömmliche Formen der körperlichen Rehabilitation?
21 responses
Ja
Nein
Bin nicht sicher
9.5%
90.5%

Copy

Welche Faktoren würden Ihre Entscheidung für den Einsatz von Serious Games in Ihrer körperlichen Rehabilitation stark beeinflussen? (Sie können mehrere Antworten auswählen)

19 responses



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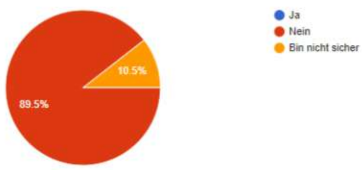
Haben Sie Bedenken hinsichtlich der Sicherheit oder Wirksamkeit von Serious Games als Mittel zur körperlichen Rehabilitation?

19 responses



Was halten Sie von dem folgenden Workflow?

1. Der Therapeut/Arzt erstellt ein bestimmtes Level/eine bestimmte Übung im Spiel
2. Das Level/die Übung wird Ihnen zugewiesen
3. Sie spielen das Spiel/machen die Übung
4. Die Ergebnisse (z.B. Spielzeit) der Übungen werden an den Therapeuten/Arzt übermittelt
5. Der Therapeut/Arzt kann die Levels/Übungen anhand der Ergebnisse anpassen

3 responses

👍

Ich find's gut, dass Menschen, die es verwenden werden, direkt an der Entstehung des Produkts beteiligt sind.

Cool, es könnte helfen, damit der Spieler das Spiel am Ende genießt

Appendix C

Game Experience Questionnaire (GEQ)

Game Experience Questionnaire

Please indicate how you felt while playing the game for each of the items, on the following scale:

not at all	slightly	moderately	fairly	extremely
0	1	2	3	4
< >	< >	< >	< >	< >

1 I felt content
2 I felt skilful
3 I was interested in the game's story
4 I thought it was fun
5 I was fully occupied with the game
6 I felt happy
7 It gave me a bad mood
8 I thought about other things
9 I found it tiresome
10 I felt competent
11 I thought it was hard
12 It was aesthetically pleasing
13 I forgot everything around me
14 I felt good
15 I was good at it
16 I felt bored
17 I felt successful
18 I felt imaginative
19 I felt that I could explore things
20 I enjoyed it
21 I was fast at reaching the game's targets
22 I felt annoyed
23 I felt pressured

24 I felt irritable
25 I lost track of time
26 I felt challenged
27 I found it impressive
28 I was deeply concentrated in the game
29 I felt frustrated
30 It felt like a rich experience
31 I lost connection with the outside world
32 I felt time pressure
33 I had to put a lot of effort into it

System Usability Scale (SUS)

System Usability Scale

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system					