TU WIEN Informatics

Analyse, Design und prototypische Entwicklung für Matchmaking von Multiplayer Serious Games in der Schlaganfallrehabilitation

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieurin

im Rahmen des Studiums

Wirtschaftsinformatik

eingereicht von

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Analysis, Design and Prototypical Implementation for Matchmaking of Multiplayer Serious Games in Stroke Rehabilitation

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Wien, 25. November 2022

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Sarah Brunner, BSc

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Wien, 25. November 2022

Sarah Brunner

Danksagung

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Kurzfassung

Nach Angaben der WHO sind Herzkrankheiten und Schlaganfälle weltweit die häufigste Todesursache, und die Überlebenden durchlaufen einen umfassenden Rehabilitationsprozess, in dem sie verlorene Fähigkeiten wiedererlernen müssen. Die häusliche Rehabilitation wird immer wichtiger, da die PatientInnen früher aus dem Krankenhaus entlassen werden und die TherapeutInnen ihnen Übungen für zu Hause verschreiben. Die PatientInnen brauchen jedoch oft mehr Motivation, um diese Übungen durchzuführen. Serious Games vermitteln Wissen und bieten somit therapeutische Anwendungen, z.B. in der Schlaganfallrehabilitation. Daher haben verschiedene AutorInnen versucht, das Motivationsproblem in der Rehabilitation mithilfe von Serious Games zu lösen. Multiplayer Serious Games bieten zusätzlich die Möglichkeit, mit anderen PatientInnen in einem kompetitiven, kollaborativen, oder kooperativen Spiel zu trainieren, um die mit Depressionen oder dem Gefühl der Isolation verbundenen Herausforderungen zu überwinden. Um ein Multiplayer Serious Game zu entwickeln, gibt es die Möglichkeit eines adaptiven Mapping-Verfahrens, bei dem die Fähigkeiten der einzelnen SpielerInnen ausgeglichen werden, einer Anpassung des Schwierigkeitsgrads der SpielerInnen oder einer Simulation der GegenspielerInnen. Matchmaking-Strategien in der Spieleindustrie ermöglichen es den SpielerInnen, geeignete GegnerInnen zu finden. In Multiplayer Serious Games für SchlaganfallpatientInnen gibt es jedoch keine Matchmaking-Strategie.
In dieser Arbeit wird untersucht, welche Matchmaking-Strategie für SchlaganfallpatientInnen geeignet ist, um ihnen das Spielen eines Multiplayer Serious Games zu ermöglichen, das für Rehabilitationszwecke geeignet ist. Das Matchmaking-System wird anhand eines Multiplayer Spiels demonstriert, und von zehn ExpertInnen bewertet.
Die Benutzerfreundlichkeit ist von entscheidender Bedeutung, da sie SchlaganfallpatientInnen in die Lage versetzen kann, digitale Anwendungen selbstständig zu nutzen. Vier gesunde Personen testeten das Matchmaking und das Spiel auf Benutzerfreundlichkeit und nahmen an den SUS und PSSUQ Fragebögen teil. Die Fragebögen ergaben eine durchschnittliche Punktzahl von 82,5 (SUS) und 2,828125 (PSSUQ). Für eine abschließende Bewertung führten die ExpertInnen ein halbstrukturiertes Interview durch, aus dem hervorging, dass sie ihren PatientInnen eine solche Anwendung empfehlen würden.

Abstract

According to the WHO, heart disease and stroke are the leading causes of death worldwide, and survivors must undergo extensive rehabilitation to re-learn lost abilities. Home-based rehabilitation becomes increasingly important since patients get released from the hospital earlier, and therapists prescribe home exercises. The patients, though, often need more motivation to perform those exercises. Serious games impart knowledge and thus provide therapeutic applications, such as stroke rehabilitation. Therefore, various authors have tried to solve the motivation problem in performing exercises in rehabilitation by developing serious games. Additionally, multiplayer serious games offer the opportunity to train with other patients in a competitive, collaborative, or cooperative game to overcome the challenges associated with depression or feeling isolated. A few techniques exist to create a multiplayer serious game, including an adaptive mapping technique that balances each player's skill, adjusting the players' difficulty level, or creating a simulation of the opponent. Matchmaking strategies in the gaming industry allow players to find a suitable opponent. However, no matchmaking strategy is available in multiplayer serious games for stroke patients.

This thesis investigates which matchmaking strategy is suitable for stroke patients enabling them to play a multiplayer serious game that is applicable for rehabilitation purposes. A game shows the utilization of the matchmaking system and ten experts evaluate it.

Usability is critical as it can enable stroke survivors to use digital applications independently. Four healthy people tested the matchmaking and the game for usability and took part in the SUS and PSSUQ questionnaires. The usability questionnaires yielded an average score of 82.5 (SUS) and 2.828125 (PSSUQ). Experts conducted a semi-structured interview for a final evaluation, which revealed that they would recommend such an application to their patients.

Contents

CHAPTER 1

Introduction

This chapter provides an overview of the contents of this work. The thesis analyses the impact of multiplayer serious games and how patients can get connected with the help of a matchmaking strategy. In the following, the problem statement explains the focus of this thesis and why multiplayer serious games are relevant. The motivation presents the resulting research questions, and the methodology to answer these questions is elaborated. An outline for this work is presented at the end of the chapter.

1.1 Problem Definition

According to the World Health Organisation (WHO), Cardiovascular diseases (CVDs) are diseases of the heart and blood vessels and include: Coronary heart disease, cerebrovascular disease, peripheral arterial disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis, and pulmonary embolism [95]. Cardiovascular disease can be prevented by eating a healthy diet, avoiding obesity, reducing tobacco consumption, regular exercise, and decreasing harmful alcohol consumption. Elevated blood pressure, elevated blood sugar, elevated blood lipids, and overweight and obesity may be a forewarning. Therefore, preventive examinations are essential and are recommended yearly in Austria.

The WHO states that in 2019 17.9 million people died worldwide because of cardiovascular diseases [95]. Stroke survivors may experience cognitive or motor impairments that, if left untreated, can permanently affect the patient. Patients may experience difficulty in everyday activities such as getting dressed, making coffee, or brushing their teeth. Hence, rehabilitation is essential to regain lost abilities, but this process has been observed as de-motivating for patients.

According to Maclean [52], motivation is a crucial aspect of stroke rehabilitation regarding the outcome of an exercise for a patient. Although patients know that rehabilitation is vital for regaining lost abilities, they often have difficulties staying motivated for being

consistent with the necessary training. Since it may take some time before one can see results, training can lead to frustration and hence further decrease motivation.
Performing exercises in the context of serious games can help maintain motivation while gradually increasing the difficulty of the exercises [64]. To further maintain motivation, patients need to understand the movements of the exercises and the importance of staying consistent. Also, the difficulty of the exercises needs to be just right: not too hard and not too easy.
According to Zyda [99], serious games can be applied to various domains ranging from healthcare, public policy, strategic communication, military defense, training, and to education. Serious games can be defined as games that have an entertaining purpose and provide a learning effect. Creating a concept for a game and designing it is critical for developing such a game, especially when a training effect is involved, such as in stroke rehabilitation.
Further, multiplayer serious games allow patients to interact with each other and boost their motivation to continue the rehabilitation exercises. Multiplayer games can be categorized into cooperative, collaborative, or competitive game modes. To enable multiplayer gameplay, the players can either use one screen per player, a shared screen, or take turns. Different people may have different preferences for a game, such as game genre or game type [94], which can be a challenge when developing multiplayer serious games. These differences can also lead to more complex matchmaking between players, as some may not want or be able to participate in a game.
Based on this knowledge, this work is devoted to establishing a matchmaking strategy for stroke patients, which is applicable in a game for rehabilitation purposes. A matchmaking strategy can allow stroke patients to be brought together rather than recovering alone. So far, research has not been done on matchmaking strategies for stroke survivors in a multiplayer serious game. A tool is missing where patients can exchange about their challenges and commonalities. When developing a matchmaking strategy, it is crucial to ensure fair play for all players. Therefore, their abilities and impairments must be considered in this process. A strategy has to be established to define under which criteria players are matching.

1.2 Motivation

Technology plays an increasingly important role in our lives, especially smartphones, an everyday companion of almost everyone. Occupational therapists and physiotherapists help stroke patients get back to everyday life. Among rehabilitation exercises, playful exercises are performed, and variety of those is particularly important. Therapists often see patients with phones scrolling meaningless while watching short videos on social media. This time could be better used with, for example, a game on the phone that has rehabilitative purposes. Digital means, such as serious games, are still rarely used, although they have already been well-researched. Serious games can offer digital variety for patients in rehabilitation. For additional therapy at home, serious games are also applicable. Stroke patients want to improve their cognitive and motor skills, some of which they have to relearn. In doing so, they often lack motivation and feel alone. Therefore, they would appreciate a game that they can play with others.

Multiplayer serious games already exist, but therapists still have to decide who plays against whom. Neither a cross-clinic system exists nor one where the patient can play online with or against someone at home. Most devices that are used for home rehabilitation are also expensive. Therefore, this work is dedicated to finding a suitable matchmaking system, which is presented by means of a simple game and subsequently evaluated by experts.

This thesis aims to provide answers to the following research questions:

1. What is a suitable matchmaking strategy between two or more players of a Multiplayer Serious Game in stroke rehabilitation?
   In order to answer this research question, a prototype of a multiplayer serious game is developed based on a literature review of matchmaking strategies in regular games. The literature findings are described in the chapters 2 and 3. Experts, such as therapists, a nurse, or an assistant doctor, are contacted to evaluate which matchmaking strategy is the most suitable for stroke patients. The matchmaking strategy depends on the game mode, the number of players involved, and the waiting queue. Matching players can base on having adequate skills, complementary skills, or different capabilities. The quality of matchmaking is vital to make accurate predictions for stroke patients. It should also not reduce the game's enjoyment, as this can affect the gaming experience and motivation to continue using the game.

2. What are the requirements for a prototype of a Multiplayer Serious Game in the context of stroke rehabilitation?
   The literature review, state of the art, and interviews with experts help to derive requirements. The experts, such as occupational, physical, or speech therapists who work with stroke patients, are considered for the interviews. Based on the requirements, a small game is developed that incorporates the matchmaking strategy to demonstrate and analyze the matchmaking solution. From the initial brainstorming phase to the finalization, 4 iterations occur, and a semi-structured interview is conducted as part of the final evaluation of the prototype.

3. What is the best way to design a multiplayer serious game to ensure good usability?
   The target group for this work is stroke patients in rehabilitation, but unfortunately, there is no way to ask them for direct feedback on the prototype. Instead, usability tests will be conducted with four users, who test the matchmaking and the game. Usability tests help validate the design and the requirements of the prototype. The System Usability Score and Post-Study System Usability Questionnaire help evaluate the system's usability. Usability is critical for stroke patients since they have impairments that do not allow them to grasp things as quickly as a healthy human. Bad usability, therefore, can make them frustrated quickly.

1.3 Methodology

The execution of the thesis is divided into four iterations, where in each iteration, several experts who work with stroke patients are consulted for questioning. To answer the first and second research questions, the literature research on multiplayer serious games in stroke rehabilitation and the current state of the art serve as a foundation for the requirements analysis of the prototype to be developed. Furthermore, findings are compiled and evaluated, which are then incorporated into an interview guide that serves as the basis for the expert interviews. Finally, a test session is conducted involving users to test the matchmaking and gaming experience, and a final evaluation by the experts using a questionnaire. The figure 1.1 provides an overview of the process followed in this work. The respective research methods are further outlined in this chapter.

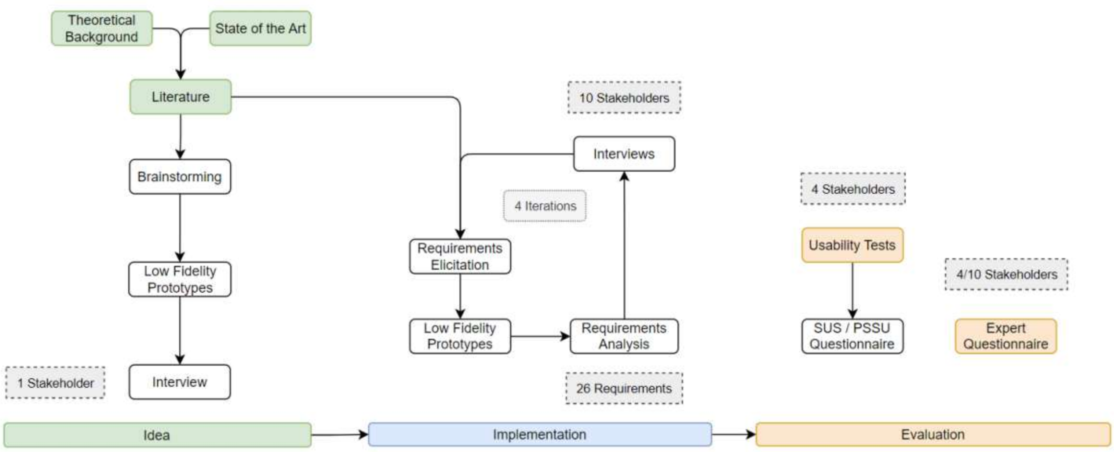


Figure 1.1: Overview of the applied Methodology

1.3.1 Literature Review

According to Kitchenham [43], a systematic literature review (SLR) is a way to identify, evaluate, and interpret research relevant to a particular topic area or research question. There are three primary phases to consider when conducting an SLR: First, the review is planned, including defining the research questions. The second phase is conducting the review, which involves selecting primary studies and extracting data. The final phase is reporting on the review.

For this work, a literature review will be conducted to gather information on stroke and related stroke rehabilitation. Research on existing multiplayer serious games and matchmaking algorithms will be conducted. PubMed, Science Direct, IEEE Xplore Digital Library, CatalogPlus, and Google Scholar are used for the literature review. Among others, relevant terms such as "stroke", "stroke rehabilitation", "multiplayer serious games", "serious games", "matchmaking", "matching players", "ranking", and "usability" are searched.

1.3.2 Design Science Research

Design science, also known as constructive research, builds and evaluates an artifact to show the solution to a problem. This thesis follows the design science feedback cycle shown in figure 1.2. The cycles can be further understood with a checklist consisting of 8

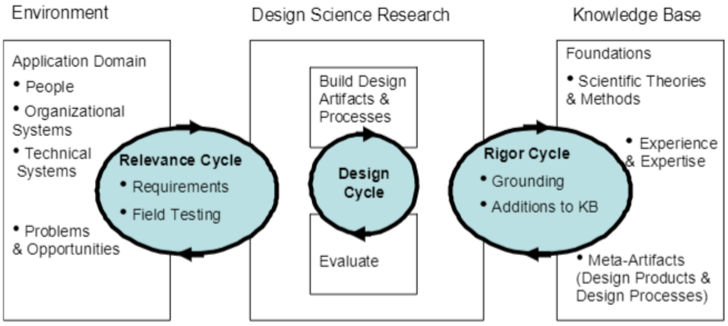


Figure 1.2: Design Science Research Cycles [35]

questions [34]. Those questions are frequently used by researchers who evaluate their research projects.
The first cycle (Relevance Cycle) connects the people, organizational, and technical systems and makes them work toward a common goal. Problems and opportunities are identified, and the criteria for evaluation are specified. With Field testing, it can be decided if more iterations of the Relevance Cycle are needed. Questions such as *What are the research questions?*, *How is the artifact introduced into the application environment and how is it field tested?*, *Was the research question properly addressed?* [34] can be asked. In order to develop a prototype for a multiplayer serious game, a list of requirements will be prepared based on the literature review and further extended by various experts. The requirements priority influences the development cycle, and various iterations will be made until the specifications are sufficient.
The third cycle (Rigor Cycle) describes the knowledge base of the scientific theories, methods, expertise, and experience. The research will be based on the state of the art of multiplayer serious games and matchmaking concepts. In this cycle, it can be considered which additions to the knowledge base can be made. *What theories support the artifact design and the design process?*, *What new knowledge is added to the knowledge base and in what form (e.g., peer-reviewed literature, meta-artifacts, new theory, new method)?* [34].
Finally, the design cycle depends on the other two cycles and involves constant repetition between the creation of design artifacts, development, and evaluation. Questions that should be addressed are *What is the artifact? How is the artifact represented? What design processes (search heuristics) will be used to build the artifact? What evaluations*

are performed during the internal design cycles? What design improvements are identified during each design cycle?[34]. The research questions of this thesis lead to three artifacts: the first is the matchmaking strategy for stroke patients, the second is the requirements and a prototype, and the third artifact is the usability evaluations. The user-centered design approach will be used to design the prototype and define the requirements. During the iterative development process, experts, such as therapists, give feedback and refine the requirements. With wireframes, an initial game design will be made, experts will evaluate the design, and the resulting feedback will be incorporated.

1.3.3 User Centered Design

A User-Centered Design approach (UCD) is used to design the prototype. According to Abras et al. [1], UCD describes how end users are involved in shaping the design process in an iterative process. UCD has various definitions in the literature. One is by the International Organization for Standards (ISO 9241-110), where UCD consists of mainly 4 steps [23]: understanding and specifying the context, specifying the requirements of the user, providing a solution in the form of a design and finally to evaluate and test it.

Wallach et al. [90] focus on 5 usability design activities, which emerge based on the foundation of Gould and Lewis. Gould and Lewis defined early focus on the users, empirical measurement with prototypes and iterative design as fundamental principles [29]. Wallach et al. focus on the design activities as seen in figure 1.3: scope, analyze, design, validate and deliver. The categories "design and validate" are closely linked to each other. Throughout the whole design process, an iterative approach is suggested.

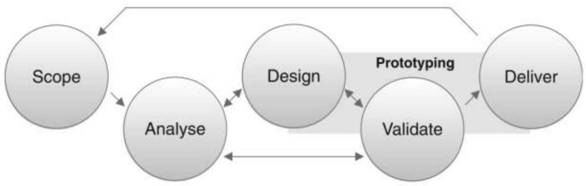


Figure 1.3: User-Centered Design Activities [90]

Scope In this category, the concrete goal and constraints of the project are defined. Given that an interface serves a specific purpose, the functional goals must base on sufficient expertise and specific domain knowledge. These goals usually range from redesigning the existing application to designing new functionalities for an entirely new application. Constraints must be defined to reduce the risk of over-designing and over-engineering the prototype. Addressing the different goals and constraints of the stakeholders allows for a common ground of understanding between them [90].

Analysis Analytic activities help to determine the user's characteristics, tasks, and the context of an application's use. Analysis can be done with or without end-users. According to Nielsen et al. [67], there are 4 ways to evaluate a user interface: formally (use any analysis technique), automatically (computerized help), empirically (experiments with users), or heuristic (looking at the interface and judging it).
For this thesis, asking stroke patients directly for feedback is impossible. Instead, therapists can evaluate what is necessary to succeed in rehabilitation exercises with the game. Analysis without end-users can occur through heuristic analysis. In heuristic analysis, anyone can be incorporated and provide an opinion on the suitability of the interface, e.g., if it is good or bad [67]. Nielsen et al. [67] recommend having 3 - 5 independent reviewers. Experts detect usability obstacles of an interface.
Analysis with end-users can be done by job shadowing and/or contextual interviews [90]. From the gained knowledge, the analysis phase can be summarized by creating affinity diagrams, personas, mental models, and performed scenarios. The knowledge can be written on post-its in affinity diagrams and then clustered into categories. A persona represents an application's typical user and helps get a clear idea of this person's needs. With a persona, a problem can be evaluated from different perspectives [17]. The mental model describes a user's subjective ideas and beliefs of how the application should work based on their experiences [49]. Scenarios are descriptions of how the defined persona could interact with the system. They also provide the view of the user.

Design According to Wallach et al. [90], user interface design balances conflicting requirements, compromising on solutions, and recognizing the limitations in the solution domain. The previous phases' findings are incorporated into a potential artifact's design process.
At the conceptual level of a user interface, decisions about layout, workflow, and the underlying interaction model are considered. This level includes defining screen views, their dimensions, user interface controls, and the interrelationships among screens. Scenario definition focuses on why a user performs a task, and requirements can be derived from this. Conceptual decisions help answer the so-called how questions. These two steps are interrelated and an essential part of designing the interface. Scribbles are suitable for sketching initial ideas without committing to them. Screen areas and relationships between the screens are drawn. When scribbling in the early development stages, feedback can be incorporated quickly and easily [90].
The next step is to create wireframes. Wireframes provide further insight into the selection of controls and navigation elements. They also allow, for example, the use of a particular color to see if the user's attention is on specific areas of the user interface. As this is in an early design phase, applying changes through feedback happens iteratively. Prototypes go a step further by allowing interaction with the User interface. For example, it may be possible to click on a button and instantly see where that click would lead the user. User interface mock-ups are for detailed visual design decisions (colors, textures, fonts, icons, and embellishments). Based on the results and inputs in the scoping phase, visual styles are tested in mock-ups [90].

The following nine usability principles discussed by Molich et al. [61] are: Simple and natural dialogue, Speak the user's language, Minimize user memory load, Be consistent, Provide feedback, Provide clearly marked exits, Provide shortcuts, Good error messages, and Prevent errors.

Validate The design needs to be validated and questioned against the defined requirements. The main question is if a typical user can achieve a scenario's goal through the designed artifact. Other forms of validation are heuristic analysis for inspecting usability and empirical usability testing. In usability testing, it often helps to think out loud [20]. A user could talk in such a testing session about their thoughts while using the artifact, which helps understand the user. Then usability questionnaires can be performed to get further insight into the user's perception. The System Usability Scale (SUS) consists of ten questions that provide an overall view of the subjective evaluation of usability. It is an effortless 5-point Likert scale, where 1 means strongly disagree, and 5 strongly agree. The scale should be used when the user has interacted with the system that is under evaluation [10]. It has been shown that valid insights into usability problems can be gained even with a small number of participants. Assuming the group of participants was composed correctly.
Another usability questionnaire is the Post-Study System Usability Questionnaire (PSSUQ) developed by John Lewis [48]. The PSSUQ measures the users' satisfaction when interacting with a system. It can be used with a small number of participants. This questionnaire consists of 16 questions with a 7-point Likert Scale, where 1 is strongly agree and 7 is strongly disagree. It also has 3 subscales: the System Usefulness scale (Questions 1-6), the Information Quality scale (Questions 7-12), and the Interface quality scale (Questions 13-15). The 16th question is only used for the overall rating. Overall, the lower the score, the better the user satisfaction.

Deliver In the delivery phase, the result is handed over to development. Usually, explanatory documents and instructions are provided for this purpose. The outcomes can range from mock-ups of some selected primary user interfaces to interactive prototypes, which short descriptions can document. The scope may be extended and adapted from this phase iteratively until the final product is fully delivered.

1.3.4 Expert Interview

To evaluate the prototype for its applicability in rehabilitation and also the usability, a semi-structured interview will be conducted that includes a combination of specific questions and open-ended questions. Questions can be open, where the ones asked can answer freely, or closed, when a list of possible answers is given. To design questions, Shull et al. [82] provide 9 guidelines to formulate precise and understandable questions. Those guidelines include using appropriate language to avoid ambiguous questions, keeping them short but meaningful, and using standard grammar, punctuation, and spelling. To avoid researcher bias, choosing the right questions and their ordering and using neutral words is essential. Positive and Negative questions should be included, but not using negated or double-negated questions. When asking closed questions, answers can be yes/no, numerical values (e.g., age), response categories (e.g., job type), or ordinal scales. Yes/No answers are considered problematic since people may answer differently at different times or places. Instead, it is recommended to use ordinal scales: agreement scales (strongly agree, agree, neither of, disagree, strongly disagree), frequency scales (most of the time, sometimes, seldom, occasionally, never), or evaluation scales (excellent, good, acceptable, inferior, awful).

A questionnaire should include the purpose of the study, information on who makes the study, and an estimate of the time it needs to fill out the questionnaire. Furthermore, the motivation of a person filling out the questionnaire is often low. Therefore they need to be informed how important their participation is, how it may also benefit them if the answers are stored confidentially and what the purpose is. It is also vital that the people who receive the questionnaire are competent to answer it.

Questions for this thesis could include: "Which matchmaking parameters would you include in the matchmaking of such a game?", "Is the matchmaking system fair for all players? If yes, why? If no, why not?".

1.4 Structure of the Work

In the following, the respective content of the chapters in this thesis is described.

Chapter 1: Introduction
The first chapter provides an introduction to the subject of this thesis. The problem statement, the motivation, the resulting research questions, and the methodology are presented.

Chapter 2: Theoretical Background
The theoretical background provides a fundamental understanding of stroke, rehabilitation, serious games, multiplayer games, multiplayer serious games, matchmaking and ranking strategies, usability engineering, and requirements engineering.

Chapter 3: State of the Art
Chapter 3 provides an overview of current research contrasting different solutions for enabling multiplayer serious games, and matchmaking strategies used in regular online games. Matchmaking strategies of regular games provide the basis for the solution proposed in this thesis.

Chapter 4: Results
In Chapter 4, the results are presented in the context of four iterations. This chapter discusses the requirements analysis, prototyping, and subsequent implementation. Interviews are conducted with ten stakeholders to accumulate the requirements, and prototyping techniques are applied as part of user-centered design. Based on the requirements and wireframes, a prototype is created to answer the research questions. Users test the prototype and provide feedback, and conduct usability questionnaires. On completion of the prototype, an expert survey takes place, which is subsequently evaluated.

Chapter 5: Discussion
Chapter 5 discusses the research questions in detail with the respective research method. The results, the significance of these results and the shortcomings are being stated.

Chapter 6: Conclusion and Outlook
This chapter concludes with the most important findings from this work. Potential areas of application and possible further developments of the work are outlined.

CHAPTER 2

Theoretical Background

This chapter first provides a general understanding of cardiovascular diseases and post-stroke rehabilitation. Then, serious games are explained with some recommendations on game design, game experience and examples of game elements are given. These are necessary for the development of a prototype. Game modes of multiplayer serious games are presented and analyzed with regard to their suitability for stroke patients. Furthermore, a brief introduction on matchmaking algorithms and ranking strategies are given. For this purpose Skill-Based matching strategies such as Elo, Glicko/Glicko2 and TrueSkill are compared to each other. Finally, a short introduction on requirements engineering is given, which is necessary for the different iterations in the development of the prototype.

2.1 Stroke

The term cardiovascular disease is collectively used for different diseases affecting the heart or blood vessels. Cardiovascular diseases can be subdivided into coronary heart disease, cerebrovascular disease, peripheral arterial disease, rheumatic heart disease, congenital heart disease, and deep vein thrombosis and pulmonary embolism [95]. Coronary heart disease involves a blockage of the arteries that supply the heart with blood. This blockage can be due to a buildup of plaque in the arteries. The cerebrovascular disease affects the vessels that supply the brain with blood, and those arteries get blocked. The peripheral arterial disease affects the blood supply in the arms or legs. Rheumatic heart disease comprises damage on the heart valves when having a rheumatic fever, caused by bacteria. Congenital heart diseases are defects on the heart that are present from the birth of a child, such as holes in the heart or malformation of the heart. Deep vein thrombosis and pulmonary embolism happen when blood clots in the legs appear and then move up to the heart or lungs. [95], [51] According to the WHO, heart diseases and strokes are the number 1 reason for death globally, with about 17.9 Million incidents in 2019 [95]. A comparison of death causes is shown in figure 2.1 by the WHO. The death causes can be grouped into three categories: Noncommunicable include chronic causes, such as ischaemic heart diseases or stroke, which are the top 2 causes of death. Communicable causes include infectious and parasitic diseases and maternal, perinatal, and nutritional conditions. The third category is injuries and not displayed in the figure.

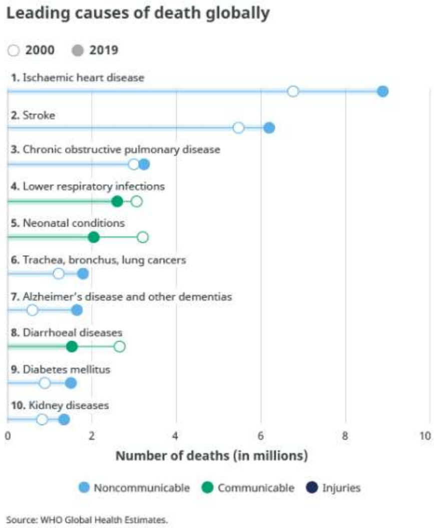


Figure 2.1: Top 10 Causes of Death according to the WHO [71]

Types of Stroke are ischemic stroke, hemorrhagic stroke, and sinus vein thrombosis, which is illustrated in figure 2.2.

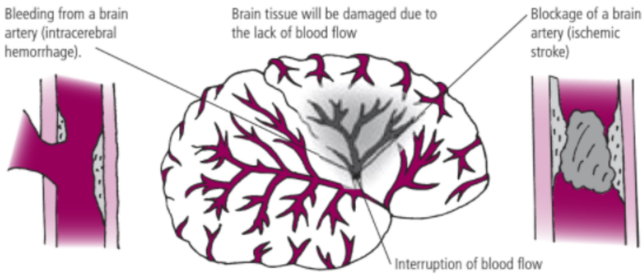


Figure 2.2: Types of Stroke [72]

A stroke results from an interruption due to a blockage or tearing of blood vessels in the blood supply to the brain. A blockage of a blood vessel is called an ischaemic stroke, and the tearing of a blood vessel is called a hemorrhagic stroke. In most conditions, blood flow is impaired in a clogged blood vessel area. In rarer cases, a stroke is due to

an interruption in blood supply to the entire brain. Nevertheless, brain cell loss and neurological deficits are inevitable. These deficits vary depending on the location and extent of the brain area affected [51], [50].
An ischemic stroke can be an infarction of the brain, spinal cord, or retina, accounting for around 71%-80% of all strokes worldwide. Around 15% are hemorrhagic strokes, and Sinus vein thrombosis is around 5%. A transient ischemic attack is a temporary interruption of blood flow that resolves before causing long-term damage. The cause of the disease can be the same as that of an ischemic stroke. Examinations and secondary prevention strategies are identical to those for an ischemic stroke [15].

The transient ischemic attack is a warning signal that usually does not involve any impairment. As a matter of fact 1 out of 10 people will have an ischemic stroke within 3 months after this incident. The transient ischemic attack is caused by a small blood clot, which usually dissolves within 24 hours. Two significant pairs of arteries deliver blood from the heart to the brain: One is the internal carotid arteries that carry blood through the neck, and the other is the vertebral arteries that go through the neck to the brain. Intracerebral hemorrhage result from bleeding in the brain (intracerebral hemorrhage) or bleeding between the inner and outer tissue layers around the brain (subarachnoid hemorrhage). Weakened blood vessels in the brain or pressure can cause such [9].

According to the National Stroke Association, about 10% of stroke survivors will recover completely, 10% will need care in a nursing home or even a long-term rehabilitation facility, 25% recover with mild deficits, 40% suffer from moderate to strong deficits, and 15% die not long after their stroke [4].

Symptoms of a stroke can be motor disorders (movement disorders, sagging corner of the mouth, no strength in the arms or legs), sensory disorders (sensory disturbances), speech disorders (difficulties in understanding spoken words, senseless babbling, difficulty in finding words), visual disturbances, coordination disturbances, sometimes dizziness and very rarely sudden, severe headaches (only in case of cerebral hemorrhage). The consequences are speech disorders, visual disturbances, hemiplegia, balance and coordination disorders. Strokes in the brain stem are particularly dangerous. Also, for example, for most people, the speech center is located in the left hemisphere of the brain: if a stroke occurs in the left hemisphere of the brain, it has more serious consequences for speech function [31].

Risk factors that may result in having a stroke are high blood pressure, obesity, abnormal blood lipids, unhealthy diets, smoking, physical inactivity, and diabetes mellitus. Other factors that can contribute to having a stroke are alcohol consumption, certain medications, stress, or mental health issues. Not modifiable factors are aging, family history, gender, or inflammation [51].

More than half of all strokes are due to high blood pressure. The higher the pressure within an artery, the greater the strain on the vessel and the damage to the inner vessel wall. Foremost high levels of LDL-cholesterol damage the vessels and lead to atherosclerosis. Triglycerides also cause damage, and other factors that play a role include smoking, a lack of exercise, having a tumor, or diabetes [72].

2.2 Rehabilitation

Rehabilitation aims to achieve the patient's autonomy and to minimize or, if possible, even prevent the physical, social, and psychological consequences. It supports patients in reversing the disabilities caused by stroke through repeated motions with a therapist. During rehabilitation, it is important to separate the acute phase (within 3 months after the incident) and the chronic state. The first month after a stroke is crucial, as this is when the brain's plasticity, and therefore the ability to recover, can be maximized [9].

After a stroke, the brain, the cardiovascular system, the legs and arms, and the shoulder area are particularly affected. The activities that are most affected after a stroke are communication and speech, reading, writing and mathematical calculations, problem-solving, executing single or multiple tasks, holding body position, walking, mobility, going to the toilet, getting dressed, getting around, driving and transportation, washing, self-care, use of hands and arms, eat and drink, meal preparation, and housework. Stroke rehabilitation is a process that includes an assessment to determine the patient's needs, goal setting to define achievable goals for improvement of impairments, assistance in achieving the established goals, and finally, the evaluation of progress made towards achieving the agreed-upon goals [47].

Recovery involves restitution (restoring damaged nervous tissues to function again), substitution (relearning lost abilities), and compensation (improving the impaired skills to meet the demands of daily living). Though restoring the functions is the best outcome, a permanent injury often leads to permanent damage of cognitive function, behavior, and emotional regulation. Substitution is applied when recovery is not achievable [46], [97]. The repetition of specific movements is essential for motor recovery in patients with hemiparesis [14].

The acute therapy of a stroke is to save the patient's life and treat complications. Rehabilitation then helps the patient to return back to life. The goal is to recover the impairments, to reintegrate the patient into the social environment and work life, and to enable the patient to live independently. Additionally, rehabilitation contributes to the prevention of further strokes and is an essential part of secondary prevention. Rehabilitation begins depending on the patient's condition on the first day of hospitalization [31].

Stroke units take care of patients who have experienced an ischaemic stroke. A team of physicians, nursing staff, and therapists are present to apply intravenous thrombolysis or endovascular thrombectomy. Intravenous thrombolysis, which dissolves a triggering thrombus in a cerebral artery, reduces impairments if provided within 4.5 hours of the stroke. Endovascular thrombectomy (i.e., removal of blood clots by catheter angiography) reduces impairments in patients with large vessel blockages and has to be made within 6 hours after a stroke. Intravenous thrombolysis, as well as endovascular thrombectomy, are time-critical [15].
Recovery is related to neuroplasticity in the brain, which is the ability to use other neural pathways and to replace those that have been lost. However, younger patients often recover well physically but have difficulty processing concurrent events and feel exhausted.

Studies show that they need to recover more complex networks, which requires a lot of effort [15].

Once the patient returns home, rehabilitation should continue with the experts and at home. It is crucial to continue the therapy every day because, without regular training, it is possible to forget what has been relearned. Dead brain cells cannot be replaced, but the brain can compensate for lost functionality by neighboring areas. This regenerative ability is called neuroplasticity, and the brain needs incentives to take full advantage of it. The lost functions can be trained again through physiotherapeutic, logopedic, or occupational exercises. In rehabilitation medicine for neurological diseases, patients are divided into phases according to severity levels A to F.
A rehabilitation team may include nurses, physical and occupational therapists, psychologists, speech therapists, social workers, dieticians, and neuropsychologists. The main task of occupational therapy is to support reintegration into everyday life. Therapists assist patients in relearning activities, such as getting dressed, washing, or brushing their teeth. In the following the differences between therapists are outlined [31]:

- Physical therapists: Physical therapists help patients improve balance and coordination. They also help relearn movement sequences required for sitting, standing, and walking. In doing so, they take particular care to avoid excessive cramping of the paralyzed muscles and provide special support for the restricted side of the body.

- Speech therapists: About one-third of stroke patients have speech disorders (aphasias) or problems with speaking. Depending on the type of disorder, therapy includes speech, comprehension, writing, and reading. Speech therapists also help with swallowing problems and disturbed breathing rhythms.

- Occupational therapists: Occupational therapists help stroke patients perform everyday tasks such as eating, dressing, doing groceries, and washing. These tasks are practiced until they can be performed as independently as possible.

- Neuropsychology therapy: Neuropsychological rehabilitation aims to minimize cognitive deficits, such as memory and concentration or communication problems. Cognitive functions include mental activities and abilities that involve language, abstract thinking, attention, memory, action planning, and perception.

Specialized and experienced interdisciplinary teams are crucial for rehabilitation after a stroke. Nevertheless, one big obstacle can be the motivation of the patient. Due to constant and monotonous repetition of the same exercises and an absence of visible results in the short term, patients can be demotivated so that they do not want to continue with their exercises.

Cognitive Rehabilitation
A cognitively impaired person's goal is to relearn cognitive abilities to perform everyday

tasks again. Cognitive impairments are apparent in reduced efficiency and speed of recovery, reduced ability to complete daily routine activities, or inability to adjust to new situations [3]. The impairments include deficits in long-term memory recording and retrieval, focused attention, executive functions, and spatial-constructive skills [40].

In the following, according to Mateer, general principles for the practice of cognitive rehabilitation are outlined. [55]:

1. Cognitive interventions must be personalized for the individual.
2. Cognitive interventions are most effective when working with the client, the client's family or caregivers, and the therapist.
3. Cognitive intervention should be directed towards commonly defined and relevant goals.
4. An assessment of effectiveness and outcomes should consider and capture changes in functional abilities.
5. The most successful cognitive interventions incorporate multiple approaches.
6. Interventions should address the effective and emotional components of cognitive loss or inadequacy.
7. Interventions should be self-evaluating.

Motor Rehabilitation
According to Schaechter, motor impairments (hemiplegia, dyscoordination, and spasticity) are among the most common deficits after stroke. Most patients recover from their lost motor skills to some extent, although it varies per individual. Intensive therapy after stroke enhances motor recovery. Motor rehabilitation includes neurofacilitation techniques, task-specific training, and task-oriented training [81]:

- Neurofacilitation techniques: To relearn motor skills by promoting correct movements as well as inhibiting incorrect movements.
- Task-specific training: to improve the ability to perform specific movements.
- Task-oriented training: functional tasks should be relearned by focusing on the musculoskeletal, perceptual, cognitive, and neural systems.

In the initial post-stroke period, physical and occupational therapies include 30-60 minutes daily sessions. Therapy usually lasts a maximum of 6 months, depending on the degree of impairments.

2.3 Serious Games

According to Zyda [99], serious games can be applied to various domains such as healthcare, public policy, strategic communication, military defense, training, and education. It does not have to be a specific genre, instead, it can be a strategy game, action, adventure game, or even a life simulation. Serious games can be defined as games that not only have an entertaining purpose but also provide a learning effect. The development of such a game involves design and implementation. Serious games show great potential since perceptual and coordination abilities can be seen. The gaming concept is one of the most important factors for the success of a serious game. Not only the concept, also the gaming environment needs to be suitable and the interface for the target group should be operable and understandable. Gaming rules, mechanics and the gameplay need to be carefully designed to ensure that optimal results are achieved. Further the game should have sustainable impact in terms of learnings achieved. According to Dörner et al. [19] a serious game is defined as:

> *A Serious Game is a digital game created with the intention to entertain and to achieve at least one additional goal (e.g., learning or health).*

Wattanasoontorn et al. [92] describe 5 components that all games are composed of. However, the last component distinguishes a serious game from other games:
Rule or Gameplay is the first component that connects the player to the game. It establishes a set of rules which determine the outcome of a game. The second component is *challenge*, which provides rewards for good performance, but also creates obstacles for the player so that the game task is not too easily achieved. Different difficulty levels should motivate the player to spend more time with the game. The third component, *interaction*, achieves communication within a game. The action by the player triggers an activity. Actions can be visual, auditory, physical (typing on the keyboard, using the mouse or touchpad), dialogical, and others. The last component is the *goal*, i.e., something one wants to achieve. A goal can be explicit but also implicit. Any game has the explicit goal of being entertaining. The implicit goals are to improve skills and acquire knowledge and experience. Thus, the authors distinguish between traditional computer games (having explicit goals) and serious games (containing both implicit and explicit goals).

A serious game in stroke rehabilitation can enhance willingness, sensory-motor skills, cognitive and perceptual competencies, and social and emotional skills.

In the systematic review by Krath et al. [45], 118 theoretical foundations have been examined that explain how gamification, serious games, and game-based learning are effective in practice. In the past, research focused on whether gamification actually can have positive effects, while in recent years, research was done on how and why gamification has positive effects. Gamification, serious games, and game-based learning can improve motivation, behavior, and learning outcomes in various areas, such as education, health, or work. Game elements, such as points or badges, guide players to goal-oriented activities, providing almost immediate feedback and reinforcing good performance. The user can choose between different progress paths while the system can adjust the difficulty and complexity to the player's abilities. Krath et al. could categorize 3 principles for gamification:

1. Principles leading to the desired behavioral outcomes/achievements
   - P1: Clear and relevant goals that are presented transparently. Self-determination
   - P3: Direct feedback on users' actions.
   - P4: Positive reinforcement: users are rewarded for their performance, and its relevance is communicated.
   - P8: Guided paths: users can be guided on paths to perform the actions necessary to achieve the goals.
   - P10: Simplified user experience: ease of use and simplification of content.
2. Principles that promote individual relevance
   - P2: Individual goals of the user
   - P7: Adaptive content: Tasks and complexity can be adapted to the user's skills and knowledge
   - P9: Multiple choices: The user can choose between different variations to reach a certain goal.
3. Principles that enable and have a positive impact on social interactions
   - P5: Social comparison, as the performance of other users, can be seen.
   - P6: Social normalization by connecting users to assist each other and work towards a common goal

2.3.1 Game Design and Experience

Randriambelonoro et al. further proposed some design recommendations when developing a serious game: They suggest including playfulness, personalization, performance feedback, and safety. Playfulness was observed as it brought back memories from their own family, as playing with children. Personalization would be used to react to the patient's improvements by increasing or decreasing the difficulty. Consideration should be given to providing visible and easily understood feedback on the patient's rehabilitation exercise to increase self-efficacy [79].

Game experience and flow are crucial to achieving the impact of serious games. It helps the player to stay immersed and involved in the game. Game flow can be seen as a part of the game experience, where the player focuses on the game, has the feeling of control over the game, and has clear goals. Game flow occurs when task difficulty and player skill are adequately matched. As shown in figure 2.3, it is necessary to maintain the balance between the skill level and task difficulty to ensure the player stays motivated in continuing the game [19].

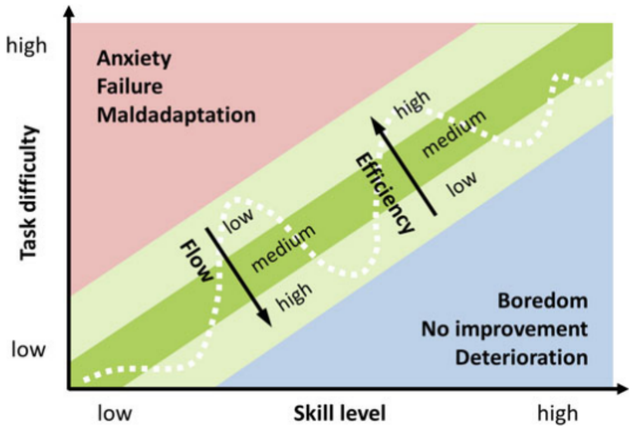


Figure 2.3: Balance between Skill level and Task difficulty [19]

The lifecycle and various iterations of developing a serious game can be found in figure 2.4. The development phase involves collecting information on the needs of the target user group (stroke survivors) and occupational therapists. Functional requirements may be defined with occupational therapists, and simple mock-ups may show the underlying elements of the game. In an iterative process, feedback is gathered, and depending on the result, modifications are applied to the mock-ups, requirements, and finally, to the game [19].

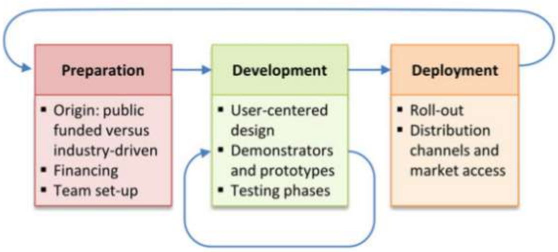


Figure 2.4: Lifecycle of a Serious Game [19]

2.3.2 Game Elements

> *When you strip away the genre differences and the technological complexities, all games share four defining traits: a goal, rules, a feedback system, and voluntary participation.* - McGonigal Jane [57]

As McGonigal Jane said in her quote, games include a goal, a set of rules, feedback, and voluntary participation. Further, the correct game elements are required to ensure that players stay engaged and have a meaningful gaming experience. Tuah et al [87] have compared gaming elements in various studies and extended this list with their findings.

1. Points: To indicate the player's performance, points are given for certain challenges or tasks.

2. Leaderboard: The player's scores and achievements for a task are shown in a ranked list. It can be publicly available where the overall score is shown, or when a certain game round is finished, it can be shown among the competitors.

3. Badges: A badge is a symbol that shows the achievement(s) of the player. Examples of earning a badge are when someone completes a challenge, gains a new skill, or reaches several points and gets to the next level.

4. Trophies: When a player accomplishes a particular task, an award is given as a trophy. Compared to a badge, a trophy is considered as something more exclusive.

5. Ranks: Players are positioned from the top to the lowest. Ranks encourage competition since everyone can know who the top players are, and it can be a goal to get among those.

6. Level: When the player reaches a certain number of points or completes different quests, he or she can move to the next level. Usually, the higher the level, the more difficult challenges await the player.

7. Story: A game can have a storyline with a plot built around a character.

8. Progression: Progress can be seen as milestones. With this, the player is aware of his current position wherefrom the player knows where they stand. Sometimes in the corner of the game, a progression bar is represented to show how many more points the player has to reach.

9. Challenge: A challenge is sometimes called a quest, which is a task that usually has increased difficulty on higher levels.

10. Roles/Avatar: An avatar can be seen as the player's identity and representation in the gameplay. The avatar is also related to the character.

11. Status: The status relates to the ranking of the player, also known as reputation.

12. Voting: Often, voting is used as an element for feedback to get information from the players. Players will, in turn, be rewarded with points or bonuses.

13. Feedback: The player should get a response for successes and failures in the game.

An example of the use of gamification and game elements is the training App *Freeletics* [1]. This App offers a training coach that guides the user through a training journey consisting of a 6-12 week program. After each workout, the user gives feedback on how the exercises were performed (e.g., with excellent form, needed breaks, had difficulty with one or more exercises) and if the next workout should have an adapted difficulty. Each workout brings several points, which are then calculated to determine the user's level. One can receive badges for different achievements: best time in a workout, different streaks (14 Perfect weeks, 2-Week Streak), completed training journeys, skill progressions (learning a new skill such as one-handed push-ups), completed god-workouts, and completed training sessions. An example is shown in figure 2.5. Also, skills can have milestones; for example, if knee push-ups and regular push-ups are achieved, the next milestone will be unlocked, which consists of one-handed push-ups. It also has the option to get applause on completed workouts by other athletes, and if a friend has also done the same workout, their duration can be seen, which enhances competition.

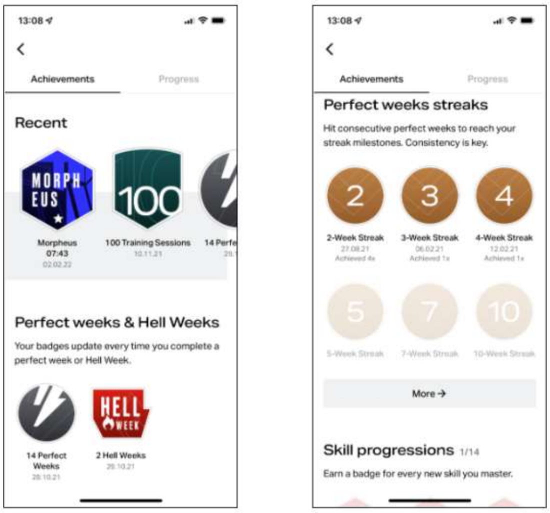


Figure 2.5: Gamification the Freeletics App (own Screenshot)

In the context of serious games, gamification is the application of game methodologies or elements to a non-game area [18]. The process of gamification must not always result in a game.

2.4 Multiplayer Games

A multiplayer game usually involves the interaction of one player with other players or against a bot. There have to be at least two players involved. Several types of multiplayer techniques affect the players' screen usage. The number of players and the type of game

[1] `https://www.freeletics.com/de/`, visited Oct 22, 2022

mode decide the game type. Players can use one screen together where they can take turns or have a split screen to play simultaneously. Another possibility is to have a shared screen where the players use one screen simultaneously. Multiplayer game genres have an impact on the game design itself. Factors such as the number of players, and technological aspects such as latency or control and input devices, determine the multiplayer genre. Genres can vary from strategy games, first-person shooters, simulation games, multiplayer online games, or virtual games [94].

Zagal et al. describe 4 characteristics of multiplayer games [96]:

1. Social interaction: while some multiplayer games have absolutely no social interaction, others have a great extent; sometimes, players can only complete missions when interacting with each other is present. Other times interaction occurs naturally but is not necessary to reach the mission's goal.

2. Competition and Cooperation: represent a multiplayer game, as it is impossible in single-player games. In competitive games, only one player wins, and in cooperative games, the players have to achieve a shared goal to win.

3. Synchronicity: a game is concurrent when it requires all participants to act simultaneously. Their actions are usually synchronized such that they do not act simultaneously; instead, when it is their turn (turn-based systems). Other games uphold the interactions of the players independently from each other. In that case, players do not have to be present simultaneously.

4. Coordination represents the control of the game process. A single individual or a computer can coordinate the game.

Bartle categorizes four player types. Figure 2.6 shows how differently player types want to influence things rather than interact with them and how much they want to focus on the players and the game world. Achievers like to accomplish a defined goal and progress in the game. They enjoy acting in the virtual world. Killers enjoy acting on other players. They act selfishly and want to dominate other players. Explorers want to explore the game world, interact with it, and gather knowledge about it. Socializers want to interact with others and get the most out of it [7].

Multiplayer games can be categorized into cooperative, collaborative, and competitive game modes. In cooperative games, players win or lose together. Once a player is not replaceable, and there is a dependency on each other, the game can be termed cooperative. Players must interact, communicate, and strategize to achieve common goals. In cooperative game mode, players complement each other's skills, knowledge, and resources. Players must work as a team, coordinating and complementing each other. In the competitive game mode, players compete with each other and want to defeat their opponents. The co-players are seen as opponents. The goal of each player is to win the game by being the first or scoring a certain number of points. The competitive drive

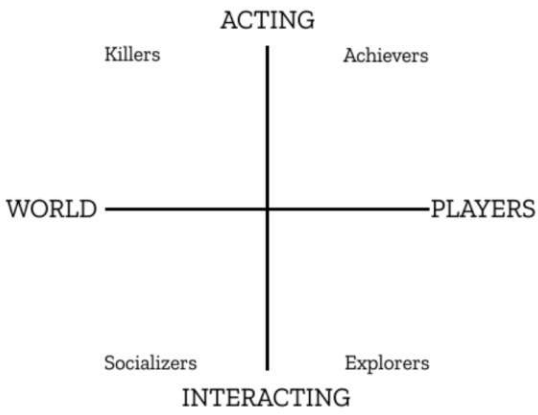


Figure 2.6: Player Types [7]

to defeat the opponent and win the game creates a driving force for improvement [59], [94].

A game can allow asynchronous or synchronous gameplay. In a synchronous game, all players must be connected to the game simultaneously to play with each other. It is also called simultaneous play, where many players play the game at the same time. An Asynchronous setting means a player can join or leave the game whenever they want. They can progress the game without depending on another player. The progress is stored, and other players may be able to see that result at any time [8]. According to Bogost, four characteristics of asynchronous multiplay exist:

1. "*Asynchronous play supports multiple players playing in sequence, not in tandem*" [8].
   Players play in sequence, where sometimes they play right after each other, and sometimes time passes before the next player makes their move. It can take place on the same device or on separate devices.

2. "*Asynchronous play requires some kind of persistent state which all players affect, and which in turn affects all players*" [8].
   Persistence of world (POW) means that the game world can continue even when the player is not online or playing the game.

3. "*Breaks between players are the organizing principle of asynchronous play*" [8].
   Sequential and interrupting gameplay is a characteristic feature of asynchronous multiplayer games. It is more flexible and casual for the players.

4. "*Asynchronous play need not be the defining characteristic of a game*" [8].
   Just because a game is asynchronous, it does not mean that it needs to be the center of the game. Instead, other features or elements may be more relevant to the game [8].

Important decisions to be made are the number of players, the target group if the gameplay is asynchronous or simultaneous for the players if it is a competition or a collaborative game, the duration of a game round, the matchmaking of players, and the flow of the game. Communication between players impacts how the game is played. Communication tools can be via chat, in-game signs, or voice communication. In the game, signs are often used in strategy games, which one can use to get the other players' attention. A chatroom is used to write messages privately or publicly. Communication over voice can be achieved by being in the same room or using an online tool such as Discord or Skype [94].

2.5 Multiplayer Serious Games

Pereira et al. study how the game mode can impact engagement and social involvement in the context of stroke motor rehabilitation. They distinguish between different multiplayer settings, mainly between collaborative and cooperative modes. Their game consists of a two-player upper limb rehabilitation game with 3 different modes: competitive, co-active, and collaborative. To their understanding, the various game modes can be identified as defined in the following [76]:

- Cooperative: players have different roles and need to work together to complete a task
- Collaborative: players have the same role and need to work together to complete a task
- Competitive: players play against each other
- Co-Active: cooperative with a shared field

The games were tested on healthy elderly individuals to avoid confounding factors that may occur after a stroke. Pereira et al. argue that it is important first to assess people who are healthy but of the same age range as most stroke patients without any significant deficits. This should allow them to analyze the effects of play modes on engagement and social participation.
The players in the game had to catch balls that were falling from the top of the screen. This was done by moving a virtual ring over the ball with a handle positioned on a table, as depicted in figure 2.7. The player with the highest score would win the round in the competitive game mode. In the co-active and collaborative game mode, the players had to work in a team. While in the collaborative mode, the player had to catch a ball of the same color, their score was simply combined in the co-active mode.
Their results include games in collaborative mode being the most influential for social involvement compared to the other game modes. Players depend on each other to perform a particular task successfully in this mode. This promotes significantly more empathy and behavioral involvement, which can be explained with increased attention toward others

Figure 2.7: Game Setup: Camera and Handles with Tracking Pattern [77]

since actions depend on each other in the game. Another reason is participants having higher cognitive skills and being more extroverted. Those who are more extroverted may also feel more empathy. For behavioral involvement, the collaborative mode may also be beneficial since players with lower skills will be supported by their co-player, and at the same time, the co-player will be more challenged. Their study showed that those who are the most extroverted benefit more from the collaborative game mode in behavioral involvement [76].

In the follow-up study [77], stroke patients were assessed for effects on engagement and social involvement in the context of a multiplayer game instead of healthy elders. The aim was to determine the most appropriate multiplayer game approach for motor rehabilitation. Another goal was to analyze how motor and cognitive impairments affect the game modes' experience and how personality affects preferences. As in the previous study shown, it was again shown how collaborative game mode is better for behavioral involvement. Participants with more severe cognitive difficulties experienced more empathy with the collaborative mode. Those with fewer motor skills, or an extrovert personality, also preferred collaborative or co-active game modes. Participants with better cognitive performance, less extroverted, and those with higher motor skills benefited

more from the competitive mode in terms of flow and challenge.
This is also a result of Novak et al.[68], where it is stated that the emotional stability and competitiveness of a player can predict if they prefer competitive or collaborative games, and also of the co-player. Those who enjoyed the competitive game mode would not necessarily enjoy the cooperative game mode and the other way around. A competitive mode may be more suitable when there is the possibility to play with someone in a closer relationship since they feel more empathy towards them and they can better deal with losing or winning the game [76]. Novak et al. also state that players prefer two-player rehabilitation games to single-player games as they have the possibility to interact with the other player. They suggest making more complex two-player games where patients from different rehabilitation clinics could also play with each other via the internet [68].

Goršič et al. [28] distinguish between people who like competitive games and others who like cooperative games. About half of the 29 participants in their study enjoyed playing competitive games, whereas the other half enjoyed playing cooperative games. They observed that people who enjoyed competitive games had higher motivation and training intensity, while those who preferred cooperative games also had higher motivation but no higher intensity.

To conclude, the competitive, co-active, and collaborative game modes are all suitable for engagement factors such as game flow, positive affect, and competence [77]. The collaborative game mode is the most useful for behavioral involvement, according to [77].

For someone with severe cognitive disabilities, the collaborative game mode is the most suitable since such a player could be paired with someone with higher cognitive skills. More empathy has been observed for those players in the collaborative game mode. Nevertheless, they still need to establish a strategy on gameplay and working together. Also, for players who have fewer motor skills or are extroverts, the collaborative or co-active modes are suitable [77].
For those who have better cognitive performance, are less extroverted, or have higher motor skills, the competitive mode has been the most suitable [77]. Also, several studies ([68], [77], [28] [76]) suggest that when people know each other by being friends or in some closer relationship, the competitive game mode is the most suitable.

According to [75], the co-active game mode, compared to the competitive, had higher motivation among the users. Those who enjoy competitive games also showed more motivation, and higher exercise intensity than the others [28], [68].

Novak et al. [68] suggest that the preference for a game mode is strongly correlated to the individual personality of the person. Those who enjoy competitive game modes do not necessarily enjoy collaborative modes and vice versa. Further, they suggest using emotional stability and competitiveness as an indicator for someone liking competitive gameplay.

To conclude, the preference for collaborative, competitive, and co-active game modes depends on various factors and needs to be carefully considered. Skill, personality, disabilities, and the co-player influence the game modes' preferences.

2.6 Matchmaking and Ranking Systems

The most crucial aspect of matchmaking, especially in health games, is to ensure fair play for everyone. A sound matchmaking system gives players a 50% chance of winning. The matchmaking quality is essential to make accurate predictions in the player's matchmaking and to have fun during the game since it influences the game experience. Players usually want to feel progression, hence it is not always recommended to show the ranking for everyone but instead to use a hierarchy (e.g., silver, gold, diamond players). Since players like to win, side activities and missions can be offered. Players and game developers have different constraints on the matchmaking systems: A player's condition ranges from the waiting time for a match (some do not want to wait too long) and game content to whom they want to play with. On the other hand, developers want to offer fair matches, keep the waiting time for a match low, and provide a variety of players to play against[98].

Matchmaking

Measuring player skill is critical to providing a good gaming experience and incentivizing continued play. Ideally, there would be enough players online at all times for each game mode and each skill level. However, in reality, there are not always players online at all times or who have similar skills, and not everyone wants to play in the same game mode. The equation 2.1 describes factors that influence the waiting time for a match. The waiting time decreases the more people are online. It increases the more game modes, the more participants and skills are needed for a match.

$$T_{Waiting} = \frac{N_{Modes} * T_{Match} * N_{Participants} * N_{Skill}}{N_{Online}} \tag{2.1}$$

$T_{Waiting}$ is the waiting time for the start of a match, N_{Modes} is the number of game modes available, T_{Match} is the average duration of a match, $N_{Participants}$ is the number of player's in a match, N_{Skill} is the number of skill-buckets needed for a game, and N_{Online} is the number of player's being online. Hence, it is better to have fewer game modes and similar skills should be needed for a certain game mode [30].

In figure 2.8, a matchmaking system flow is shown, made by Alex Zook [98]. He divided the matchmaking architecture into 4 components, and each component has to be analyzed on its quality:

- Queue: the players who want to participate in a game are placed in a waiting room.
- Match Builder: players from the waiting queue are matched together, and matching rules are applied. If the players' circumstances change (such as long waiting times and few players in the waiting pool), the defined rules can be eased. This needs to be done in an evaluation.

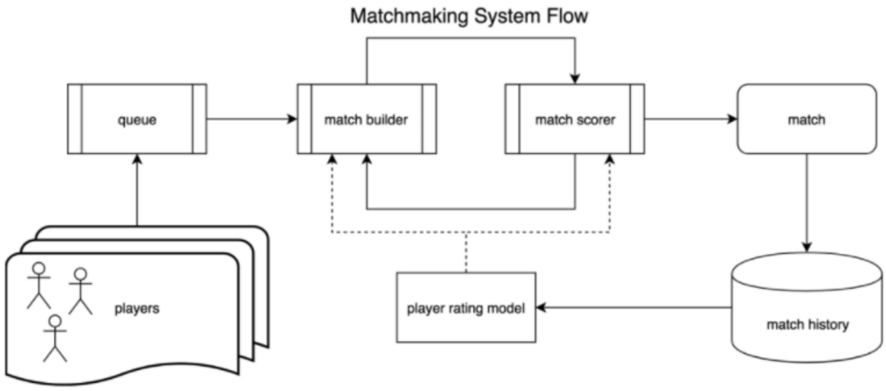


Figure 2.8: Matchmaking System Flow and Architecture [98]

- Match scorer: the match has a quality value, and based on that, the match is either canceled or carried out. If the players have different roles in the game, the roles can be rearranged, and a re-match is done.
- Player rating model: the player rating model gives an estimate of the player's skill based on their history. It should be analyzed how the rating system calculates the individual performance and if the rating is comparable to other players, hence allowing a match.

The player's game experience starts with the queuing system, hence this is an important component to begin with. The matchmaking scalability can be improved with queues by dividing the players into groups and subgroups. This may enable parallel matchmaking. The main focus of designing a queue should be the duration a player has to wait. Analyze when the players enter or leave the queue and how long they spend there. An example of a queuing discrepancy occurs when a particularly experienced player and many less skilled players are waiting for a match. Measures must be taken in such an event and if there are exceptionally long waiting times.
Match builders use rules to define appropriate matches. Games involving teams with different roles have further implications for matchmaking. Characteristics such as the size of teams, rating differences between teams, or the choice of roles in teams can constrain the matchmaking. An example of a match builder analysis can be a comparison of teams with different numbers of players in each of the possible roles to determine if one party has an advantage in terms of winning chances. This analysis could introduce a rule requiring both teams to have a specific role. Another rule could limit the number of certain characters in a game round. Other than roles, the size of player parties or rating differences influence the match.
While the match builders compose the players, the match scorers evaluate the quality of that match. They optimize the composition based on the information about the players in the match. They decide whether a match should be started or discarded or whether

the teams need to be reassigned. In competitive games, the win rates can be evaluated for analysis based on the score. Comparing the distribution of predictions with match outcomes across the range of observed predictions can be a metric for evaluating a scoring model. Then the performance of the match can be evaluated. However, when the game endures some changes, such as introducing a new character or skills, the matchmaking can become outdated.
With player rating models, an estimate of the player's skill is created; hence, the matchmaking rating can be updated. There are two approaches: either use the player's history or predict the outcomes of future games. A rating should have different properties: quickly learn the skill of new players, inactivity should be recognized and the resulting skill reduction, it should be stable, and it should be able to predict match outcomes. A win rate of 50% is optimal for the player's matchmaking, regardless of their skill level. Low win rates (below 50%) may indicate that optimization is needed. Regarding the rating of new players, there are a few options to enable fair and exciting gameplay while also learning their actual skill. A possibility would be having separate waiting queues, where only new players are entering. This way, they can also be protected from exceptionally experienced players. Another approach is to take the history of all the players and use their starting skill as an average for the first games of the new player [98].

Wardaszko et al. [91] distinguish 2 types of matchmaking: random and factor-based matchmaking. In a random or partially random matchmaking, all players are placed in a queue and randomly connected. Semi-random matchmaking divides players further into groups (e.g., based on language or location). The disadvantage of such a system is the unpredictability of matches, in which novice players may be randomly matched with experienced players. This leads to lower satisfaction among players. A significant advantage is that players only have to wait a short time for their match.

According to the authors, factor-based matchmaking can be skill-based, role-based, technical factor-based, or engagement-based systems:

1. Skill-based systems: a rating is defined, which measures the skill. An example of such matchmaking is the Elo System. The authors argue that such matchmaking might be suitable for chess but not live games. Finding suitable players within a certain time range may be challenging.

2. Role-based systems: those are used in games where a type of class or role is played, such as LoL or WoW. In such a system, it is hard to compare the classes between each other, and players could misuse the choice of roles by choosing a role they are not good at but skipping the waiting times.

3. Technical factor-based systems: used in cross platform online games, where the matchmaking is optimized on the device and latency information. This matchmaking provides fair play by matching such that players have similar game behavior as their opponent or co-player and is especially important for FPS games.

4. Engagement and churn-based systems: the term engagement indicates the likelihood of a player continuing to play in the same session and in the near future. The churn risk describes the probability that a player leaves the game and stops playing it for a certain time range. Also, instead of matching based on the skill level, the match is done based on the win-loss track record and the forecast of the churn risk.

In the following Skill- and Engagement-based Systems are described:

Skill-based Systems
The 3 most used skill-based matchmaking systems are Elo, Glicko, and TrueSkill. These systems rate players, which can also be seen as an estimation problem. Bell curves, or gaussian probability densities, are used to model the probabilities of game outcomes for a player [30].
The most known and widest-used matchmaking algorithm for competitive games is the Elo rating system, invented by Arpad Elo in 1960. Initially, it was used to match chess players according to their skills, and nowadays, it is extended by different games. Elo is based on the normal distribution and assigns every player a value R, which is the skill level. The skill level R is the true average strength of the player. For a fair matching between 2 players, A and B, the probability of A winning (expected score) is calculated as follows [26]:

$$E_A = \frac{1}{1 + 10^{(R_B - R_A)/400}} \tag{2.2}$$

If player A wins, the game's score will be 1, 0 if lost, and 1/2 if there is a draw. When the first round of the game is finished, the Elo value of the players is updated with the following:

$$R'_A = R_A + k * (S_A - E_A)$$

where k is a weighting constant, S is the score of the game, and E_A is the expected score, or also the probability that A wins. The weighting constant k can be interpreted as the weight which is given to the new game performance relative to the pre-game evaluation. It shows the maximum amount that someone's rating can change. The larger the value k, the more the rating can be changed. A well-proven K-factor for beginners is 32 since they have high fluctuations. To support weaker players, the K-factor can be even higher. Usually, experienced players have a K-factor of 10. In figure 2.9, the change of the K-factor in relation to the weight of the last game can be seen [63]. The result of the game, S_A, can be 1 if the player won, 0 if he or she lost, and 0.5 if there was a draw. The rating goes up if a player wins and plays better than expected. Conversely, if the player plays worse than expected, it goes down. When the player plays exactly as expected, there is only a small difference in the rating. Thus, there is no advantage for

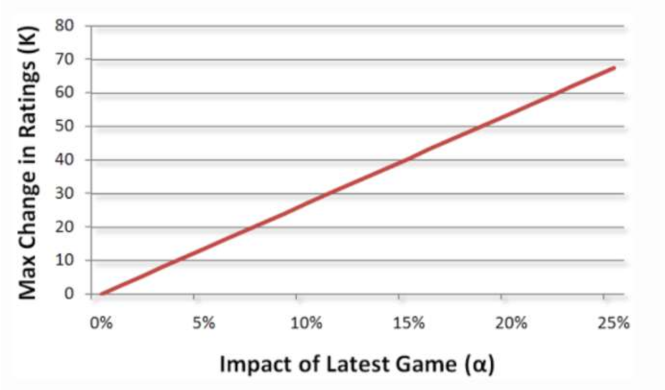


Figure 2.9: Change of the K-factor in Relation to the Weight of the Last Game [63]

strong players to play against weak players when they want to increase their scores. If player A is 0 points better than B, their chance of winning or losing is 50%. The rating of a player is determined by the rating of the opponent and the results against him. After the game, the points are re-calculated; for example, player A is the one with a higher ranking, and player B with a lower ranking. Then, if player A wins against B, only a few points are deducted from B. When player B wins, many points are deducted from player A. In case of a draw, player B gets a few points, and player A loses a few [60]. Over time, with each round, the score becomes an actual indicator of their skill.
The advantage of Elo's update formula is that it involves the history of all played games of a player but gives more emphasis on the game played recently. This is especially helpful when a player takes a more extended break from playing. A disadvantage of this formula is that it is not suitable for teams playing against each other. It is only suitable for 1 vs. 1. Further, it is not suggested to use this formula for an initial game rating since it can take a long time until the skill rating is a correct representation of their actual skill. When a player has not attended a game and hence has no ratings, so-called provisional ratings are conducted. For instance, age can be a parameter to assign a rating.

Another matchmaking approach is the Glicko-System. Mark Glickman invented the Glicko algorithm in 1995. Glicko extends the Elo-System by a rating deviation, and the Glicko-2-System has an additional rating volatility. The rating deviation (RD), also called standard deviation, measures the uncertainty in a rating. A high RD means that the rating is unreliable, which can be because a player is not competing regularly or has only started playing games. The rating becomes more uncertain when someone is not playing, hence the high rating deviation shows the uncertainty. If someone plays more frequently, the rating decreases since there is more information on the player's skill. The RD can change even if a player is not playing and it also changes from the outcomes of the games [24].
An interval indicates the player's skill instead of a rating. A 95% confidence interval can be used: the lowest value in this interval is the rating $R - 2 * RD$. The highest value is $R + 2 * RD$.

The Glicko rating could be a disadvantage for someone who plays very often because the RD will be very small for that player. This can cause the RD to stop changing even though the player is improving. Glickman, therefore, recommends that the RD never drops below a certain threshold, such as 30 [24].

In the updated Glicko-2 system, each player has a rating r, rating deviation RD, and rating volatility σ. The added volatility indicates how far apart the data is spread out. It measures the degree of expected fluctuation in a player's rating. When a player's performance fluctuates, for example, when he or she suddenly performs very well after a steady period, the measure is high. On the other hand, it is low when the player performs in a constant manner. Glicko-2 is suitable when a player has participated in about 10-15 games in a rating period [25].

The third ranking system, TrueSkill, was developed by Microsoft Research for the Xbox [33]. It is a bayesian skill rating system. The Gaussian curve allows to calculate how likely something should be, given an average mean skill μ and the standard deviation σ, which measures the uncertainty of the estimate. Hence, σ is also called the degree of uncertainty, where the smaller the sigma, the less uncertainty there is. The standard deviation ranges from 1-3: 68% of the results will be obtained between $\pm$ 1, 95% within 2, and 99.7% within 3 standard deviations. TrueSkill suggests using μ - 3σ for an initial skill estimation. 3σ is a good estimate for a player's skill since a player is probably better than this but not worse than the estimate. TrueSkill splits the results of a match into several small parts with the intent of easier processing. Then those parts are compared with each other, and pairwise comparisons are created. TrueSkill can also be viewed as a factor chart. The minimum number of games per player also depends on the game mode and team size. Depending on the number of players, the true skill can already be determined after a few game rounds. In an 8-player game with the game mode free-for-all, it can take only 3 games for each player to have an appropriate ranking of their skill. However, with a 2-player game free-for-all, the ranking is accurate after 12 played games. An advantage is that new players are easy to model and do not have provisional games or rankings. Their true skill converges quickly. Another advantage is that 3 vs 3 players or even bigger team sizes can be modeled [58].

Engagement and Churn based Systems Zhengxing et al. [16] developed a new framework, engagement optimization matchmaking (EOMM). In this framework, matchmaking is considered an optimization problem in which the total commitment of players is maximized. Their paper imposes conditions on the applicability of the matchmaking systems, and with real game data, the advantages of EOMM over traditional matchmaking methods are analyzed. EOMM has a skill model, churn prediction, and a graph-matching model. Player Engagement can be measured by time or money spent in a game, the number of games played in a time frame, or the churn risk. They define churn as a player having no gameplay within a time period, such as a week. Their framework measures the player's churn rate after each matchmaking decision. Then all waiting players are modeled as a complete graph, which can be seen in figure 2.10. A node in the graph represents a player, and the edge between two nodes is the sum of churn risks when they get paired. Only non-overlapping pairs are created. They solve the minimum weight perfect matching (MWPM), leading to optimized engagement matchmaking. The MWPM is the sum of the lowest edge weights when matching.

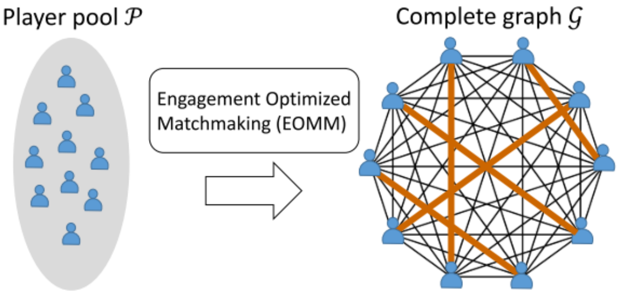


Figure 2.10: EOMM on a Complete Graph [16]

A pool of players $P = p_1, ..., p_N$ is defined, where N is an even number so that every player can be paired. The churn risk of player p_i after matchmaking with player p_j is defined as $c_{i,j}$.
$c_{i,j} = Pr(p_i churns|s_i, s_j) = c(s_i, s_j)$.
The state of the player (s_i) can be features such as the installation date, skill, gaming frequency, style and many more. $c_{i,j} \neq c_{j,i}$. A pair assignment of players is denoted as $M = (p_i, p_j)$. The players disengagement rate is equal to the sum of each players churn risks, which is then converted to a minimum weight perfect matching problem:

$$M^* = argmin_M = \sum_{(p_i,p_j)\in M} c(s_i, s_j) + c(s_j, s_i) \tag{2.3}$$

In the graph, the edge between the nodes of two players has the weight of $c_{i,j} + c_{j,i}$. Finding an optimal M^*, where all possible pair assignments are compared, can be too time-complex to be feasible in finding a match. Therefore, it is recommended to use already existing algorithms that have solved the MWPM problem in the worst time complexity of O(N^3). Another solution is to use greedy algorithms or solve the MWPM in parallel [16].

In the case study, Zhengxing et al. compared their matchmaking strategy with skill-based and random matchmaking for 100, 200, 300, 400, and 500 players in the player pool. They used real game data in their simulation. For each matchmaking method, the waiting pool was created, then the pairs got assigned, then the match outcome was simulated according to the probability of the skill model for winning, losing, or draws. In the

	Elo	Glicko/Glicko-2	TrueSkill
Statistics	Normal distribution	Bayesian	Bayesian
Players	1 vs. 1	1 vs. 1	Multiple Teams
Accurate Ranking	> 10 Games	10-15 Games in a Rating period	3-20 Games (depends on team size)
Initial Setting	high K-factor	highest confidence interval	Flat & Wide gaussian curve: μ - 3σ
Ranking Update	After each game	After each tournament	After each game

Table 2.1: Comparison of Elo, Glicko/Glicko2 and TrueSkill

end, the retained players were collected and compared among the different matchmaking strategies. Their results included the outperformance of EOMM compared to the other strategies, except for the player pool size of 100. The authors suggest from this result that for small pool size, the randomness factor has a higher impact but to approve this finding, more simulations should be done. EOMM retains more players compared to skill-based matchmaking by about 0.7% [16].

Summary To conclude, the update of a player's ranking in Elo, Glicko, and Trueskill depends on the game outcomes (mainly wins and losses), not on the game achievements [30].

In table 2.1 a comparison of the Elo, Glicko, and TrueSkill can be seen. According to Elo, the rank calculation includes predicting the player's result (expected result), observing the actual outcome, and finally updating the player's rating. Glicko calculates the rank after a collection of matches in a certain time frame, such as 10-15 games, which is also called a tournament. TrueSkill considers teams and calculates the probability of a player's true skill by considering the average skill and uncertainty of that skill.
For finding the right skill of a new player, TrueSkill is the most suitable. The skill can already be considered accurate after very few games. Zook [98] also confirms that these ranking systems ignore the information on the player's contribution to their team or, in general, the contribution to the game. Also, no information is provided if the game was barely won or lost. Instead, the focus lies on the probability of a player winning against another.

Visti et al. suggest that the reason for no further advancements in rating strategies in recent years is that skill-based systems are good enough. They argue that for games such as chess, or in general, 1v1 game settings, it should be sufficient to use those rating systems. However, there should be actions that have value and contribute to the player's performance. These values should be included in the calculation of ratings [89].

Alternatives to skill-based ranking systems, are engagement-optimized and churn-based systems. Zhengxing et al. [16] propose that matches suggesting fair play due to having equally skilled players paired is not optimal for engagement and player experience.

Instead, an alternative is to use engagement-optimized and churn-based systems that maximize overall player engagement: The churn risk after matchmaking represents the disengagement of a player. All players waiting in the matchmaking pool form a complete graph. The minimum weight perfect matching (MWPM) problem is solved by finding pairs with the minimum sum of edge weights, which represent the churn risk. EOMM was initially designed for 1 vs 1 player settings, but the authors suggest it can be easily converted to team-based games. Then instead of pair assignments, grouping assignments would have to be done in the complete graph.

2.7 Usability Engineering

According to Nielsen usability consists of 5 characteristics [65]:

- Learnability: the system should be easy to learn
- Efficiency: once the user learns how to use the system, they should use it productively
- Memorability: if the user has not used the system for a long time, it should be easy for them to get back into it
- Error: low error rate, if the user makes mistakes, it should be easy to recover from them
- Satisfaction: it should be pleasant to use so that they are satisfied

According to Macleod and Rengger, general Usability Testing Methods include expert methods (where usability problems are identified), theoretical methods (where the theoretical user behavior is compared to the actual behavior), and user methods (where end users interact with the system). For user methods, they further classify observational analysis and survey based-methods. In observational analysis, a user interacts with the prototype while the developers observe them. In survey-based-methods, the user fills out a questionnaire after interacting with the system [53].

Moreno-Ger et al. developed the Serious Game Usability Evaluator (SeGUE), a framework that can be used to assess usability. It consists of system and user dimensions. System dimensions refer to gameplay, game functionality, layout, and content. Errors in the game functionality cause profound changes in the implementation. User dimensions describe the learning and reflection phases of the game and the emotions with which the user reacts, such as being satisfied, frustrated, confused, annoyed, or even unable to continue playing the game.
They also present guidelines for assessing usability events: The evaluation session should have clear objectives. Testers must be selected who are similar to the actual end users. The tasks to be performed by the testers must be prepared. After a short introduction of the game, the testers should play independently while expressing their thoughts. After

the test session, the evaluators review the events that happened and determine the results. Then they prepare the changes that need to be made to the game [62].

Prototype usability testing is important when the game is intended for a diverse group of users or when these users are not technically proficient. Especially with serious games, the learning experience and motivation can be easily affected, hence, usability is essential. Further, in a serious game, the user should explore the application to learn new skills or train skills. Hence it needs to be distinguished between lousy UI design, where the user flow is disturbed and unclear, and between exploring and discovering the application [62]. Obstacles are possible if they enable the players to achieve something, however, frustration within the game is to be distinguished from frustration with the game. The latter is not desired.

Test users should be similar to the target audience and have traits relevant to the purpose of a serious game. As for the number of test users, according to Virzi, 5 users should be sufficient to identify 80 percent of possible problems [88]. Nielsen and Landauer suggest, with a mathematical model (maximum benefit-cost-ratio), that 4 testers are sufficient, but this number is dependent on the size of the project [66].

2.8 Requirements Engineering

Requirements Engineering is a process that identifies stakeholders and their needs. Stakeholders (paying customers, users, and developers) can vary and have different - even conflicting - goals. Their goals depend on the tasks they need to accomplish. Documentation of findings on the stakeholder's needs is necessary for analysis, communication, and implementation [69].
Requirements engineering involves the discovery, elicitation, development, analysis, verification, validation, communication, documentation, and management of requirements [39]. Others name five main activities: Elicitation, Analysis and Negotiation, Documentation, Validation, and Management [74]. Requirements elicitation involves identifying the need of the stakeholders. Requirements analysis ensures necessity, completeness, and feasibility [74]. In the following Requirements Elicitation will be described in more detail.

Requirements elicitation aims to discover and define requirements with the help of stakeholders. The stakeholders and system boundaries are identified to define problems that have to be solved. The goals of Stakeholders indicate which requirements a system has to fulfill. The domain, business needs, system constraints, and the problem must be understood. However, users often can not express their needs; thus, collecting information on the tasks they are currently performing and those they want to perform can be valuable. Authors differ differently between requirements elicitation techniques and requirements analysis techniques. Paetsch et al. see the JAD technique as a requirements analysis technique, but Escalona et al. view it as a requirements elicitation technique. Paetsch et al. suggest interviews, use cases/scenarios, observation, focus groups, brainstorming, and prototyping as relevant techniques. When using interviews, they differentiate between closed interviews and open-ended interviews. In closed interviews, pre-defined questions

are used. An open-ended interview involves stakeholders discussing their needs without a set of specific questions [74]. The interview process involves identifying stakeholders, preparing the interview, conducting the interview, and documenting the results. [21]
Paetsch et al. suggest that brainstorming has 2 phases: in the first, the ideas are collected, and in the second, they undergo discussion. Brainstorming helps to understand the problem domain [74]. According to Escalona, the goal of brainstorming is to collect non-evaluated ideas from the stakeholders [21].
Other techniques suggested by Escalona are concept maps, Sketching and Storyboarding, use case modeling, JAD (Joint Application Development), and questionnaires. When creating concept maps, graphs represent concepts and their relationships. Sketching and Storyboarding are used for schematic representations of user interfaces. Use case models contain actors and the relationship to the use cases. They are used to define functional requirements. Questionnaires can be done during an interview or separately and include short and concrete answers [21].

Interviews
To find the user's needs, they need to be involved in the design process of a prototype.
- Questionnaire Interviews: questionnaires are complex because the context of questions or the wordings can have different meanings to the individual participants [27].
Abras et al. suggest the use of background interviews and questionnaires for data collection that is relevant to the users' needs [2].
- Open-ended Interviews: The respondent to the interview can answer the question as they want to. The interviewer can ask for more details [27].
- Focus Groups: to discuss the issues and requirements with various stakeholders in a group setting [2]. They allow natural interactions between the interviewees and interviewers. A disadvantage is that someone does not feel free to say whatever he or she wants because of group pressure[27].

Prototyping
Prototyping methods involve low-fidelity and high-fidelity prototyping. They range from sketches on paper, wireframes, mock-ups to clickable prototypes. Prototyping is used when requirements are unclear or to obtain early feedback from stakeholders [74].

Rapid prototyping should solve most design problems. Heaton proposes 7 important elements of rapid prototyping [32]: Start early (even before the decision on hardware and software). Involve users in the design process from the first iteration onwards. Use minimal design functionality. Have multiple iterations. Use suitable prototyping tools. Throw away the prototype when it does not meet the requirements. Finally, do not spend too much time prototyping.

In the early design phases, typically low-fidelity prototypes are used. Low-fidelity prototypes intend to represent concepts, design options, and screen layouts. They show approximately how a design can look. An example of a low-fidelity prototype is a paper and pencil mock-up. Such mock-ups are unsuitable for providing details such as navigation or user interactions within the application. They are inexpensive, simple, and fast to create. In comparison, high-fidelity prototypes are entirely interactive. Users can enter data into input fields, click buttons, be routed to the next screen, and interact as if it were the final product. High-fidelity prototypes trade off speed and accuracy. Compared to low-fidelity prototypes, they take longer to make and are more expensive [80]. Figure 2.11 shows an example of designing a login screen, where a pencil and wireframes create first low-fidelity prototypes and then result in high-fidelity prototypes.

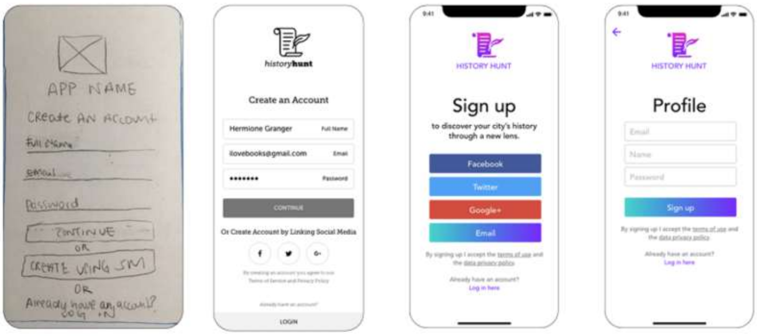


Figure 2.11: Prototyping: from Low-fidelity to High-fidelity[2]

In summary, Rudd et al. recommend using low-fidelity prototypes to evaluate user requirements and develop ideas on how the product could work. It helps to examine early concepts and choose the design and user experience. They are great for exploring alternative designs at low cost. In addition, high-fidelity prototyping is to create a specification for programmers and information developers. The specification should include a written description, user guide, and corresponding screenshots. It is also suitable for testing user interface issues [80].

[2]https://michelleytlock.notion.site/History-Hunt-7686dffb433f49bcbb1062f8154d93fa accessed Nov 04, 2022

CHAPTER 3

State of the Art

This chapter offers an overview of existing solutions for stroke rehabilitation. Various serious games have already been developed to support rehabilitation after having a stroke. Since nowadays patients go home earlier, therapists are involved in outpatient therapy. The patient must continue rehabilitation with at-home exercises. As therapists do not supervise patients at home, it is essential for the patient to stay motivated. With Gamification elements, serious games can offer the necessary motivation. Idriss et al.[36], Brox et al.[12] have already shown that serious games can increase rehabilitation motivation despite repetitive exercises. Gamification can contribute to a distraction of pain and boredom [13].

Serious games, however, often have expensive hardware that needs a setup. Therefore, as presented in this work, a mobile application is a promising alternative.

3.1 Simulating Players in a Collaborative Multiplayer Serious Game

Wendel et al. [93] developed a method for simulating players. Since opponents or teammates are often hard to find, they developed a simulation of players, which should model realistic player behavior. They implemented their model in an existing collaborative multiplayer serious game ("Escape From Wilson Island"). This action-adventure game is designed for four stranded people on an island who have to escape. To succeed in fleeing from the island, the players must collaborate: build a shelter, collect food and build a raft. Figure 3.1 gives an overview of the developed simulation model. The game gives information about its state to the player simulation, which gets processed in the *Perception Module*. Subsequently, the Perception Module updates the *World State*. When the game state changes, the *Player Model* is updated. The Player Model represents the players' gameplay style, knowledge, and communication skills. *Planning Module*:

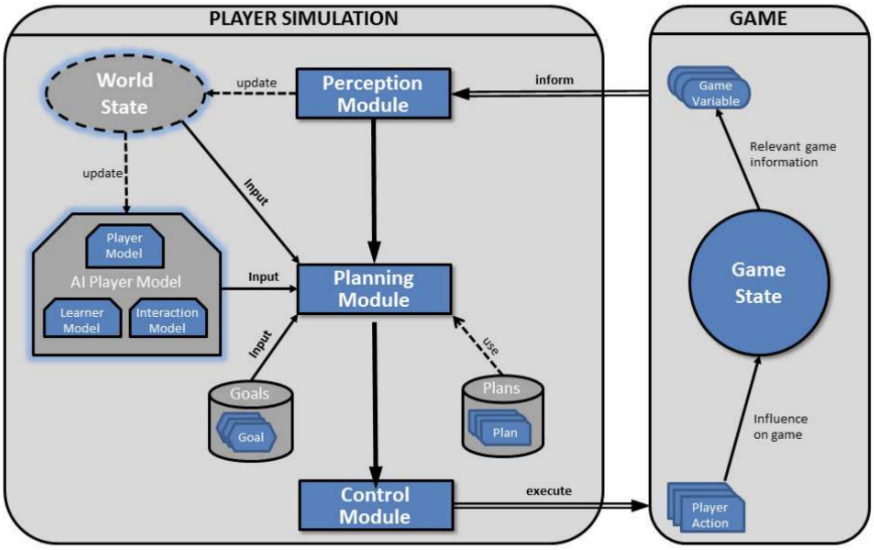
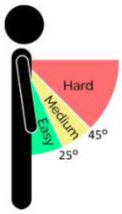


Figure 3.1: Simulation of a Player [93]

evaluates the AI *Player Model*, information on the World State to make decisions on the following plans. The player's goals depend on the player's model and skills. A complex goal can only be reached by having a plan, a set of consecutive actions. The model uses plans to model player actions and decides which goals to do next based on the current game state. The *Control Module* determines the player's actions.
To test the results, the *AI Player Model* has three variables that can be changed independently for evaluation. The variables comprise the design of the player model, the learner model, and the interaction model. Concluding, the simulated players act as expected concerning changes in the player, learner, and interaction models. Furthermore, with this model, it is possible to adapt the player's behavior.

3.2 Adaptability of Serious Games and Difficulty Adjustment

Pinto et al.[78] analyzed how the adaptability of difficulty based on the players' ability in a serious game can solve the motivation problem in stroke rehabilitation. Using adaptive difficulty for a rehabilitative serious game has two main benefits: to keep the player in a "flow state" and to deal with the patient's impairments by increasing or decreasing the difficulty depending on the patient's progress with the exercise. The goal is to keep the difficulty low enough to avoid frustration and high enough to keep them engaged [78].
They had 4 mini-games: *Abstract Masterpiece, Boat Sailing, Classic Rock, and Butterflies*. An excerpt of the games is shown in figure 3.2 (b), where the top left image is the game *Abstract Masterpiece*, the top right image is *Boat Sailing*, bottom left *Classic Rock*, and the last remaining image is *Butterflies*. The adaption of the difficulty levels ranges from



(a) Difficulty Adjustment based on Arm Movements

(b) Examples of 4 Mini-Games

Figure 3.2: Adaptability of the Mini-Games [78]

easy to medium to hard Figure 3.2 (a) shows the degree points at which a difficulty level is classified. Nevertheless, participants got stuck at the lower or higher difficulty level, which indicates the need for more difficulty levels. The state machine controls the player's transition from one level to the next. If the player is having difficulty, they are moved to a lower level. The current level is upheld if the player remains consistent in their movements. The games addressed upper-limb rehabilitation.
In *Abstract Masterpiece*, the player must flex the upper limbs to hit the paintball. Depending on the difficulty level, the ball appears in its respective position. When they hit their target, the ball lands on a white canvas, creating an abstract painting.
Boat Sailing is a game where the patient sits in a boat and steers the boat by moving their forearm.
The game *Classic Clock* takes place in a living room with a clock in it. The player has to imitate the movements of the clock's pendulum. The difficulty of this game can be increased by making the pendulum swing faster or by increasing the range of motion.
In *Butterflies*, the flexion of the upper limbs is again trained. The player's task is to touch butterflies.

3.3 Adaptive Mapping in a Multiplayer Serious Game

Virtual Reality (VR) Environments are popular for multiplayer serious game rehabilitation studies. One example of a game in a VR environment is by Maier et al.[54]. They developed a multiplayer serious game which can improve the patient's performance in at-home rehabilitation. Their game included an adaptive mapping method compensating for the player's motor impairments. This, in turn, allows them to play with other healthy players on the same level. They conducted a psycho-social study of the patient's social environment and tested the game in at-home experiments. The Virtual Reality based rehabilitation tool targets motor recovery of upper limbs. The game was similar to air puck, or airfield hockey, which is a two-player game. An example of the game setting is displayed in figure 3.3, where two players throw the puck by moving their upper limbs.

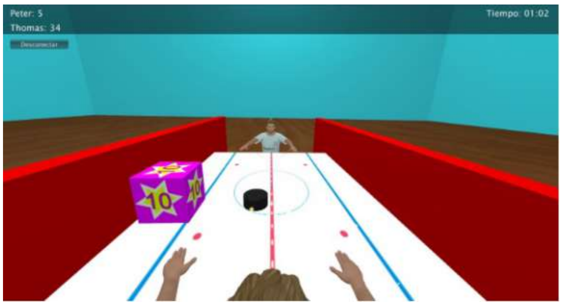


Figure 3.3: Two Players playing Air Puck [54]

In the game, one player has to hit a puck to another player over a field and vice versa. They have to hit the puck with their hand; if one player can not hit it back, the opponent gains a point. During the game, boxes (as in figure 3.3 the pink box) can appear on the playing field, and if a player hits one of those boxes, they gain extra points. Depending on the player's capabilities, the system can adapt and determine how much support the user's movements need to accomplish the task. With the help of adaptive mapping, the player can achieve the game goals more quickly. It learns how much support the player requires to complete a task. This allows the player to perform movements in the virtual environment that they would otherwise be unable to perform in real life. Thus, performance differences among the players are balanced out. For this reason, the game's outcome cannot be predicted based on the player's status (caregiver or patient). Users are enabled to perform movements that they cannot yet perform in the real world. Hence, with the adaptive mapping methodology, a player can play against whom they wish. It can be a therapist, a family member, or a friend. Stroke patients are enabled to interact with each other at the same level. The result of the study is that players stayed motivated and played more rounds than required. It helped improve social interaction and acceptance for the patient [54].

3.4 Home-based rehabilitation in a Multiplayer Serious Game

Tsoupikova et al. [86] developed the *Virtual Environment for Rehabilitative Gaming Exercises (VERGE)* system for home therapy. The games allow multiplayer gameplay and are designed to train movements important for motor control of the upper extremities. According to the authors, the players can interact with therapists, family members, or other stroke survivors as their opponents. Three games were provided on two computers with Kinect, where players had to use their arms and hands. The VERGE system consists of a laptop, an Xbox Kinect sensor (Microsoft Corp, Redmond, WA), and a pen mouse for every user. The avatar controls the player's movement. The goal of the games (Ball, Retracing, and Food Fight games) was to move the avatar and the view of the room. Figure 3.4 shows the game design. They hypothesized that training with someone else

(a) Ball Bump: send the ball to the other side

(b) Food Fight: throw food at the other avatar

Figure 3.4: 2 Games from the VR Environment [86]

leads to greater training compliance and intensity.

They first tested the VERGE system in a laboratory setting and then in a home-based setting: For the evaluation, 15 participants with chronic upper extremity hemiparesis were obtained. The intervention lasted for 3 weeks in a laboratory setting. The participating stroke survivors had 3 training sessions per week that lasted one hour. One session used the VERGE system, another used an existing VR environment, and the third session used a home exercise program (HEP). The study personnel in the laboratory had the role of being the other player in the VR environment. The HEP consists of exercises that must be done at home in a seated position.
Overall, participants had a great interest in continuing home-based training: In their study, all participants said they would like to train 2-3 times per week at home. Two-thirds of the participants said they would be willing to do home-based training six to seven times per week. They conclude that multiplayer VR environments are suitable for home use [85].

After the laboratory study, the authors extended the VERGE system with the received feedback and started an at-home-based study [84]. This study lasted for 4 weeks, and the users had to perform 4 training sessions each week. In 2 of the weeks, the multiplayer VERGE was used, where again, the study personnel served as the other player. For the other 2 weeks, the single-player VERGE exercises were done. In single-player mode, the task was to throw food at targets instead of throwing food at the opponent.
Overall, in the multiplayer mode, the patients trained longer, and moved their paretic hand more than in the single-player setting. They even improved their score on the *Fugl-Meyer Assessment of Motor Recovery after Stroke.*

Usually, high costs are an obstacle to introducing such new technologies. However, in this study, there were hardly any costs that would allow this technology to be used. In addition, the games are developed with Unity 3D, but can also be run in web mode, so the software does not have to be installed on the computer (which could also be a bottleneck due to the high processing power required). There were players who had little or no computer skills and could still play the games and use the system. A significant advantage is that such a system can be used for progression tracking, where metrics such as the training duration, hand placement, velocity, joint kinematics, and performance are easily measurable. This data can be evaluated and provide further assistance in rehabilitation. In this study, the use of multiplayer also proved to be a great advantage, as it provides motivation and reduces the feeling of isolation among players.

3.5 Regular Games with Matchmaking

So far no serious games include a matchmaking strategy. Therefore other games will be considered, such as League Of Legends which is a multiplayer online battle arena (MOBA) game or Overwatch which is a Multiplayer-Ego-Shooter.

In general, Elo's matchmaking system is used in athletic sports (Universal Tennis Rating (organizations that use it are Intercollegiate Tennis Association and World TeamTennis), FIFA, NBA, etc.), board games, card games, video games (Overwatch uses it, Counter Strike Global offensive uses it with Glicko2, World of Warcraft used it in the past and now switched to TrueSkill), FaceMash (previous version of Facebook), and tinder used to use it) [60].

League of Legends League of Legends (LoL) Matchmaking Rank (MMR) [70]: A player's strength depends on whom they are playing against. The rank is calculated according to whom the player has defeated and against whom the player has lost. According to the LoL documentation, the system tries to match players so they have a fair chance (50:50) of winning the game. It also tries to allow players to choose which position they want to take in a game. The player must specify two preferred positions, with the second serving as a backup. Further, it takes care of minimizing the queuing time of finding matches. As for matchmaking, an adapted version of Elo ranking is used. Usually, Elo is for two-player games, but in LoL, it is adapted for teams playing against each other. Each player has an MMR unknown to the players, and matchmaking for a team is based on their MMRs. Contrary to MMR, there are league points (LP) where players can see their rank and points. MMR has an influence not only on the team matches and opponents but also on the LP. Meaning if a player loses a game, the LP will also get less and vice versa for winning a game. If a player plays over a long period of time and wins many games, the MMR will increase compared to the rank.MMR only changes when a game is won or lost; hence it does not change when someone takes a break from the game for a period of time. Each game mode has its own ranking [42].

Overwatch 1 Another example is Overwatch 1, which had its servers shut down in October 2022, yet it used the Elo ranking system prior to that. It had different play modes, and in the following quick play and competitive play are considered: In Quick Play, players compete against each other based on skill, time, ping, group size, and account level. Team members should have similar skills to the opposing team. Skill is a hidden matchmaking property based on a player's performance in Quick Play. Time and ping are essential factors to consider, as players want to be matched quickly and should not experience any latency. The group sizes of the teams playing against each other must be equal. The account level of the players playing against and with each other should also be similar. Players also have the option to leave the game early since it is perceived as a casual game. However, this will result in a points deduction for them [22].

In competitive play, more emphasis is placed on matchmaking accuracy as opposed to quick play.The players have to play 5 placement matches, assigning each player a skill rating (SR) from 0-5000. If a player with a high SR plays against a player with a low SR, the player with the higher SR wins. Their rank can also be viewed publicly, where the SR is categorized into bronze, silver, gold, platinum, diamond, master, and grandmaster. Players participating in competitive rank for the first time receive a higher SR gain and loss until 10-20 rounds are played. If players in the categories master or grandmaster (SR from 3500) could not keep up with their minimum skill rating, they would instantly be moved to a lower skill rating. The players from the other categories have the chance to play 5 games, and if they still can not meet their minimum SR, they are ranked lower. In a ranked match, 2 teams compete against each other, with team assignments based on players with similar SR. The opposing team is formed based on the average SR of each team. After the match, each player's SR is updated accordingly, depending on whether they won or lost. In case of a draw, nothing changes [22].

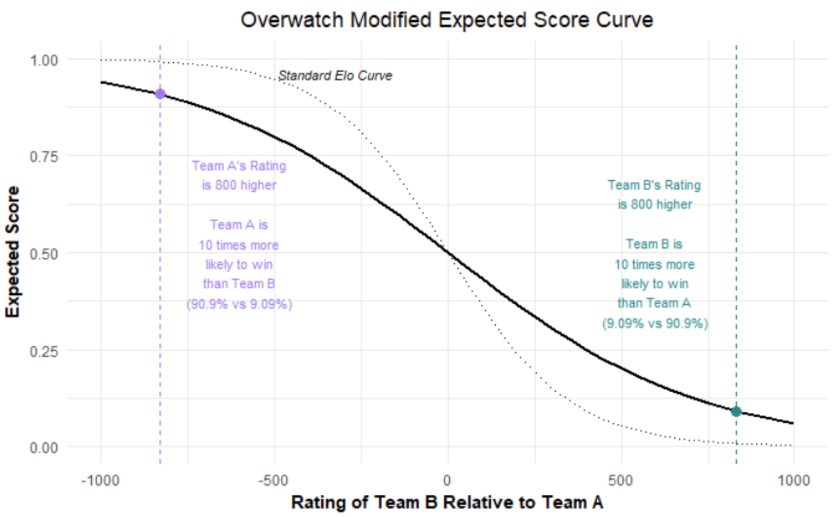


Figure 3.5: Overwatch Modified Expected Score Curve compared to Elo [56]

Lance McDiffett has written an analysis on matchmaking in competitive play [56]. By analyzing 3000 Competitive Overwatch games, he wanted to determine if and how much the Elo equation has been modified. The author's goal was to calculate which k-value is used by Overwatch for the Expected Score Equation 2.2, which has the standard value k = 400. Preliminary analysis showed that competency scores were generally evenly distributed between teams, with an average difference of 100 competency score points.

Finally, the author found that Overwatch uses a value close to 800 for k instead of 400. This results in the curve being flatter, as shown in figure 3.5. If Team B's Rating is higher, with a value of 800, then that Team is 10 times more likely to win compared to the opponent Team A.

3.6 Summary

Table 3.1 illustrates how this work differs from the current state-of-the-art. Home-based rehabilitation becomes increasingly important since patients get released from the hospital earlier, and therapists prescribe home exercises. The patients, though, often need more motivation to perform those exercises. The consensus among researchers is that home-based rehabilitation of stroke patients is becoming more common. Accordingly, solutions enabling multiplayer games are becoming increasingly important to keep patients engaged in exercise. Studies such as Maier or Tsoupikova et al. address multiplayer games in home-based rehabilitation. Another common finding in the research is that multiplayer games can enhance motivation even more. Multiplayer serious games have the advantage of providing further motivation and reducing the feeling of isolation among stroke patients. Tsoupikova et al. also discuss the use of low-cost and easy-to-set-up tools.

The remaining challenge, however, is balancing the individual players' skills to enable multiplayer games. The adaptability of difficulty levels is addressed by Pinto et al. but has the shortcoming of being implemented only in single-player games.
Another preceding solution was the investigation by Wendel et al., who proposed a simulation of an opponent to simulate a realistic opponent. Although this allows multiplayer games against a game bot, it does not allow multiplayer games against another player.
As of the current research, an interaction between stroke patients is made possible by balancing the players' abilities through compensating for motor impairments, as described by Maier et al. This contribution may allow patients to interact with each other, but a matchmaking strategy has yet to be developed. Multiplayer serious games miss a strategy that enables players to play with each other without a therapist's help in deciding who should play with whom and without adapting the skill to compensate for the player's abilities. Up to now, no matchmaking strategy for multiplayer serious games has been proposed.
However, when reviewing the gaming industry, it becomes evident that they have adopted matchmaking and ranking strategies in their games. Regular games mainly use skill-based matchmaking strategies such as Elo or Glicko/Glicko2, and a few also use TrueSkill or their own versions of TrueSkill. Known games, such as League of Legends or Overwatch, have developed their own Elo strategies for team-based competitive games.

Therefore, this thesis proposes a solution to the matchmaking problem in stroke patients using Elo for ranking and defining a distance function for matchmaking. The matchmaking strategies of regular games are analyzed concerning the applicability of a serious game in stroke rehabilitation. The players' abilities are determined and compared to other players of the same ability range to find suitable competitors. The abilities are determined anew

Authors	Player Mode	Game Mode	Game Platform	Goal	Solution
Pinto et al. [78]	Single Player	—	VR	Adaptability of SG and difficulty adjustment	State Machine and Mini Games
Tsoupikova et al. [83]	Multi and Single Player	Competitive, Collaborative	VR	Home based rehabilitation	Easy and Cheap tool for at-home
Maier et al. [54]	Multi Player	Competitive	VR	Motivation for at-home rehabilitation	Adaptive Mapping
Wendel et al. [93]	Multi Player	Collaborative	Browser	Simulation of opponent	Simulation Model
Riot Games [38]	Multi Player	Team-based Competitive (co-op)	Windows, macOS	League of Legends Matchmaking	Elo for Teams
Blizzard Entertainment [37]	Multi Player	Team-based Competitive	Windows, PlayStation 4, Xbox One, Nintendo Switch	Overwatch Matchmaking	Elo for Teams
This Work	Multi Player	Competitive	Browser (Phone)	Matchmaking for Stroke Patients	Poker Dice with Elo Ranking and Matchmaking

Table 3.1: Comparison of This Work and State of the Art

after each game. Skill-based algorithms such as Elo or Glicko/Glicko2 are best suited to learning a player's skill, so since the present work focuses only on 1 vs. 1 player, TrueSkill is not considered.

A small browser-based mobile game will introduce the matchmaking solution and the corresponding ranking strategy. Gamification elements in the application keep players engaged and motivated. In the game, players are matched to compete against each other depending on their ranking. Long waiting queues can be de-motivating; therefore, this work proposes a distance function to enable faster matches.

The use of the application is intended for at-home rehabilitation without outside help. It can also be used during waiting times, for instance, before a therapy session or at the train station, and a change from non-digital rehabilitation tools. A usability test session and surveys are conducted to evaluate the usability, and experts evaluate the applicability of the developed solution by means of a survey questionnaire.

CHAPTER 4

Results

The methods listed in Chapter 2 for performing requirements analysis (2.8) and usability engineering (2.7) are applied to the concrete problem in this thesis. In the brainstorming phase, with the help of mind maps, interviews, personas, and low-fidelity prototypes, an idea is elaborated to serve as the basis for this thesis. The matchmaking and multiplayer serious game requirements are prepared based on the principles from Chapter 2 and on the brainstorming phase. Iteratively, low-fidelity prototypes are created, and requirements are defined and evaluated by experts working with stroke patients. Each iteration's results are the starting point for subsequent iterations. The results of the evaluation phase from the usability tests and the interviewed experts on the game and matchmaking conclude this chapter.

4.0.1 Overview

The development of the prototype for this work consists of 4 iterations:

1. Iteration: includes a brainstorming phase where the first idea, pencil sketches, and personas are created based on conversations with therapists. Requirements are analyzed regarding literature, state of the art, and personas. Based on this analysis, the initial requirements for the game and the interview guide are created.

2. Iteration: in this iteration, the requirements for matchmaking get defined using the results obtained from the interviews, the literature review, and state of the art. The initial wireframes are created and evaluated by the experts. The matchmaking requirements and interview guide are expanded. Furthermore, the implementation begins.

3. Iteration: finalization of the requirements and the implementation of statistics and achievements

4. Iteration: conduction of usability tests, final interviews, and the final implementation.

Finally, a final evaluation is conducted by having the experts complete a semi-structured questionnaire.

Table 4.1 summarizes the experts involved in the interviews and discussions and the users involved in the test session. There was no success in contacting ambulances, clinics, and

Participant	Gender	Age	Role	Work	Iterations
T1	m	28	Occupational Therapist	Neurostation, Neuroambulance	IT1, IT2, IT3
T2	f	26	Speech Therapist	Phoniatri, Neuroambulance	IT1, IT2, IT3
T3	f	26	Physical Therapist	Neurostation, Neuroambulance	IT1, IT2
T4	f	28	Physical Therapist	Stroke Unit	IT2, IT3
T5	f	30	Nurse	Neurostation	IT2, IT3
T6	f	24	Assistant Doctor	Neurostation Acute care	IT2, IT3
T7	f	52	Physical Therapist	Neurological Clinic	IT2
T8	m	31	Physical Therapist	Self-Employed, Neurological Clinic	IT3, IT4
T9	f	30	Physical Therapist	Self-Employed (Neuro-patients)	IT3, IT4
T10	f	29	Occupational Therapist	Neurostation Acute care	IT3, IT4
U1	f	27	Usability Tester	Software Engineer	IT4
U2	f	26	Usability Tester	Self-employed Illustrator	IT4
U3	m	26	Usability Tester	Student and Caregiver	IT4
U4	m	30	Usability Tester	IT Administrator	IT4

Table 4.1: Overview of the interviewed Stakeholders

independent therapists on the Internet. Therefore, school friends, family members, work colleagues, and other acquaintances were asked if they knew someone working with stroke patients. One therapist could refer three additional work colleagues for an interview. The contact with the experts occurred via Whatsapp/SMS. Most of the conversations were via telephone, one via Skype, and with one therapist several personal meetings could be held. Some have worked with stroke patients for over eight years, while others have only started in the last year.

An interview guide is prepared to serve as a basis for the interviews with the experts. The interview guide is divided into a welcome, followed by preliminary questions to gather the experts' knowledge and clarify questions if necessary, the presentation of the idea for this thesis, and questions regarding the idea. The questions are derived from the obtained knowledge in chapter 2 and the current state of the art 3. It includes questions about the matchmaking strategy and the waiting queue, the game (rules, exceptions, boundaries), the user interface, the relevant achievements and statistics, gamification elements, and what to consider for stroke patients. Not every expert received the same questions. The original German version and the translated English interview guide are attached in *Appendix A*. To obtain unbiased answers to the question of an appropriate matchmaking strategy for stroke patients, questions 3 and 4 were asked before the ideas for this work were discussed.
From some conversations, follow-up questions arose, which got subsequently incorporated into this guideline. T1, T2, T3, and T4 could already clarify some questions at the beginning. Those who spoke candidly went into more detail about the matchmaking, shaking, and cognition. Others, however, spoke less freely. There were also differences in the responses of experienced therapists. There were conflicting responses, for example, whether the vibration or sound of the phone was helpful to patients. Another contradiction was whether matchmaking should be based on cognitive and motor skills or only on cognitive skills. By comparing who said what and why, some contradictions could be clarified, such as matchmaking focusing on cognitive skills by having Elo update based on the player's success rate. Shaking the phone would then serve as a training effect where achievement badges can be obtained.

4.1 Iteration 1: Initial Decisions

The first iteration consists of a brainstorming phase for the game, the resulting decisions, a requirements elicitation from the literature review in chapter 2, and state of the art 3. The first low-fidelity prototypes (pencil sketches and wireframes) are drafted. The consecutive subsections describe the results of the first iteration.

4.1.1 Initial Brainstorming and Discussion

At the beginning of this project, a one-hour meeting was held with the occupational therapist T1 to propose the idea of multiplayer serious games (research question 2) and a matchmaking for stroke patients (research question 1). T1 provided insights into an occupational therapist's work with stroke patients and affirmed the need for a multiplayer serious game and matchmaking. From the audience of the proposal presentation for this thesis, the idea came about to extend an existing game to a multiplayer game mode and to focus solely on the matchmaking strategy and the multiplayer game, which are essential for answering research questions 1 and 2. In the brainstorming phase, games such as

FoxJump [44], and Reha@Stroke [6], [5] were considered since source code already exists, and there was a possibility to extend those games to enable multiplayer gameplay. The games are single-player games, so the first task was to think about how to convert them into multiplayer games. They could be competitive, where the players play time-based against each other and try to collect more points than the other person, or collaborative, where the players have to achieve a task together. Different game variants were created as part of the brainstorming process, and a mind map depicts them. In Appendix C, the respective results of the mind maps are shown and are explained in more detail in the following.

FoxJump is a game where the user has to collect various items (cherries, etc.) and take them into a house. The player has to use a hand gesture to direct the figure. They have to jump over objects or blocks to reach the house. Figure 4.1 shows an example scene of the fox jumping over a hole in the direction of the cherry. The following are ideas that

Figure 4.1: Screenshot of the Game FoxJump [44]

the author of this paper has considered to make FoxJump a competitive or collaborative multiplayer game.

1. Competitive
   a) Which player collects more items in a specific time?
2. Collaborative Game Mode
   a) Each player has to collect certain items. When everyone has collected those items, the level is finished.
   b) One player has to collect the items the other has to sort them accordingly.

Reha@Stroke by Baranyi et al. [6], [5] is a mobile application that uses the integrated sensors of mobile phones to help patients with their rehabilitation. It focuses on the wrist's movement, touch with the fingers, and training of gestures. Exercises can be selected from the movement, touch, and gesture categories. For executing the movement exercises, the phone uses the gyroscope. The interface of the touch screen controls the exercises requiring touch and gesture. Each category has 3 difficulty levels, and after completing one level, the user receives a badge (bronze, silver, gold) as a reward. Examples of the exercises are pouring water into a glass, which trains the wrist by using it to rotate the phone in radial deviation. An example of the category touch is placing cards in the proper order by tapping on the screen. A game in the gesture category is about having a small grey cube within a white cube displayed. The grey cube needs to be scaled until it fits the size of the white cube. The advantage of these mini-games is that they can be used with a mobile phone from everywhere.

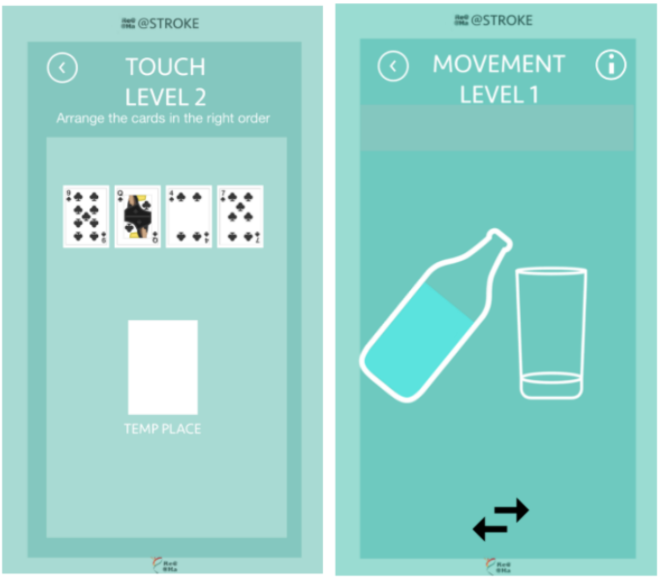


Figure 4.2: 2 Example Games from Reha@Stroke [5]

To make out of Reha@Stroke a multiplayer game, the author of this thesis has worked out ideas for a collaborative game mode, which are described in the following:

1. Collaborative Game Mode - Movement
   a) Pouring water into a glass: Player 1 pours water into a glass by rotating the wrist, as in the initial version. Then player 2 takes that glass and waters some plants with it.
2. Collaborative Game Mode - Touch
   a) Drag a Shape into a Hole: The screen could be divided into two parts. On one side, player 1 drags the shapes into the hole, and on the other side, player 2. Each player receives points for successfully dragging a shape into a hole, but only the total sum shows. The individual ranking flows into the next matchmaking round.

b) Put cards in the correct order: Each player has a set of cards. The current card and free space are displayed to put the cards in the right order. Players must then match the current card with their cards and decide which card is next in order. Depending on whether player 1 or 2 has that card, that person moves it to the free space. In the end, the correct order of all cards is displayed.

In order to develop a multiplayer game from Reha@Stroke or FoxJump, the results of the brainstorming phase were discussed with the supervisor using the mind map. The ideas were not convincing enough, as the flow of a multiplayer game might be unclear to the patient, and the parameters for matchmaking might be challenging to define precisely. The main drawback of the collaborative game mode is the waiting time for each player. For example, if one player has to sort items that the other player has previously collected, it can get boring for them to wait for their partner to finish sorting the items, and vice versa. Furthermore, it is a challenge to define comparable matchmaking parameters. Moreover, the screen size of a multiplayer game in Reha@Stroke may become too small for stroke patients if the gameplay is simultaneous. More screen space is necessary to water a plant or move the shapes in the correct place while all the necessary information is displayed for each player. It could also be too redundant for the players when there are so many different shapes to see. The simpler the game is, the better it is for stroke patients. These games are more suitable when solved together on-site on a bigger screen, but this work aims to develop a matchmaking strategy that enables remote gameplay.

To conclude, as it was challenging to turn single-player games into multiplayer games where matchmaking could be incorporated, the idea of dice games emerged from the game *Putting cards in the right order*. The advantage of using dice games is that many patients already know them from their lives as they might have played such games before. Dice games are something they are familiar with and relate to, and therefore they can memorize the rules better and faster. The rehabilitation factors in a mobile dice game consist of a combination of both cognitive and motor skills. The results of the conducted investigation on dice games are detailed as follows.

- Roll the dice in the right order: The first player who rolls all the numbers from 1 to 12 in sequence wins. Throwing is done with 2 dice; to roll a 2, players can either roll a 2 with one die or two 1s. The player who did not roll a 1 in the first round must try again in the next round. The game could also be simplified by rolling only to 6.
- Put dice in the right order: Two dice are thrown alternately per player. The dice then have to be placed in the order in which the highest possible number results. The phone needs to be shaken and rotated with a wrist movement to roll the dice. Then, the dice are sorted by touching the screen with the fingers.
- Poker Dice: For this, either poker dice with six sides can be used or regular dice. The sides of poker dice are Ace, King, Queen, Jack, 10, and 9. Regular dice have

numbers from 1 to 6. Each player can throw their dice 3 times. Figure 4.3 illustrates an example cup and the poker dice. In the first round, the player shakes the 5 dice in a cup and throws them on some surface. Then they can decide which dice to keep for the end and which to roll again. This also applies to the second round. After the second round, they can take a third and final roll. After this round, the dice are kept, and a combination is selected. The goal is to reach a higher poker combination than the opponent. Those combinations sorted from highest to lowest ranking are: *five of a kind*, *four of a kind*, *full house*, *straight*, *three of a kind*, *one pair*, *two pairs* or *bust*.

Figure 4.3: Poker Dice[1]

- Liar's Dice: in this game, one has to be able to bluff well and recognize a bluff. Each player has their dice cup and 5 poker dice. A player may not see the other player's dice, as shown in figure 4.4. The first player, a caller, rolls the dice and

Figure 4.4: Liars Dice[2]

[1] `https://pixabay.com/de/photos/poker-w%c3%bcrfelpoker-gl%c3%bccksspiel-3891473/` accessed Nov 04, 2022

[2] `https://eightygames.files.wordpress.com/2017/01/img_1193-0.jpg` accessed Nov 04, 2022

must describe the result precisely without saying the name of the combination. One can throw combinations like in poker dice. Then if the opponent does not believe the result, the game ends, and the dice are shown. If he/she was right and the result is lower than what the caller said, the caller has lost the game. If the caller is correct, he/she wins.

These games must be evaluated by an expert, such as an occupational therapist, for their suitability for stroke rehabilitation and rehabilitative factors.

4.1.2 Initial decisions for dice games and pencil sketches

A low-fidelity prototype was created as part of the initial design phase's brainstorming process. The prototypes were pencil sketches since the creation of such is fast and cheap. The goal was to evaluate the sketches and describe the initial idea. Further, with the help of the sketches, a discussion of possible requirements was conducted.

The therapist, T1, reviewed the dice games that emerged as part of the brainstorming phase in another one-hour in-person meeting. The evaluation focused on the suitability for stroke rehabilitation from the point of an occupational therapist. Liars Dice requires a combination of luck and strategy. It demands numerical skills, observational skills, knowledge of human nature, and proper timing. As it has minor rehabilitation factors, the idea got excluded. The ideas *Poker Dice*, *Roll the dice in the right order*, and *Put Dice in the Right Order* seemed to be the most suitable and were presented with the help of pencil sketches.

The therapist explained that dice games generally require the movement of the wrist and fingers, which the smartphone can simulate. The rehabilitation factors in a dice game consist of a good combination of cognitive and motor factors. Shaking the smartphone is equivalent to rolling dice, whereas the intensity of shaking can lead to different results. The phone's motion sensors (e.g., Accelerometer, Gyrosensor) can control the shaking. Dice games also benefit from cognitive training skills, such as number recognition, memory, planning ahead, and a risk assessment of the opponent.

Poker Dice: Each player only sees themselves rolling the dice. After rolling the dice, they see their result and the result of the player. They click on the dice they want to put back in the cup to shake them again. They can roll their dice 3 times, of which 2 times can be chosen which dice to reroll. After the final round, they cannot reroll their dice, and the winner is declared. They get points and some badges for choosing the best combination. The first drawing of poker dice can be seen in figure 4.5. The roll of the dice in poker is essentially a game of chance, but players can influence their luck by choosing certain combinations. They need to grasp the phone and know the movement for shaking it and touching the dice. Players are required to have both combinatorial skills and numerical understanding, and these skills improve as the players play the game. They also need to be able to estimate risk, plan ahead, and finally make a decision.

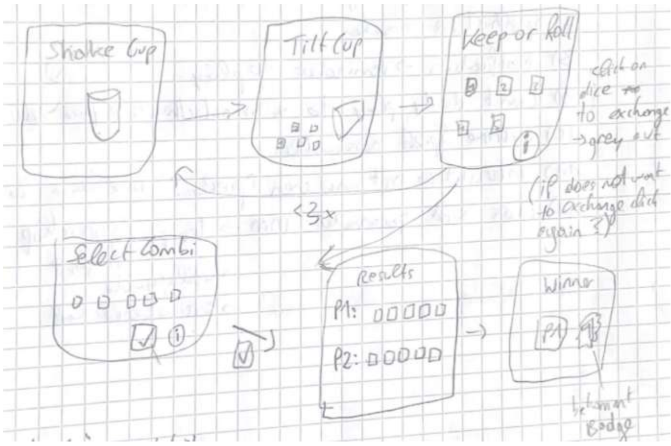


Figure 4.5: Pen and Paper Sketch of *Poker Dice*

Roll the dice in the right order: Depending on the chosen level, a player has 1 or 2 dice, and they need to roll them by shaking the phone. They need to dice them in ascending order, which can be done simultaneously. Adding a timer can turn the game into a competitive game, where one of the players will be the first to win. Alternatively, they take turns, and each waits until the other is finished with their round. As it is a game of chance, no strategic skills are required, and the game outcome can not be influenced. However, players can practice patience, cognitive skills, and mathematical skills such as number recognition, addition, and even about probabilities.

Put dice in the right order: They can roll x times by shaking the phone, and after the final round, they have to use the touch gesture to put the dice in ascending order. This can also be collaborative, where if they need to roll a total of 6 times, then each player rolls 3 times. Then they can take turns putting the dice in the right order. This can also be done competitively or simultaneously, where each player sees the other's results. An initial sketch for this game can be seen in figure 4.6. The game is a game of chance where a strategy can not influence the outcome. It requires the skill of number recognition, knowledge of number sequencing, and motor skills such as moving the wrist to roll the dice with the phone and touching the dice to put them in order.

Finally, the suitability of the games was discussed, and the pencil sketches were evaluated. The games *Roll the dice in the right order* and *Put the dice in the right order* are too simple for a rehabilitative exercise or a matchmaking strategy. Instead, they are more applicable for an initial skill determination or for people who suffer from severe impairments. With therapist T1, the decision was made to focus on *Poker Dice*. Although poker dice is a very abstract game, it is suitable for moderate rehabilitative purposes, fulfilling the multiplayer aspects and allowing the incorporation of a matchmaking strategy. The game's outcome can be influenced by the player estimating the opponent's next move. For this, the patient needs an understanding of numbers, combinatorial skills, concentration ability, risk assessment, and planning ahead. Motorically, the patient must be able to

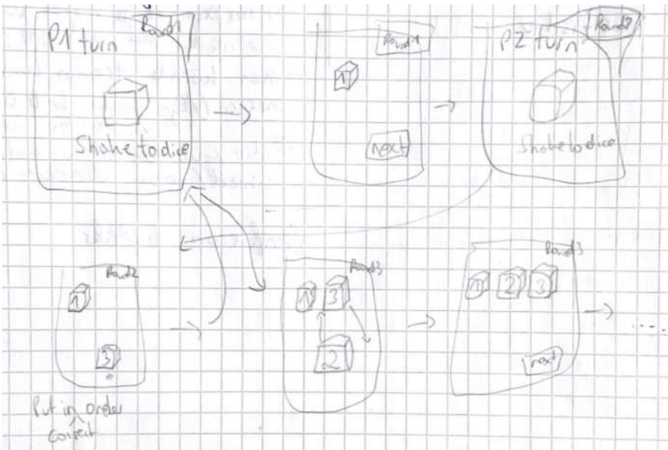


Figure 4.6: Pen and Paper Sketch of *Put Dice in the Right Order*

grasp and hold the smartphone and perform the shaking motion. Matchmaking can focus on these skills. Another advantage is that many patients already know the game and can understand and use the rules better and faster.

4.1.3 Initial Requirements Analysis

In the same meeting as discussing the ideas *Poker Dice*, *Roll the dice in the right order*, and *Put the dice in the right order*, the first requirements for the game were defined, with the help of personas who showcase the stakeholders, with the therapist T1 in the meeting on site. The persona of the occupational therapist was adjusted based on talking to therapists T2 and T3.
Stakeholders for poker dice are therapists who suggest the application to their patients and the patient who uses it. The therapist will not use the application directly but rather guide the patient on how to use it and evaluate if the patient is fit enough to use it.

A persona can be defined to show how a typical stroke patient could use the game. Personas are a realistic representation of a typical user. They can include real and fictional information for a more comprehensive description, as well as demographic and biographical characteristics. A persona has a name and can be represented by a picture or photograph. Information on the profession, relationships, and opinions ought to be included. Questions such as “what does the user do”, “what frustrates the user” and “what makes the user satisfied” should be asked, and the question “what does the user want” should be avoided. For example, their work shifts, solutions, current frustrations, relationships, and goals can be described narratively [41].

Persona Occupational Therapist - Alex Smith:
Alex is an occupational therapist for stroke patients. He recommends the application to a patient in the course of their treatment. Before recommending it, the therapist evaluates whether the patient can hold the cell phone in their hand, type, and cognitively

grasp what is happening. The patient should operate the cell phone on their own. The patient can use the application during waiting times, before a therapy session, to change from other exercises, play in the ambulance, or at home when bored. In settings where a therapist is near, the advantage is that the patient can still approach the therapist if anything is unclear.

Persona Stroke Patient - Karl Fischer:
Karl is 80 years old and retired, and he used to work as a shipping warehouse worker. He was diagnosed with CVI (Cerebrovascular Insult), where he had a medial infarction on the right, with hemiparesis on the left. He has hemiplegia of the upper extremities on the left but can hold the cell phone in his hand. He also has a mild attention deficit disorder and finds it difficult to concentrate on one thing and suppress non-relevant irritants. Nevertheless, he still takes care of his grandchildren, prepares breakfast, and goes grocery shopping. However, Karl cannot carry the shopping bag as long as he used to, and it takes longer to focus on the necessary groceries. He can no longer grip the coffee cup securely with his left hand. If he were to operate the cell phone with his left hand, he would have difficulty because he has a fine motor disorder on the left-hand side. He would then have to hold the cell phone with his left hand and operate it with his right. In a hand strength measurement test with the Jamar hand dynamometer, he can lift 30kg with his right hand but only 15kg with his left. In the Nine-Hole-Peg Test (NHPT), 9 dowels are taken individually from a flat container and placed in a matching hole on a board. They are then placed back into the container one at a time. In this test, it took him 23 seconds with his right hand and 48 seconds with his left.
His occupational therapist at the rehabilitation center suggests the application *Poker Dice* as an additional exercise. With the therapist's help, Karl sets it up on his phone and starts playing it at home. At first, he has difficulties with the shaking motion, and it also takes a while to click on the correct dice while focusing on choosing the dice he wants to reroll. He also has to reread the instructions before each new game. After a few weeks, he notices a slight improvement in the shaking motion. Further, his motivation is boosted since he earns more achievements and wins more games.

With the knowledge of the defined personas and the literature (chapters 2.2 - 2.6) in mind, the first requirements were defined. The necessity of a login/logout (R01, R02), having a time limit on the rounds (R11), having a matchmaking (R07), and a game explanation for the patient (R03) were under discussion. The importance of a simple interface was particularly strongly emphasized by the therapist. Someone who has survived a stroke, like the persona Karl Fischer, is particularly sensitive to visual distractions. Gamification elements that came in mind were to receive badges for the shaking motion or achieving certain dice combinations. The full list of requirements is given in the table 4.2.

4.1.4 Definition of the Game and Matchmaking Strategy

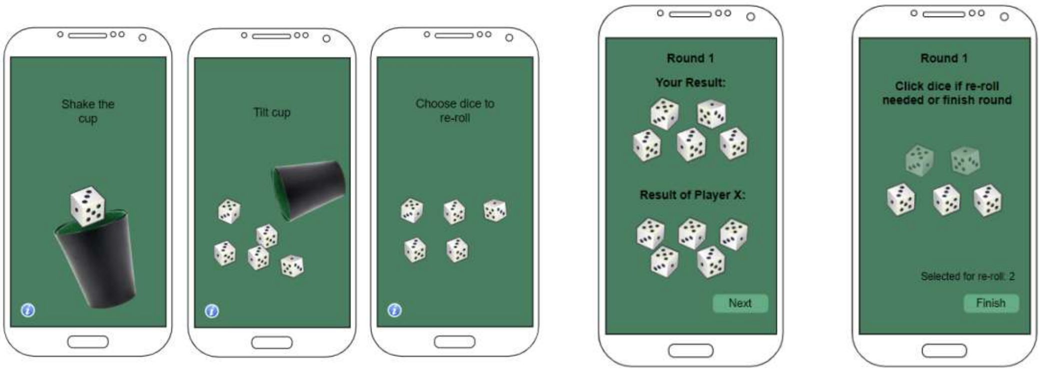
According to the findings from the literature review, matchmaking requires developing a suitable strategy, where it is possible, for instance, to create a match after each game or a certain number of games - for more details, refer to chapter 2.6. Matchmaking could even apply only to a specific category. Another option would be to create a match until there is a perfect match and make no changes after such. The algorithm used and the ranking strategy determine the matchmaking strategy. Elo calculates the rank after each round, and Glicko after a certain number of rounds. A matchmaking strategy must definitely consider the time spent in a queue. The distinction between an asynchronous and a synchronous game is necessary for the matchmaking system.

Due to the importance of the considerations mentioned above for further definition of requirements, a short questionnaire was created. Therapist T1 received the small questionnaire with 4 questions, where the answers intended to help specify the game and the matchmaking strategy: Should the game be synchronous, where two players play simultaneously, or asynchronous, where players take turns? When comparing role-based, skill-based, technical, and engagement-based matchmaking strategies: which is relevant for stroke patients? Should a new match happen after every game or a set of games? How much skill is needed so that the patient can play poker dice?

Using the responses from therapist T1 and the information gathered from the literature (chapter 2.6), a matchmaking, and ranking strategy could be devised. According to T1, asynchronous gameplay enables patients to take breaks when exhausted or get a visitation. For such a game, matchmaking could happen while the player is offline. Thus there would be little to no waiting queue. For this, engagement-based matchmaking is suitable since players that play often have a match, and players that play occasionally have a match. While the player is offline, matchmaking is beneficial against technical implications such as latency.
In a synchronous game, the players can also have their own individual training time as long as there are players in the waiting queue. In this case, skill- and engagement-based matchmaking are suitable.

As described in chapter 2.6, skill-based matchmaking is well and fair enough to compare a player's skills [89]. Hence, skill-based or engagement-based matchmaking is the most suitable for a game like poker dice to keep the patient engaged and motivated to continue their exercises. Elo focuses on the outcome of a match and is relatively easy to implement. The actions performed in a game must have a value that contributes to the player's performance. The calculation of the game result should include those values. Even those unable to train regularly due to health reasons or missing motivation can play against similar players with skill-based matchmaking. Nevertheless, the game challenge should be kept within the training range for both players, regardless of the individual sensorimotor recovery. The agreed training period with the therapist team must not be neglected and independent training can be done in the training-free time.

Additional requirements emerged from T1's responses in the questionnaire. One suggestion was to include emotes, which could provide social interaction for a more severe or speech-impaired patient. In addition, a feedback function (R25) could be integrated to provide information on whether the teammate is suitable. Another suggestion was to allow a rematch between both players if they agree (R23) within a time frame after the game.



(a) Shaking Dice in a Cup

(b) Result of Round 1

Figure 4.7: Initial Wireframes

This would undoubtedly increase the engagement and competitive nature of the game. The complete list of requirements is given in the table 4.2.

4.1.5 Initial Low Fidelity Prototypes

It was decided to design wireframes as low-fidelity prototypes, as described in Section 2.7. The online tool draw.io [3] was used to create and design low-fidelity wireframes, as it already includes example elements, such as a mobile frame, various icons, or buttons. The wireframes were derived based on the pencil sketches that have been discussed with T1, and the emerging preliminary requirements. In the pencil sketch 4.5 a cup was sketched to be on the display as is shown in figure 4.7(a). The dice were initially three Dimensional, as seen in figure 4.7(b). Therapists T1 and T2 were involved in evaluating the wireframes by receiving screenshots and commenting on them.

This design of three dimensional dice was rejected, as therapist T1 pointed out that patients with spatial deficits may have difficulties handling three dimensional dice. Hence, the 3D dice were changed to 2D, since patients can handle 2-dimensional dice more easily. Further feedback on the wireframes was to make the background screen white as stroke patients can have a "red-green" color vision deficiency, which was was changed in iteration 2, described in 4.2. Therapist T2 suggested writing more explicit instructions for the actions the user can take. For example, the text "Your Result" may not be sufficient enough for all patients. Some may need help with understanding the result, such as displaying the meaning of the combination. Other feedback, was to remove the cup, as it would create visual confusing during the shaking period, in which the dice are inside the cup. Figure 4.8 shows the adapted wireframes, where the three dimensional clickable dice are exchanged for two dimensional dice.

[3] https://draw.io/

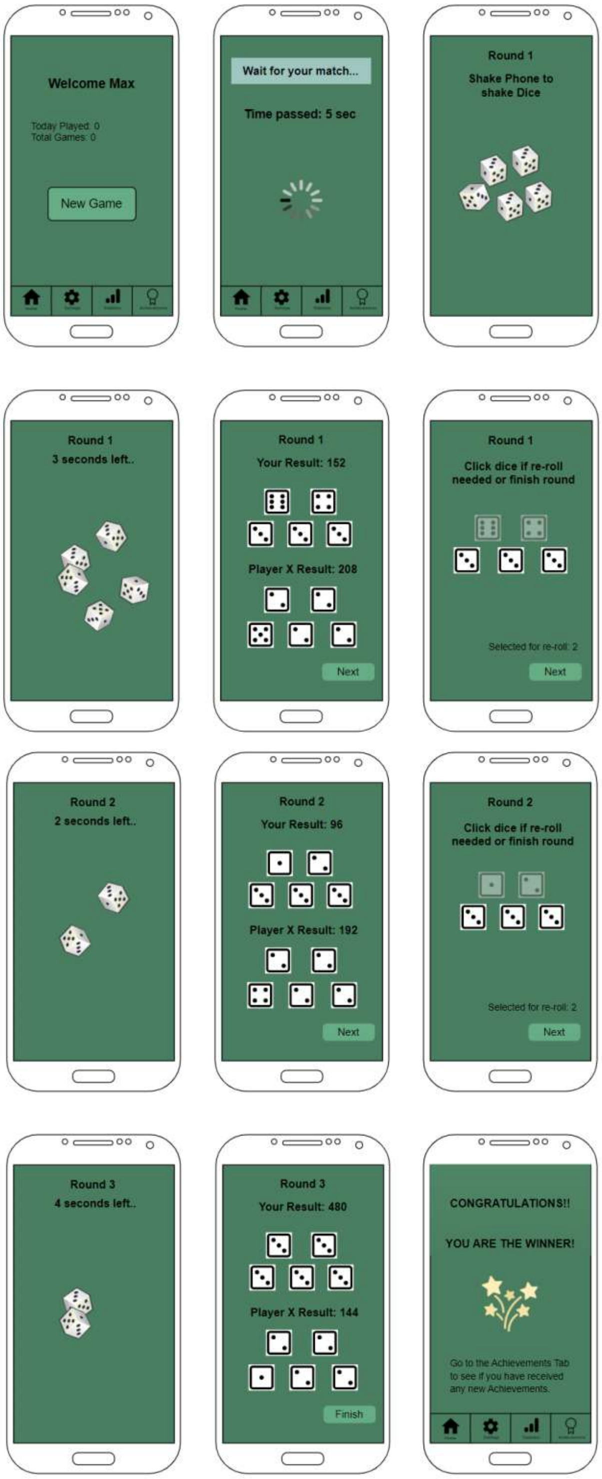


Figure 4.8: Wireframe of Game Start, Matchmaking, Rounds 1-3 and Winner

4.2 Iteration 2: Game and Matchmaking

In the second iteration, the already elicited requirements are refined again, and a more detailed requirements elicitation is defined with the stakeholders. Furthermore, the wireframes are revised several times, and the matchmaking queue and the ranking system are implemented as part of the requirements. The results of these individual iteration steps are described below.

4.2.1 Requirements

Requirements Definition

Interviews, use-case scenarios, or prototypes can be used to define the requirements. Questions to keep in mind are *what should the product do, how well should it do it and under which conditions should things be done.* Requirements containing the details, prioritization, feasibility, and test cases to accept the implementation can be described.

The literature review in chapters 2 provided the foundation for the requirements. Initial requirements for the game poker dice and matchmaking were drafted with the persona of Karl Fischer from chapter 4.1.3 in mind and reviewed by various therapists. The final result of the requirements is listed in table 4.2 with the respective Requirement ID, Title, Implementation Priority, and involved Stakeholders.
The requirements definition happened in an iterative process, where changes were made according to the interviews. The priority of implementation ranges from 1-4, where those with priority 1 are the most important ones to answer the research questions and make gameplay possible. Those with priority 4 are not likely to be implemented in this work but may be considered for future work. Sometimes the experts had differing opinions on the importance of a requirement. In that case, the pros and cons were evaluated to decide on the priority.
To use the game poker dice, stroke patients must use cognitive and motor skills. Cognitively they have to understand numbers, know the movement of shaking a phone, estimate a risk, plan in advance, and make a decision.
Motor-wise, they must be able to grasp and hold the phone and execute the shaking motion. Also, for selecting dice, they need to be able to touch the screen with their fingers. If the training focuses only on cognition or they need a break with their hand, they can also perform the shaking movement with the unaffected side.

A detailed description of the requirements:

- **R01 Login, R02 Logout:** The user should register (e.g. with a user name) to use the application, and after a logout the user has to be able to login with the same name again. By using their username, they can play the game and track their progress in the statistics section. This requirement emerged from one of the first discussions with T1.
- **R03 Game explanation:** To ensure the patient knows the rules, it is necessary to have an explanation of the game accessible. The explanation can either be written,

Req ID	Title	Priority	Therapists involved
R01	Login	2	T1
R02	Logout	2	T1
R03	Game Explanation	2	T1,T2,T3,T4, T7
R04	Simple and Intuitive Interface	1	T1,T5,T6, T8, T10
R05	Gamification Elements	2	T1,T2,T3
R06	Waiting Queue	1	T1.T3
R07	Fair Matchmaking	1	T1,T2,T3,T4, T6,T7,T8,T9, T10
R08	Game Start	1	T9
R09	Dice Result	1	T1
R10	Finish Game Round	1	T1
R11	Time Limit on Shaking and Game Round	2	T2,T5,T6,T7, T10
R12	Shake phone to shake dice	1	All
R13	Finish Game	1	T1
R14	Rating	1	T1,T2,T3,T4, T5,T6
R15	Players leaving the game	3	T5,T6
R16	Achievements	2	T1,T4,T5,T6, T8,T9,T10
R17	Statistics	2	T1,T2,T5,T6
R18	Sound Effects or Vibration	3	T6,T7,T9,T10
R19	Levels	3	T1
R20	Cancel matchmaking	2	T1
R21	Leaderboard	2	-
R22	Voice Assistant	4	T9,T10
R23	Revenge	4	T1,T10
R24	Push Notifications	4	T3
R25	Feedback	4	T1,T6,T8
R26	Chat with others	4	T3

Table 4.2: Poker Dice Final Requirements

spoken by a therapist, or shown in a video. For this application, it was chosen to have a written description. The following text is suitable according to T1: *Take your mobile phone and click on "New Game". This will bring you to a queue where a suitable opponent is searched for you. You will be notified when a match is found, and the game will start. Once the game starts, you should shake the phone to shake the dice. After a few seconds, the dice roll is finished, and you can see your and your opponent's result. Now consider whether you want to roll the dice again or keep your current combination. If you want to re-roll a dice, click on the dice to select them for a re-roll. In the second round, this process is repeated. After the third round, the game is over, and the player with the highest combination wins the game.* T2, T3, T4, T7 also contributed to this requirement.

- **R04 Simple and Intuitive Interface:** The interface of the application must be intuitive and self-explanatory. There should be no bright colors or flashing images. It is also important to keep the user interface fluid. When an action is performed, the user should go directly to the next screen to maintain user flow. This requirement was one of the first ones and emerged from talking with therapist T1. T5, T6, T8 and T10 also encouraged the importance of a simple UI: A serious game for stroke patients should not be graphically demanding, which means there should not be too many colors or details, and not be flashy. Players should not have to deal with rules for a long period of time. The game should be kept simple, such as throwing a ball to someone else.

- **R05 Gamification Elements:** are provided by shaking animations, the coloring of the selected dice, and rewarding game behaviors. The following behaviors can be rewarded with gamification elements: Winning streaks, streaks in shaking intensity, highest shaking intensity, and combinations of dice rolled. Reward elements could be: getting more points, getting a different dice skin, or getting badges. This was derived from the literature research on serious games in chapter 2.3. The gamification elements were also discussed with T1, T2 and T3.

- **R06 Waiting Queue:** The player needs to join a waiting queue before the start of the game. From the literature as described in section 2.6 insights on waiting queues could be gathered. An opponent should be found in the queue. If the waiting time is increasing, the defined skills should be expanded. The waiting times were discussed mainly with T1 and T3, and contributes to research question 1.

- **R07 Fair Matchmaking:** Matchmaking parameters and a rating system need to be evaluated to ensure that the player has a fair match with someone of similar skill. The success rate is measured as the main matchmaking parameter, that is, how often a user wins or loses a game. This requirement contributes to the research question 1 and was discussed with T1, T2, T3, T4, T6, T7, T8, T9, T10. The experts could not agree on the parameters for matchmaking: according to some, it would be better to include as many parameters (motor and cognitive) as possible, and according to others, for this game, it would be better to focus on a few parameters. Therefore, the advantages and disadvantages of the different parameters were evaluated in terms of the experts' experience and fairness for the players. Cognitive skills in this game include recognizing numbers, memorizing the rules (which combination is better than the other), assessing risk, considering the opponent's next move, and making a final decision. It cannot be measured directly whether the player decides to prevent the opponent's victory or simply to get a better dice combination. The motor skills consist of holding the phone, touching the display, selecting the correct dice, and shaking the phone for 5 seconds in each round. The ability to grasp the phone and make the correct touch motions is not a measurable skill, but the number of shaking motions can be measured. In addition, players with severe motor impairments can operate the phone with their other hand, which would be an incorrect measurement of the actual motor skill. However, it is always possible to measure the patient's mathematical and concentration skills. According to T7, it is better to have one main parameter, such as cognitive skill, focus on it and match the players accordingly. In general, the therapists agreed that it is challenging to compare deficits because the patients all have widely varying deficits. Nevertheless, they all have similar problems and goals. The skill-based matchmaking algorithm Elo is suitable for identifying the skill of a player by defining a rating (see also R14).

- **R08 Game Start:** When the user selects the *New Game* button, the search for matches begins. Once a match is found, a message is displayed (discussed with T9), and the user will be redirected to Round 1 of the game, which starts with rolling the dice. Both players that are in a match should start at the same time.

- **R09 Dice Result:** The result of dice combinations is displayed after each round to evaluate the next move. The first idea, was that the results of the dice combinations should be comparable by a numerical value. Each dice combination would receive a different score, as seen in wireframes 4.8 and 4.9. According to T1, such a score would cause confusion among the patients. It would be better if the score is displayed as dice combinations as in the game of poker dice. This has the advantage that many people already know this game and the corresponding rules. Thus, the dice result should be displayed as in the poker dice rules and not include factors such as the shaking amount. Thereby the dice combinations having a lower probability beat the combinations with a higher probability. The requirement derived from the initial brainstorming phase and was discussed with T1.

- **R10 Finish Game Round:** The user can select dice for a re-roll, or choose to keep all the dice and continue with the next Round. This is a requirement for the functionality of the game.

- **R11 Time Limit on Shaking and Game Round:** It is good to play for time and have to make decisions. A game round should be time-limited so that the opponent does not have to wait a long time for the next move. A time limit is also necessary to prevent the player from falling asleep. Each round should not last longer than one minute to remain competitive. To shake the dice, the player has 5 seconds. Once the result is displayed, the player has 1 minute to decide whether to keep the dice or roll them again. This requirement was discussed with T2, T5, T6, T7, T10.

- **R12 Shake Phone to Shake Dice:** Shaking the phone presents an additional motor challenge on top of touch gestures. The frequency or intensity of shaking could be measured. Including shaking in the dice outcome would be counter intuitive in terms of why someone loses despite a good dice combination. Therefore, some therapists suggested to focus on cognitive skills and use the shaking as an additional fun factor. Shaking could be rewarded with achievements and progress can be seen in the statistics section. Another opinion was that shaking should also not exist if a person's motor skills are poor. A different therapist noted that in such a case, the patient's therapist might not recommend the use of the shaking function anyway. However, another therapist suggested to set an individual threshold based on the shaking ability of the player. Discussed with all experts (T1, T2, T3, T4, t5, T6, T7, T8, T9, T10).
- **R13 Finish Game:** after finishing a game, it is shown if the user won the game or lost the game. This is a requirement for the functionality of the game.
- **R14 Rating:** the user should receive a rating that can be compared with other players. This is a requirement for the matchmaking strategy and was derived from literature described in the theoretical background (chapter 2.6). Also discussed with T1, T2, T3, T4, T5, T6 as part of the matchmaking strategy. After a game has been finished the rating has to be updated and included in the next match for the comparison of ratings.
- **R15 Players Leaving the Game:** Allow players to resume play when they accidentally leave a game. Mark the round in which they left the game as completed and continue with shaking dice for the next round. Discussed with T5 and T6.
- **R16 Achievements:** Achievements are especially important since they give motivation. With those players can notice that they make small steps towards improvement. Hence the player should view their badges and other achievements. Achievements can be received for actions during the game and the game outcomes. Discussed with T1, T4, T5, T6, T8, T9, T10 and derived from research on games.
- **R17 Statistics:** Display of the statistics and the game progress. The player is interested in seeing the development of their individual rank over time, and also how the shaking-amount develops. They can also view how many times they won or lost the game, and what combinations the user had at the end of the game. Discussed with T1, T2, T5, T6 and derived from research on games.
- **R18 Sound Effects or Vibration:** experts had differing opinions on this requirement: Some thought vibration is not good (T7, T9, T10) and sound effects should

be used instead (T9). Sound is important for patients with poor vision or who lose concentration quickly. But when a patient has hearing problems a sound would not be suitable, therefore it was suggested to use vibrations or visual effects (T6). Vibration was suggested to indicate the end of a shaking period. Sound effects could be used to shake the dice and to click on the dice for feedback.

- **R19 Levels:** Have different levels ranging from Bronze, Silver Gold, Platinum to Diamond. This requirement is inspired by the game Overwatch as described in the state of the art. Therapist T1 also suggested this idea.
- **R20 Cancel matchmaking:** Therapist T1 suggested to cancel the matchmaking process when someone is in the waiting queue. This is helpful if the player does not want to wait any longer or get back to the home page. When the user cancels the matchmaking, they are removed from the waiting queue and get back to home.
- **R21 Leaderboard:** From the literature and state of the art, it appears that many games use a ranking list. It enables the patients to compare themselves with others and get insights as to how many players are playing in their league.
- **R22 Voice Assistant:** to read the information on the site, this is not necessary to implement since operating systems have a built-in voice assistant, which can read web pages. T9 and T10 suggested these requirements.
- **R23 Revenge:** When the game is over, it could be possible to play a revenge game where both players from the last round skip the matchmaking process and start a new game against each other. This should only be possible if the level matches and they give similar answers. After each game, there could be a countdown with the option to start the revenge game if both players agree. This certainly increases engagement and competitive nature of the game. T1 suggested this requirement and T10 was also in favor of it. This requirement was currently out of scope and is suggested for future improvements.
- **R24 Push Notifications:** If matchmaking takes too long, a push notification could be sent for a found match. Then, users don't have to look at the screen at all times. The search could also start as soon as someone is online and send a push notification when someone is found. T3 first suggested to have push notifications to prevent the patient from looking at the screen at all times if the matchmaking takes too long. The requirement was not done since other experts did not find it that important.
- **R25 Feedback:** The user may give feedback on the perceived match quality. Subsequently, the feedback can also be integrated into matchmaking, e.g. whether the player was satisfied with the match. T8 suggested to use the feedback functionality for the algorithm as an input. The algorithm could learn how the shaking intensity or difficulty of the game should be adapted to help the patient. T6 suggested to enable giving feedback on how complicated or easy the patient perceived the game,

if they have fun, and if they believe that their skills are improving. This would be useful for the therapist so that they can evaluate the progress of the patient. The priority of this requirement was not high, since it is not relevant to answer the research questions but it may be considered for future improvement.

- **R26 Chat with others:** T3 suggested a chat list, where each player can see with whom a match is possible. They can write each other to arrange a game. When they are online at the same time, they can start a new game. If they develop differently, and one has more skill than the other, the match dissolves, and they can no longer play against each other. This requirement was considered for a matchmaking strategy where matching players would happen while they are offline.

Three additional requirements have been considered and discussed in the beginning but are not done. They do not contribute to the research questions because the experts did not see a need for them, but they are included here for completeness:

A daily time limit was considered at the beginning, as well as having notifications as a reminder to play. A time limit is unnecessary for poker dice since the exercises are not too demanding. The therapist can talk to the patient about the possibility of muscle soreness (when shaking the phone too often) and that they should stop playing if they experience pain.

Another idea was adapting the initial score according to the level of the player. The idea was to have three different categories, and the therapist does the category allocation with the patient on-site. If the patient sets up the application independently, the therapist can instruct the patient on which category to select at the beginning. Categorization could be severe, moderate deficits, or hardly any deficits. It is not done because the matchmaking strategy should be responsible for finding the player's skill.

Increasing the difficulty level was also considered, as therapist T2 suggested that the game may be too easy for some people. She had the idea to shorten the rounds for patients with advanced scores. Increasing the difficulty level could be considered for future improvements but is out of the scope of this thesis.

4.2.2 Low Fidelity Prototypes

The therapists T1, T2, and T3 reviewed the wireframes in this iteration. T1 additionally tested the game at one meeting in person. In total, the wireframes were adapted four times. Figures 4.9, 4.10, 4.11 show the adapted wireframes, after receiving feedback in iteration 1, not to use a green background.

If a stroke patient, such as the persona Karl Fischer as defined in chapter 4.1.3, wants to play the game, he could have the following gameplay: On the start screen, he sees an input field to log in with his username. After entering the username, Karl can access the application (*R01*). The first left upper wireframe in figure 4.9 shows the screen after login. He can trigger a new game, view his achievements or statistics, and log out (*R08,*

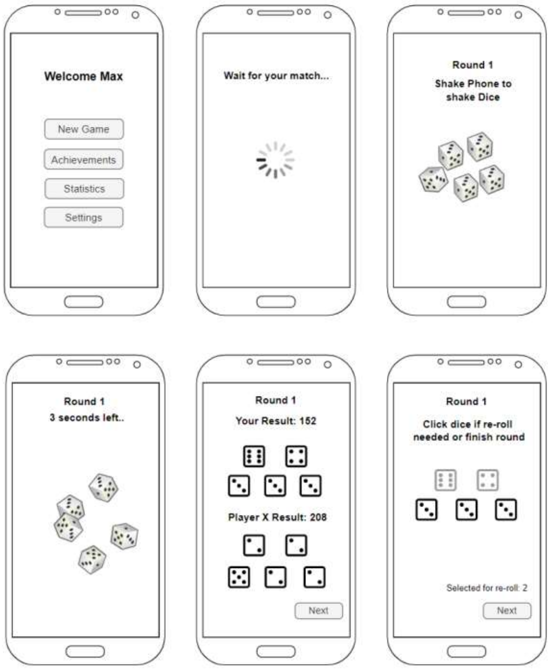


Figure 4.9: Wireframe of Game Start, Matchmaking and Round 1

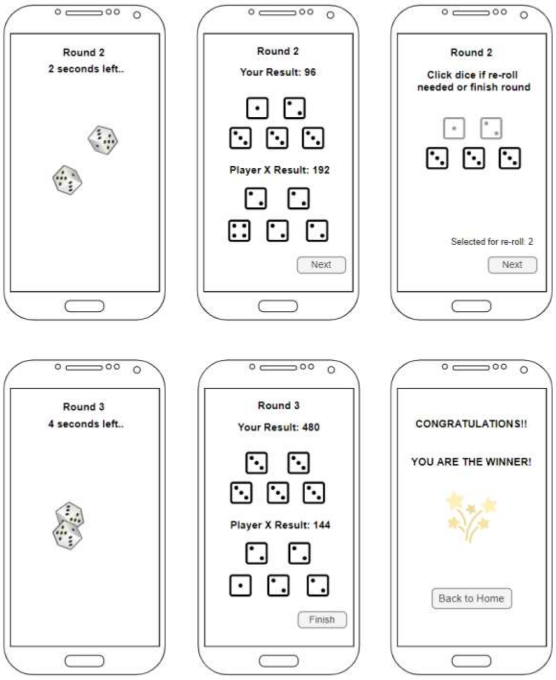


Figure 4.10: Wireframe of Round 2,3 and Finish

R16, R17, R02). When the user first wants to play a game, he clicks on the button *New Game* and waits for a match in the waiting queue (*R08, R06, R07*).
As soon as a match is found, the user gets paired with that person, and round 1 starts. Each player has 5 seconds to shake their dice (*R11, R12*). After that, the users see their dice results and which dice combination those dice represent (*R09*). Both players also can see the corresponding result of the other player. The dice combination was expressed as a numeric score in the initial wireframes and implementation. Therapists T1, T3, and T4 said that the score is not conclusive for the players. It should either be decoded or, instead of showing a score, the corresponding dice combination (such as *Full House*, *Straight*, or *Five of a Kind*) can be displayed. Those combinations also have the advantage of being familiar to the patients. The players can estimate their opponent's next move by seeing the opponent's result. When the player is ready, they select the dice they want to re-roll by clicking on them and finish the round (*R09*). An example is given in the second row of figure 4.9. The user sees that he has a 3-of-a-kind and could upgrade to a full house, 4-of-a-kind, or even 5-of-a-kind. The other player has a 4-of-a-kind, which is the second-best dice combination (*R10*). In the next round, figure 4.10, the user only shakes the selected dice for re-roll. Then the second round is displayed, and for the final time, dice can get selected for re-rolling. After the last shaking period, the final result shows figure 4.10, and the game can be finished (*R13*). On the next page, Karl can see that he won the game. In the achievements tab, figure 4.11, the users can see which achievements they received (*R16*). The statistics tab shows how the user improves during and after each game (*R17*).

Figure 4.11: Wireframe of Achievements and Statistics

4.2.3 Matchmaking - Distance Function

In order to answer research question 1, it is essential to define a matchmaking strategy. Fair matchmaking is listed as one of the requirements in table 4.2 (*R07*). As part of the matchmaking, a waiting queue has to be implemented (*R06*). Based on the literature findings from Section 2.6, skill-based matchmaking is appropriate, which are also the findings from the first iteration and the statements made by therapist T1. With the exception of T5, all experts were consulted on the matchmaking approach to develop a strategy. This section presents the results of the literature review and the expert interviews in a collected form.

There are different options for designing a waiting queue to match the players (*R06*): In the first option, the match does not distinguish between new and old players and puts them in the same queue. The second option is to put new players in a separate queue and match them according to the FIFO principle, and after the first 10 games, players could land in the standard queue. Another option is to take the average of x players who have already played y games. However, this can only be applied if there are enough players already. Based on the literature review, the first option was adopted where no distinction is made between new and old players and therefore they are placed in the same queue.

Figure 4.12 illustrates the matchmaking process for the game poker dice. After a player indicates they want to play a new game, they enter the waiting queue. In the queue, players are not supposed to wait too long; at the same time, they need to be matched with someone of a similar rank. The matches are built based on pairing players on their skill, and the matches are prioritized according to the oldest game registration. A ranking interval is defined for each player to build matches, indicating the possible ratings their opponent can have. Players are prioritized according to the time they enter the queue. The longer a player waits, the more critical it becomes to find a match for them, and thus the ranking-interval increases. The ranking interval is increased each second by some points. After that, non-overlapping matches are created, which are the final matches, and the game can start. After the game is finished, the player's rating is updated and included in the next matching round.

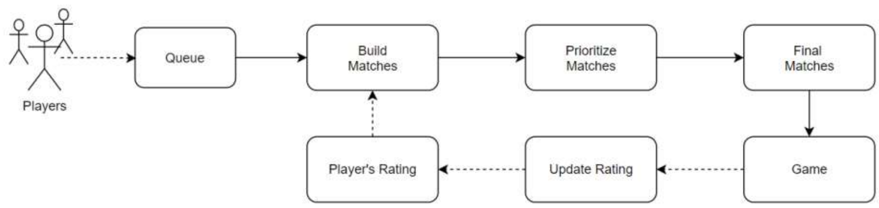


Figure 4.12: Matchmaking Process

To solve the problem of long waiting times (*R06*), the author of this thesis has considered the following solution. When a player wants to be matched with their opponent, an interval is calculated. This interval adds and subtracts 50 points from the player's rating. The longer the player waits, the more important it is to find a match, even if it is not perfect. However, since it can happen that someone is not immediately found in this interval, an adjustment is necessary. The interval adjustment counteracts long waiting times for a match. In this case the interval is recalculated every second with a distance function. The distance function is based on the following formula 4.1, where x is the time in seconds and the BASE value is 50.

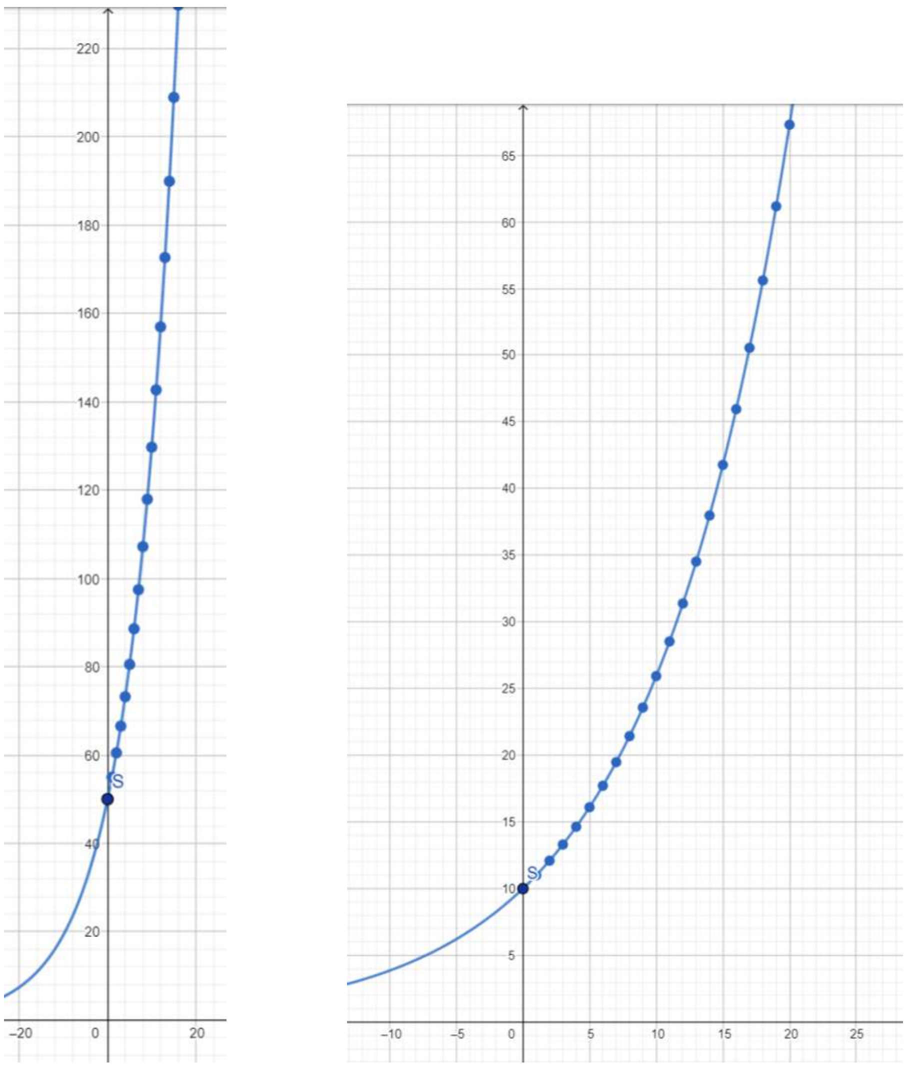
$$D = BASE * 1.1^x \tag{4.1}$$

Figure 4.13 show how the distance function changes with a base distance of 50 vs. 10. On the x-Axis the elapsed time can be seen and on the y-Axis the calculated distance is shown. Where S is the Start value, when 0 seconds have elapsed. It can be seen that a base distance of 50, leads to a more exponential growth. A base distance of 10, has a slower increase of the distance interval.
After 5 seconds, someone with a rank of 1200 would look for an opponent between 1280,53 and 1119,47, when the base distance is 50. After 5 seconds, someone with a rank of 1200 would look for an opponent between 1216,11 and 1183,89, when the base distance is 10. After 10 seconds and a base distance of 50, someone with rank 1200 would look for an opponent between 1329,69 and 1070,31. After 10 seconds and a base distance of 10, someone with rank 1200 would look for an opponent between 1225,94 and 1174,06.

Another possibility would be to change the interval every 10 seconds by a larger distance. This has the disadvantage that the player has to wait at least 10 seconds if no similar player is in the waiting queue. Therefore, the decision was made based on the gradual increase, where every second the distance is increased by a small factor, instead of using bigger leaps.

The definition of matchmaking parameters (*R07*) was solved by interviewing the experts. Since the game poker dice depends on a random factor, an essential question was whether poker dice actually qualifies for stroke rehabilitation and whether skill-based matching on cognitive or motor abilities is suitable. However, the experts have asserted that the patient needs more than enough cognitive skills to play the game. The cognitive skills required for the game are understanding and classifying numbers, remembering the combinations, estimating the opponent, reflecting, making a decision, and reacting accordingly. One of the experts (T7) suggested that it would be better to match only the cognitive domain, as the patient already needs vast skills for the game, and motor skills could always be added later in development. Regarding motor skills, it is sufficient to include motivating achievements in the game that reward shaking the smartphone. Hence, the main matchmaking parameter for poker dice is the success rate, which is influenced not only by luck, but also by the player's abilities to estimate the next move of the opponent, to make a decision and select the dice they have to re-roll, as well as being able to understand the numerical values of the dice.
For poker dice, players start with a score of 1200, and then the Elo ranking is applied (*R14*). Points get added to the winner and subtracted from the loser. With each game, the scores become more accurate. Concerning the ranking in poker dice, the Elo rating is calculated for the rating of the players when the game has been finished. For example, in

the beginning, the K-factor is 64, and as the player becomes more experienced, a lower value is recommended, such as 32. The higher the constant, the faster the rating grows. As the player's experience increases, the rating adjusts to the stability he/she gains in the game. If the K-factor is too high, the rating system is too sensitive to a few current events. A too-low K-factor leads to low sensitivity, and it is not fast enough to react to changes in the player's skill.



(a) Distance with Base = 50 (b) Distance with Base = 10

Figure 4.13: Waiting Time: Change in Ranking Interval after every Second

4.3 Iteration 3: Finalization and Implementation Details

After the game and matchmaking requirements have been established, the achievements and statistics are finalized. The expert survey revealed that patients often have little or no motivation to perform their exercises. Incorporating gamification elements, such as achievements, statistics, and a leaderboard, can increase a patient's motivation. Ideas emerged from talking with T1, T4, T5, T6, T8, T9, T10, from research on existing games, as well as the findings by Tuah et al. [87] (described in Chapter 2.3.2). This section also describes the implementation details.

4.3.1 Achievements and Statistics

Achievements
Achievements can ensure that players stay motivated. Once a user finishes a game, the number of games played and won increases. Also, the current level is displayed, which can be: Bronze, Silver, Gold, Platinum, and Diamond. If the ranking is below or equal to 1200: Bronze is received. For a score between 1200 and 1400, Silver is received, between 1400 and 1600 Gold, between 1600-1800 Platinum, and for everything above 1800 Diamond.
The user receives badges for the first game played and the first win.
The highest shaking intensity gets a badge, and the corresponding number is displayed. When a new personal record is set, the number changes accordingly.
Rolling the dice is rewarded with a badge in increments of 10.
The player also gets a reward when the result consists of all dice being 1, 2, 3, 4, 5, or 6. The achievements page also shows how many times the same number of dice were rolled. If the achievement is the same as rolling the dice, the user receives the same icon with a different color.

Statistics
Four statistics charts have been created: one which shows how the score changes after each game. Another chart shows the shaking amount of the dice in each round where the player shakes the dice. In the game rounds where no dice were selected to re-roll, the shaking is excluded from the graph. This chart allows the user to track the motor development of shaking the phone.
A bar graph shows how many games the user won or lost. The fourth chart is another bar chart that illustrates the final round's different dice results. It also illustrates how often these were rolled in the final round.

Leaderboard
On the leaderboard, the user can see in which rank they are, compared to all other players. The users are listed in order, sorted by highest ranking. Next to the ranking, the username of the player is displayed. One's ranking is highlighted from the others with a light blue color, so it is easier to see which place one stands.

4.3.2 Architecture

The Architecture in the Backend is based on a version of the hexagonal architecture [4]. Other names for the hexagonal architecture are Ports and Adapters, Clean Architecture or Onion Architecture. The Hexagonal Architecture consists of an Application, Infrastructure and Domain layer as can be seen in figure 4.14 (created with a Miro-Board [5]). The application layer is represented as a hexagon. All dependencies point towards the inside, where the business logic (domain layer) resides. On the outside is the infrastructure layer, where different adaptors interact with the application, such as the Controllers. The goal of this is that the business logic is independent of the technologies used.

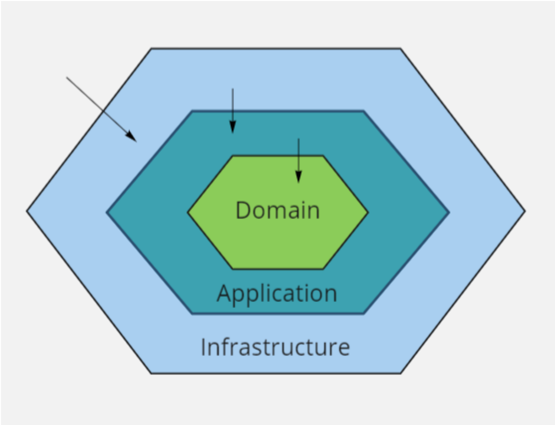


Figure 4.14: Hexagonal Architecture

An Overview of the services can be seen in figure 4.15, which was created with a Miro-Board. The application consists of a frontend and backend. The frontend calls the PlayerService, which then sends the PlayerCreationCommand to register a new player. To start the matchmaking, a player gets registered for the waiting queue in the MatchmakingService. Meanwhile, the frontend polls the GameService to get the player's current state. The state can be "waiting in the queue" or "already registered for a game". When a match is found, the MatchmakingService informs the GameService. The first round starts, and dice are rolled. For each dice roll, the services Achievements and Statistics get updated. When the game is finished, the GameService informs the RankingService, which then sends the updated ranking to the MatchmakingService, PlayerService, AchievementService, and StatisticService.

The sequence diagram created with sequencediagram.org [6] gives an overview of the communication between the services in the backend. The backend is built as a modular monolith where the services communicate with each other in an event-driven manner. The event-driven manner is elaborated in the sequence diagram 4.16, where two players

[4] `https://alistair.cockburn.us/hexagonal-architecture/` accessed Oct 1 2022
[5] `https://miro.com/` accessed Oct 1 2022
[6] `https://sequencediagram.org/` accessed Oct 1 2022

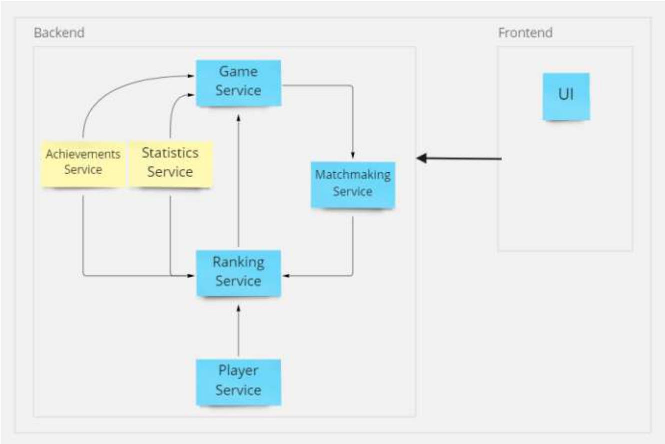


Figure 4.15: Overview of the Services

want to play the game and enter the waiting queue. Each player can only play one game simultaneously, and by triggering a GameRegistrationCommand the MatchmakingService puts the users in the waiting queue. By calculating the distance function of the matchmaking, as described in 4.2.3, the two players are matched with each other. The found match triggers the GameService by sending the PlayersMatchedEvent. Consequently, the GameStartedEvent is sent to both players. As each player rolls their dice, the RollDiceCommand is sent to the GameService, which calculates the rolled dice for each player. The DiceRolledEvent is sent back to the frontend, and at the end of a game round, an event is published with the result of each player. Rolling the dice and sending the RollDiceCommand happens 3 times, and in the last game round, the final game result is displayed. At this point, the game outcome is calculated in the GameService, where the dice combinations of the players are compared, and a winner is declared. Then the GameFinishedEvent is sent to the RankingService, which updates the Elo rank of the players. The updated score is sent to the MatchmakingService to be stored for the next round of matchmaking. The GameFinishedEvent is also sent to the players, which will show the result and update each player's achievements and statistics.

Figure 11 in Appendix D shows all services' interactions (commands, events). After a DiceRolledEvent and GameFinishedEvent the AchievementService and StatisticService are updated. There new achievements and statistics are added. The rankings of players in the PlayerService are also updated when the game has finished.
Not displayed are players leaving the queue. They are removed from it, and there is a StopGameRegistrationCommand.

Technologies and Frameworks

Before making decisions about frameworks and technologies, it is tested whether the phone's sensors (deviceemotion, deviceorientation) are accessible via the web. Findings from testing the devicemotion with ReactJS are that those who use an iOS device also need to accept permissions to enable access to the sensors. To enable the permissions

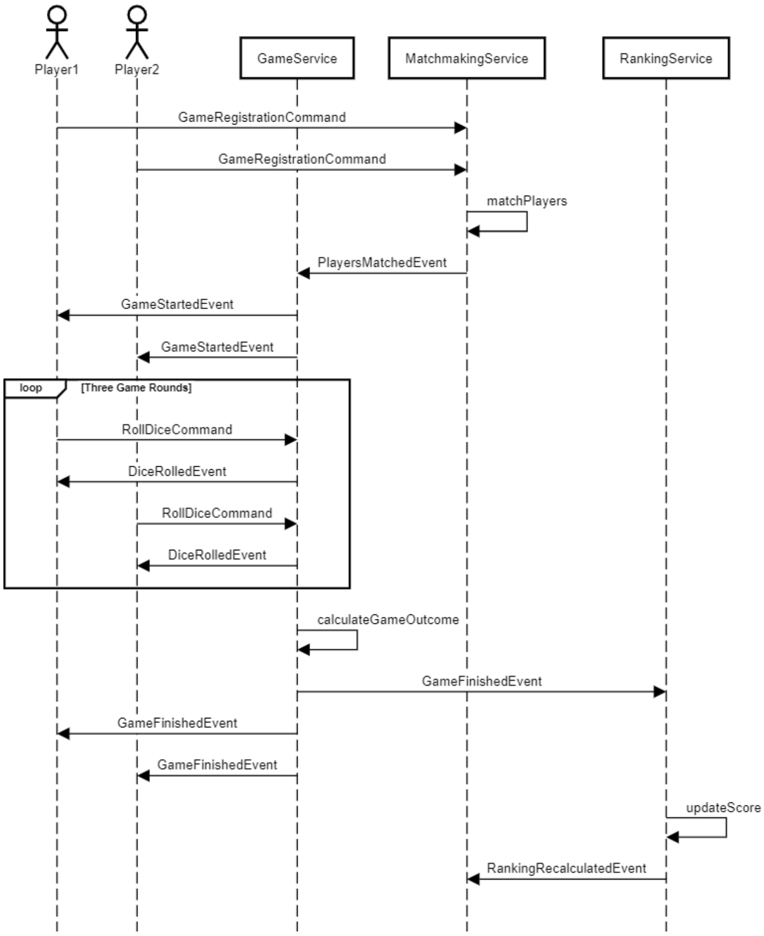


Figure 4.16: Sequence Diagram of the Core Backend Services

dialog, the page needs to be accessed with HTTPS.
The idea to make a web application instead of an App emerged due to a recommendation of two software engineers. They suggested that building, deploying, and testing an app is much more exhaustive than building a web application. Everyone can just open the link in the browser, which makes testing easier. The users do not need to download an app and install it. Another advantage is that on the web deployment can happen whenever needed, and no App Store approval for publishing an App is needed.

For the backend services, Java (version 18) with the Framework Spring Boot (2.7.1) is used. The Spring Framework also includes Spring for Graphql[7] which is used for communication between the services. By implementing a scheduler, the matchmaking is always up-to-date with players entering the waiting queue.

[7] `https://docs.spring.io/spring-graphql/docs/current/reference/html/`, accessed Oct 1 2022

The frontend uses ReactJS with version 18 [8].
To detect the shaking of the phone the devicemotionevent of the accelerometer in the phone is used [9].

It is important to understand the differences in the coordinates of the earth vs. the phone to implement the shaking amount when playing the game. The earth's coordinate system is fixed to the center of the earth, i.e., the axes are aligned with gravity and the magnetic north orientation. The X axis is along the earth's surface positive toward the east (negative towards the west). The Y-axis runs along the earth's surface, positive in the direction of the north pole (not the magnetic north). The Z axis is orthogonal to the earth's surface. The value is positive and points upwards and thus away from the center of the earth.
The device coordination system is fixed on the center of the device. When holding the device in hand, the x-axis is in the screen plane and positive in the right direction. The y-axis is also in the screen plane but is positive in the upward direction. The z-axis is perpendicular to the screen and is positive when it extends outwards from the screen. Figure 4.17 shows the coordination frame of a phone with the respective axes. When used, the acceleration of the phone is given in m/s^2.

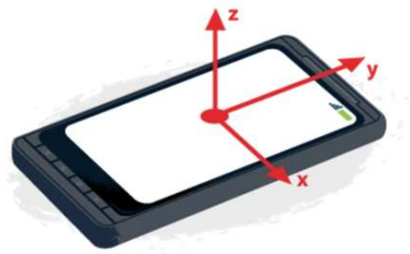


Figure 4.17: Device Coordinate Frame[10]

4.4 Iteration 4: Usability Testing

Considering that research question 3 aims to identify the best design for a multiplayer serious game so that it has good usability, a usability test was conducted. Two questionnaires were used to evaluate the usability of the application, namely the System Usability Scale and the Post-Study System Usability Questionnaire. It is impossible to ask stroke patients about the application's usability directly, as no access to them is provided. As the usability properties already described in chapter 2.7, particular emphasis was given to

[8] https://reactjs.org/ accessed Oct 1 2022
[9] https://www.w3.org/TR/orientation-event, accessed Oct 1 2022
[10] https://developer.mozilla.org/en-US/docs/Web/API/Device_orientation_events/Orientation_and_motion_data_explained#device_coordinate_frame accessed Oct 1 2022

these: learnability, efficiency, memorability, error-proneness, and satisfaction. According to Nielsen and Launder (see chapter 2.7), 4 test users should be sufficient to detect most usability problems. The users U1, U2, U3, and U4 participated in the test session and the survey, and are listed in table 4.1. The four users are between 26 and 30 years old. One of them is a student and works as a caregiver, the others are working. During the usability test, special attention was given to whether the users understood the game, as this is a fundamental requirement *(R03, R04)* concerning the game's usability for stroke patients. Furthermore, the speed of matchmaking and user satisfaction with the quality of the matches were tested. The error-proneness was tested when someone left the game or reloaded the browser tab *(R15)*. Finally, user satisfaction with the game, achievements, statistics, and general gamification elements was surveyed *(R05)*.
Thus, the goal of the evaluation test run was to validate the results according to chapter 2.7 to answer this thesis's research question 3.

In the test session, the 4 participants did not receive any instructions but were asked to familiarize themselves with the application. It was noted that 3 of the participants had read through the game instructions, and one person had not. The person who had not read the instructions had trouble navigating the game and did not know that they had to click on the dice to re-roll them or what the goal of the game was. The shaking of this user was also different compared to the others, by shaking the phone upside down instead of left to right. Nevertheless, after a few rounds and talking to the others, the participant understood the goal.

The general feedback on the matchmaking was that it worked well and quickly. General feedback on the application was that the game itself is fun, but the game explanation should be adapted. Some wanted to see a pop-up for the received achievements and more achievements. They all said a signal at the game start would be helpful, such as vibration or sound. One person also said that he would prefer to see their opponent.
During the test session, one person used the Firefox Browser, which caused some problems by not updating the current round. When this happened, they did not get adequate information on what to do next or how to fix it. Later the problem was identified as a certificate error. In the end, all users filled out both questionnaires: the System Usability Scale and the Post-Study System Usability Questionnaire.

4.4.1 System Usability Scale

The System Usability Scale (SUS) questionnaire includes 10 questions, such as listed below, with possible responses from 1-5 where 1 is strongly disagree and 5 is strongly agree [10]:

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.

To calculate the SUS score, the scale is converted to a number for each question, with " strongly disagree" getting 1 point and "strongly agree" getting 5 points. Odd numbered questions are added and from this 5 is subtracted. The sum of the even numbered questions is subtracted from 25. The total is multiplied by 2.5. Clarification of the calculation: each question has a weight of 10 points, the odd questions are positively voiced questions, and if someone strongly agrees this question is given all 10 points. On the other hand, if someone strongly disagrees, 0 points are assigned to the question. Subtracting 1 from each odd question ensures a minimum of 0. Multiplying the sum by 2.5 ensures that the maximum value for each question is 10. On the contrary, for the negatively voted questions 0 points are awarded if the participant strongly agrees. Subtracting the points for each question from 5 gives a minimum score of 0, which can then be multiplied by 2.5 to give a maximum score of 10 [11]. A SUS score between 70-80 is considered a good SUS score and an excellent SUS score is above 80 . A score with 100 indicates a system that has no usability problems and is perfect.

SUS Results
Test Person 1 had a SUS score of 97.5, which indicates that they had no problems.
Test Person 2 had a SUS score of 57.5, which indicates that they had problems.
Test Person 3 had a SUS score of 80, which shows they had few problems.
Test Person 4 had a SUS score of 95, which shows they had no problems.

The average score results in a SUS score of 82.5, which is considered a good score on the SUS scale.

4.4.2 Post-Study System Usability Questionnaire

The second questionnaire conducted was the Post-Study System Usability (PSSU) Questionnaire. It consists of 16 questions with answers from 1-7, where 1 means strongly disagree, and 7 is strongly agree [48]. The PSSU questionnaire has an overall score (questions 1-16), and it can further broken down into 3 subscales: The System Usefulness (SYSUSE) scale evaluates questions 1 to 6. The Information Quality (INFOQUAL) scale evaluates questions 7 to 12. The Interface Quality (INTERQUAL) scale evaluates questions 13 to 15. In the following the 16 questions are enumerated:

1. Overall, I am satisfied with how easy it is to use this system.
2. It was simple to use this system.
3. I was able to complete the tasks and scenarios quickly using this system.
4. I felt comfortable using this system.
5. It was easy to learn to use this system.
6. I believe I could become productive quickly using this system.
7. The system gave error messages that clearly told me how to fix problems.
8. Whenever I made a mistake using the system, I could recover easily and quickly.
9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.
10. It was easy to find the information I needed.
11. The information was effective in helping me complete the tasks and scenarios.
12. The organization of information on the system screens was clear.
13. The interface of this system was pleasant.
14. I liked using the interface of this system.
15. This system has all the functions and capabilities I expect it to have.
16. Overall, I am satisfied with this system.

PSSUQ Results
The same four test users who had already completed the SUS also completed the PSSUQ questionnaires. To calculate the total score the average of the 7 points of the scale is taken. The lower the score, the better the results and the higher the user's perceived satisfaction with the application.

Test Person 1 had an overall score of 1.0625, a SYSUSE score of 1, an INFOQUAL score of 1.167, and the INTERQUAL score of 1. This result indicates that the user is delighted with the application, understands everything, has no problems using it, and likes the user interface.

Test Person 2 had an overall score of 4.1875, a SYSUSE score of 4.167, an INFOQUAL score of 5, and the INTERQUAL score of 3. The overall score shows that the user thinks the application still needs improvement. SYSUSE score of 4.167 indicates that the user experienced some difficulties with the application. The information quality score of 5, also shows that the user did not understand everything. Finally, the quality of the user interface received an average score of 3, indicating there is room for further improvement in the interface.

Test Person 3 had an overall score of 3.625, a SYSUSE score of 2.66, an INFOQUAL score of 4.167, and the INTERQUAL score of 4.67. The overall score indicates average satisfaction with the application. The user's SYSUSE score shows a reasonable satisfaction rate with the system and its usability. What is interesting is that the user had no difficulties using the system, but the information quality could have been better. Also, according to this user, the interface needs some improvement.

Test Person 4 had an overall score of 2.4375, a SYSUSE score of 1.83, an INFOQUAL score of 3.35, and the INTERQUAL score of 2. The application was satisfactory, with an overall score of 2.4375. The system's usefulness was excellent, and the application interface was endorsed. However, according to the user, some information was missing.

The most significant feedback point was that the error displays needed to be adjusted or were not sufficiently understandable. The same applies to the game explanation. Concerning the interface, participants wished for a more colorful, vibrant, and eye-catching user interface, such as popping up achievements after completing a game. However, this contradicts requirement R03, which states that a simple interface is essential for the patients. The results of all participants yield the following average scores: Overall: 2.828125, System usefulness: 2.3975, Information quality: 3.515, and the Interface quality: 2.65.
After collecting feedback, the game explanation was adjusted, and therapists T8, T9, and T10 were asked if the application needed an info screen for a match found, sounds, or vibrations. Based on the responses received, an info screen for a match found was added and is displayed for 5 seconds before shaking begins. Sounds of dice rolling as well as dice clicking got also added (*R18*).

4.4.3 Final Game Design

The final User Interface is illustrated with an example user flow. First the User is on the Start Screen which is depicted in figure 4.18. The user decides to start a new game (*R08*) and lands in the waiting queue (*R06*). Whilst being in there, the player can also decide to cancel the matchmaking (*R20*), which will put him/her out of the waiting queue. Figure 4.19 shows an example of matchmaking, where at the left side the waiting queue of players waiting for a match is depicted. In the queue is a blue player with an Elo rank of 1200 and waiting for an opponent for 4 seconds. The other two players are outside the range of the distance function for the blue player, which is between 1126.80 and 1273.21 at 4 seconds. A green player comes into the queue, and the blue player is already waiting for 5 seconds. At 5 seconds, the algorithm looks for players with a rank

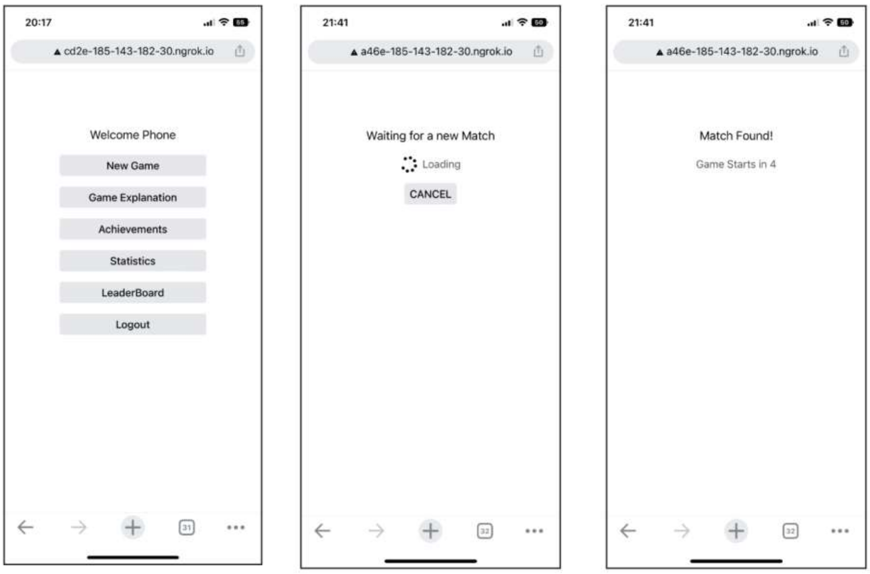


Figure 4.18: Start Screen, Matching for a New Game

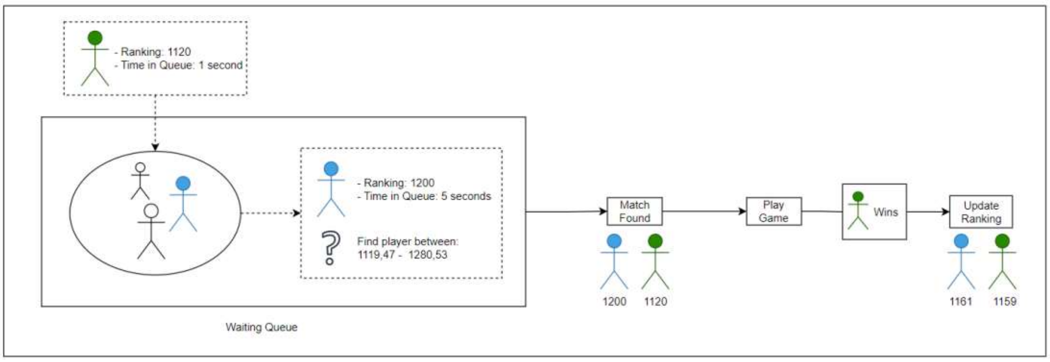


Figure 4.19: Illustration of the Matchmaking

between 1119.47 and 1280.53. The green player with an Elo of 1120 falls into this search interval, and a match between the two players occurs (*R14, R07*).

A countdown of 5 seconds starts where the player can prepare themselves to start shaking the phone. Round 1 starts, and the player has to shake the phone to roll the dice (*R12*) for 5 seconds (*R11*), which is illustrated in 4.20. During the shaking, a dice sound is played (*R18*). The dice result (*R09*) of the player Phone is *Two Pairs*, and the opponent has a worse result, namely only *One Pair*. Each player can think about the opponent's next move - where the player *laptop* probably would re-roll all dice or only those different to the pair of 5's. On the other hand, the player *Phone* could upgrade to receive a *Full House*. After each player makes their decision, they click on the dice they want to re-roll, whilst a click sound is played (*R18*), and then they finish the game round (*R10*). The

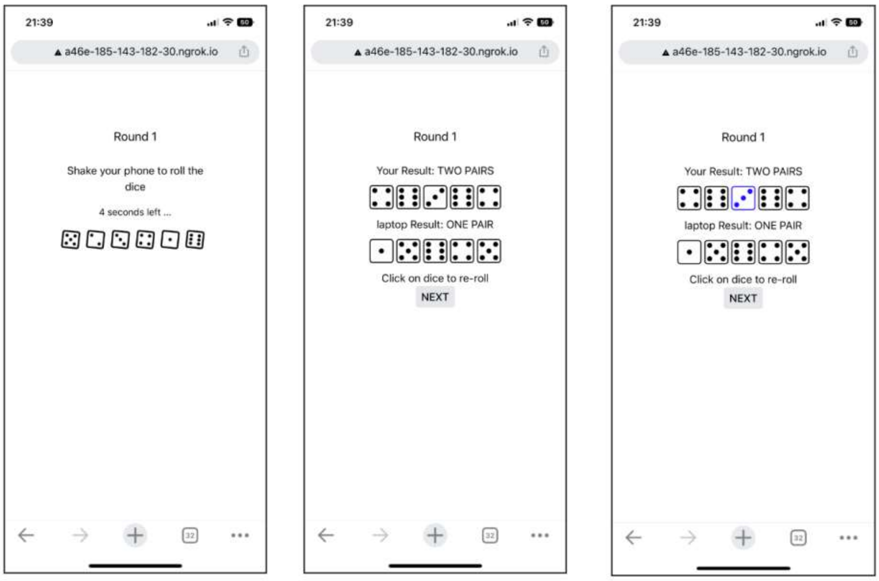


Figure 4.20: Round 1

next round, Round 2, starts, and the players again shake their dice for 5 seconds (*R11, R12*) as seen in 4.21. In this round, the player manages to achieve a *Full House*, while the other player still only has the *One Pair* (*R09*). When the player does not make a move for one minute, a dialog pops up, such as in figure 4.22 to remind the player to continue with the game (*R11*). Since the player is happy with the result, they do not want to re-roll their dice and click on next *(R10).* The final round, Round 3, starts and the opponent has managed to roll *Two Pairs* (*R09*). This was not sufficient to beat the player, and as illustrated in figure 4.23 the game is finished (*R13*): the player with the *Full House* has won and the other one lost the game.

After the green player defeats the blue player, the rankings of both players are updated according to the Elo calculation, which is illustrated on the right side of the figure 4.19. Now the blue player has an Elo of 1161, and the green player 1159.

Both can now view their achievements and statistics (*R16, R17, R05*) such as in figure 4.24. The achievements page displays the current level of the player (*R14*), which is silver. On the statistics page, it can be seen that the player could improve their ranking. At start, the player's ranking decreased, but after a few games, it started to increase. The shaking amount varies between very good and very little shaking. One can also see that the player has received quite good dice results, which probably led him to win the game (*Four of A Kind, Full House*). In the Leaderboard (*R21*), the player is also the second-best player. In figure 4.25, the explanation of the game (*R03*) can be read, and figure 4.26 shows a new player's achievements compared to someone who has more experience with the gameplay.

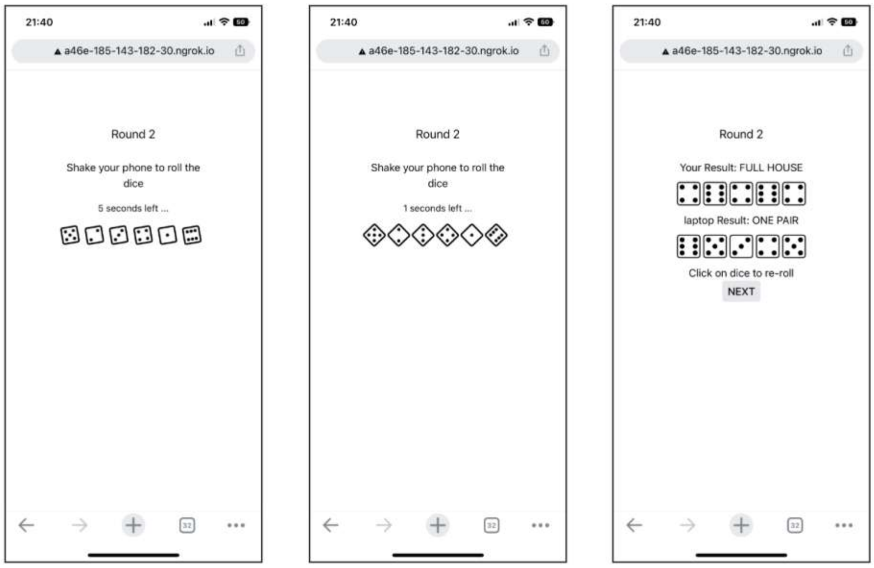


Figure 4.21: Round 2

Figure 4.22: Round 3

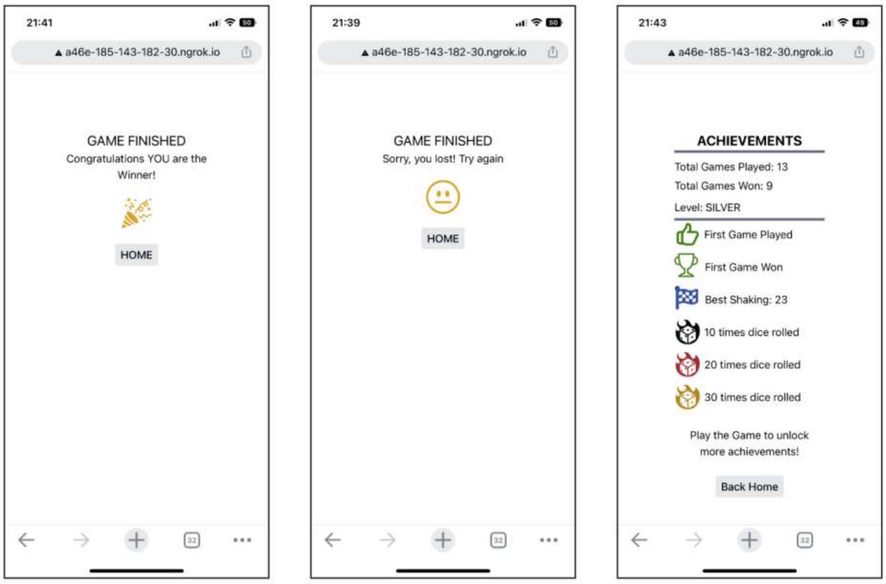


Figure 4.23: Finished Game and Achievements

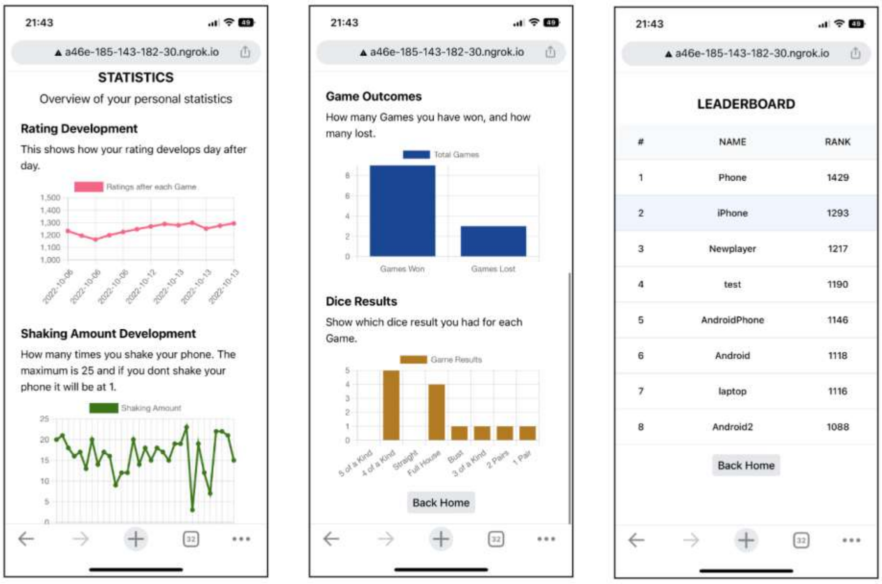


Figure 4.24: Statistics and Leaderboard

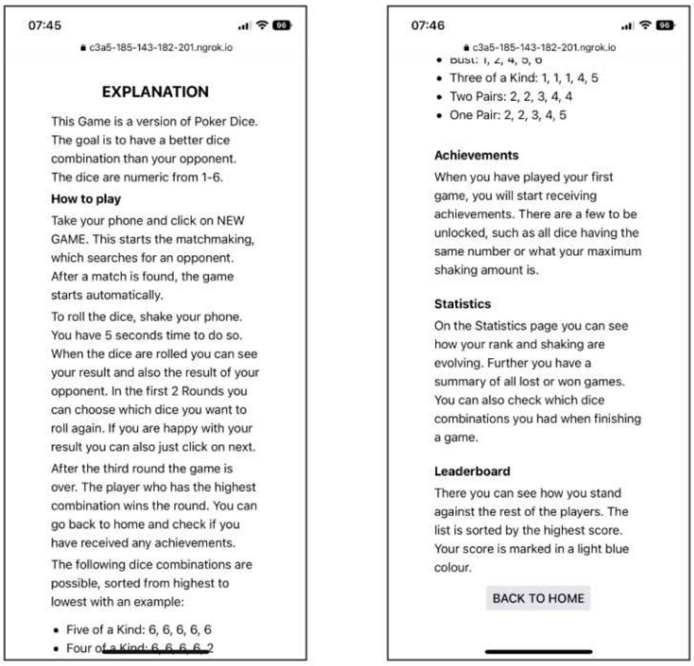


Figure 4.25: Game Explanation

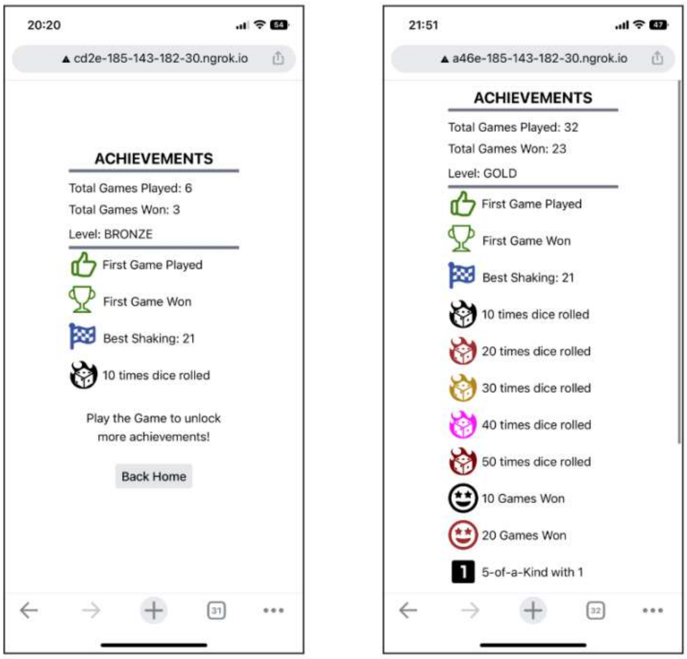


Figure 4.26: Achievements of a Beginner vs. an Advanced Player

4.5 Expert Evaluation

Finally, a qualitative analysis was conducted using the expert questionnaire, which was sent to 10 people and answered by 4. The purpose of the questions was to evaluate the results of this work, with respect to the research questions. The questionnaire is structured into an introduction, questions about matchmaking, the game, and the final questions about usability and ease of use. The experts listed in table 4.1 received the questionnaire and a link to a YouTube video, which demonstrates on how to use the application and the game. It is a semi-structured interview that consists of questions with open-ended and pre-defined answers and can be re-read in the Appendix B. Open-ended questions were primarily used to elaborate on the chosen answers.

Questionnaire Results
In total, four out of ten, who work with stroke patients, completed the questionnaire. Among the four participants two are occupational therapists, one is a nurse, and one a speech therapist. All of them think that the matchmaking strategy is suitable for the game, and the match quality and the waiting time are balanced.
Regarding matchmaking parameters, all respondents would not include the shaking amount in the current strategy. The response section of the questionnaire also includes the option to select another parameter, but no one chose this option. The selected answers is depicted in figure 4.27, where two out of the four individuals voted to include only the success rate, which is the current strategy. Those who selected the success rate

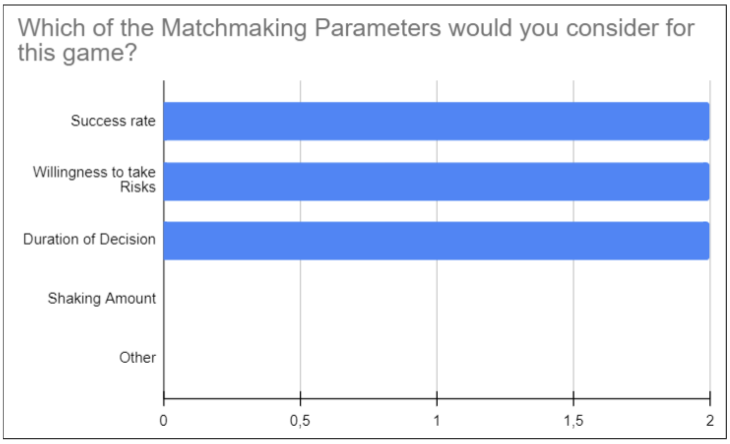


Figure 4.27: Questionnaire Results: Matchmaking Parameter

chose it due to "*strengthening self-confidence or a sense of achievement*", and the other individual said, "*the game should be as fair and understandable as possible and have a competitive dynamic without encouraging evasion or miscalculation*". The other two of the interviewees chose willingness to take risks, and the duration of making a decision as matchmaking parameters. One individual selected these for "*even better matching of the skills*" and the other individual did not specify the reason for selecting these. This result is interesting as those who chose to include only the success rate initially suggested including the shake amount and the duration of decision-making in the matchmaking.

According to the experts it is feasible if the matchmaking strategy gets more accurate after 10 or 15 games. They suggest that poker dice is a suitable solution to match stroke patients. However, explanation of the game needs fine-tuning: "*I had to read the instructions several times to understand what was meant*".

The question that dealt with distractions in the application revealed that if someone has aphasia, the statistics and written instructions might be a bit overwhelming and hence are only suitable for those with mildly affected aphasics. Someone suggested using more colors for a visual relief during the game and another individual suggested a warning for patients who have a neglect or visual field defects, that the possibility of not recognizing all the dice in the row exists. This indicates sit down with the therapists to define a re-design of the statistics section and the written introductions. Two individuals suggested adding more sounds, such as clicking buttons, finding a new match, or winning/losing the game, but the others did not find it necessary.

Regarding gamification elements and motivation, all respondents say that the achievements motivate the patients, and three of the four say the statistics motivate the patients. Nevertheless, there are some suggestions for improvement of the achievements. One person said: "*I would not add anything more, but rather leave some things out and make the existing achievements bigger and simpler*". One response was to omit the display of the number of achievements, as it could be distracting. Another person said that the achievements and statistics could be left as they are since they are easy to understand. Someone suggested displaying an accurate time or a measurement of the amount of movement to make motor progress visible.
One individual recommends simplifying the statistics; there should be less reading text, and a different visualization should be chosen for the amount of shaking. Another recommendation was to have the results read aloud and interpreted. Moreover, another suggestion was to have weekly intervals in the diagrams. Everyone feels that this application adds variety to the patient's daily routine.

The responses to the question of how the participants liked the application design, can be seen in figure 4.28. The scale ranges from 1 to 7, with 7 being very good and 1 not good. Two of the participants selected the number 5, one selected 3 and one selected number 6, which indicates an average - good design. This aligns with the usability tests.

Figure 4.29 illustrates which age group can be targeted for this application. Only one out of the four individuals selected all age groups from 20 onwards; two were more skeptical of an older target group being able to use the application and selected only between 20-40 years as target groups. Those who also selected the older age groups were occupational therapists, which could indicate that they have already experienced using serious games for older generations, while the others may not have. This aligns with the study from Oyake et al. [73], which shows that among various professionals, occupational therapists are the most likely to use game properties to motivate patients

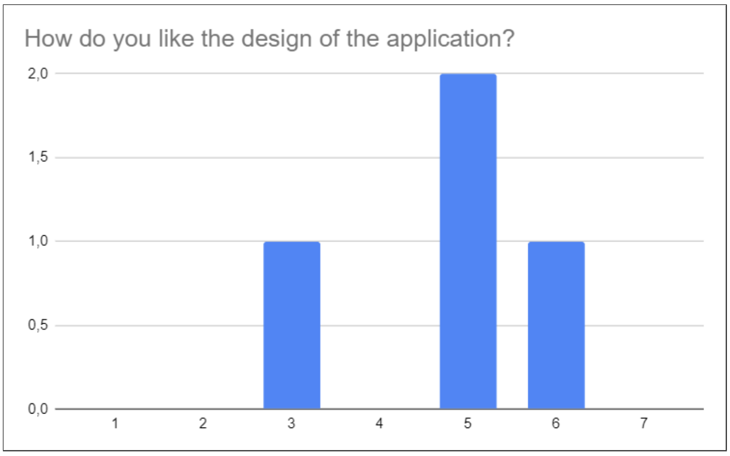


Figure 4.28: Questionnaire Results: Design of the Application

for rehabilitation. Occupational therapists reported that they would instead use game properties to motivate patients, while nurses would rate diagnosis as applicable when choosing a motivational strategy. Further, the authors argue that a lacking use of incorporating or group rehabilitation in practice may be due to time constraints and a lack of confidence in the specific practice.

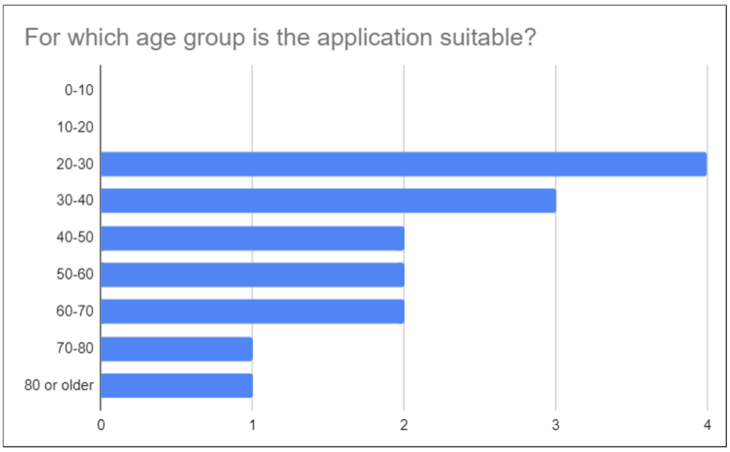


Figure 4.29: Questionnaire Results: Suitable Age Group

However, if the patient is fit enough everyone would use the application for their patients. Yet they would not recommend its use if the patient is severely impaired. The experts would use the application to improve cognitive and motor skills and as additional self-training since it is not tied to a specific location.

CHAPTER 5

Discussion

In the presented work, three research questions were identified as objectives. This chapter describes the research questions, their respective outcomes, and how they came about. The goal was to develop a multiplayer serious game incorporating a matchmaking strategy for stroke patients. The developed prototype was tested regarding usability by test users and evaluated by experts.

5.1 Research Question 1

What is a suitable matchmaking strategy between two or more players of a Multiplayer Serious Game in stroke rehabilitation?

Matchmaking aims to make it effective so that fair and enjoyable gameplay is ensured. This goal leads to a matchmaking system that brings together players with similar or even the same abilities while improving the rankings accordingly. Players want to find other players to play with or against quickly and easily. Hence waiting times for a match, such as in queues, is a vital factor to consider, as players may get frustrated if it takes too long. In general, matchmaking can either be done manually by someone or automatically by a matchmaking system. The purpose of the research question is to develop a matchmaking strategy. A matchmaking strategy consists of a waiting queue and the skill-based matching function. First, the matching function is described, followed by the waiting queue.

The matchmaking strategy was established during the first two iterations to answer the research question. The first iteration entailed extensive literature research, and the current state of the art was analyzed to clarify possible matchmaking strategies. As part of the first iteration, initial requirements were analyzed, and the interview guide containing questions on the matchmaking strategy was prepared. Chapter 3 revealed that there has yet to be a matchmaking strategy in multiplayer serious games, but regular

games and the gaming industry can provide insight into solutions, as described in chapters 2.6 and 3.5. Four matchmaking functions can be considered: technical factor-based, role-based, skill-based, and engagement-based matchmaking. The choice of matchmaking strategy also depends on the choice of the game. Therefore, an approximate definition of the game occurred concurrently. As poker dice became the selected game, role-based matchmaking could be excluded a priori as there are no roles in the selected game. Technical matchmaking was excluded, as the game is not published, and the game does not need to be optimized for latency as the players can take their turns on their own and take their time while doing so. The remaining question was whether matchmaking, based on skill or engagement, is an appropriate solution. Since stroke patients use the game for rehabilitation purposes, it needed to be clarified whether it is more important that they just play or it is more important that they play with someone at a similar level.
In the second iteration, activities became increasingly concrete, experts were surveyed to define and subsequently implement the matchmaking strategy. From the interviews, the result was that matching based on skill is critical for stroke patients, see chapter 4.1.4. Consequently, the decision was to employ skill-based matchmaking, for which a ranking strategy is required. Ranking strategies comprise Elo, Glicko, Glicko2, and TrueSkill. TrueSkill could be excluded because it is a strategy used in team-based matchmaking. In the Glicko strategy, the ranking is updated only after a certain evaluation period. Thus, the player must play a certain number of games for the ranking to adjust. Unlike Glicko, in Elo, the ranking is updated after each game. One of the consulted therapists said to update the ranking after each game. For this reason, Elo was chosen as the ranking algorithm. Elo has the disadvantage that the ranking becomes only better after more than 10 games. However, in the final evaluation, chapter 4.5, the therapists stated that this does not impose any problems.

Matchmaking also composes of a waiting queue, where players get matched based on their ranking. As soon as the player wants to start a new game, he/she enters the waiting queue, and the proposed system searches for a person within a defined interval. This interval is based on the player's ranking and increases every second. Thus, it should be ensured that a player does not have to wait forever for a match but finds a good match within a foreseeable period, such as 5-20 seconds. If the player waits longer than 30 seconds, the player will be matched with the first player in the queue.

The parameters used for matchmaking also had to be integrated into the game. Due to a skill-based matchmaking strategy, the update of the player's ranking is based on the game's outcome. In poker dice, one combination is higher than the other, and the one with the higher combination wins. When the player wins, points are credited to the player and deducted from the opponent. Thus, the ranking score gets adjusted based on the game's result.
The game outcome provides insight regarding the winner/loser, i.e., the success rate, which is relevant for calculating the player's new rank. The next matchmaking round is then based on the updated rank. If factors such as shaking have to be included in matchmaking, then the current strategy must incorporate shaking into the game result

by a fair calculation. However, according to most experts, the shaking should not be included in the game result, so matching based on the shaking was not incorporated into the strategy. Also, if both motor and cognitive skills are included in the game result, it cannot indicate the reason for winning or losing. Instead, it is better to identify and focus on cognitive skills first. Someone suggested that it is better to compare only the cognitive area because the patient already has to know a lot and one can always add comparing motor skills in a later stage. It is generally challenging to compare the deficits because the patients all have varying degrees of deficits. Nevertheless, they have joint problems and goals. Shaking the phone serves as a training effect, where the players can track their progress in the statistics, but it does not serve as a parameter for matchmaking. In addition, in the final expert review, none of the participants chose the shaking amount as a matching parameter, which is in line with the current strategy for matchmaking. However, some of those experts initially thought that matching based on the amount of shaking would be appropriate. It could be that they envisioned the game and matchmaking differently during the interview. Another reason may be that they had more time to think about the strategy during the questionnaire. The other two participants chose risk-taking and decision-making duration, which is also of interest, as they initially thought of including the success rate in the matchmaking.

One shortcoming is that there could have been two ranking values: one value to show the player where they rank in the leaderboard. The second value could be a measure that is dedicated for the Elo ranking. This value, then, could consider more matchmaking parameters and be composed of a comprehensive calculation. Matching could then be implemented based on this value, and if it proves to be a good solution, the value could be further developed. However, the opinion of the remaining people, who did not complete the questionnaire, should be sought. In addition, the experts who selected only the success rate as a parameter should be asked in more detail for what reason. If the experts consider it necessary, matchmaking can be extended to include other parameters.

As for this thesis, according to the expert interviewees poker dice is suitable enough to show how a matchmaking could work for stroke patients and that there is a need for such in practice.

5.2 Research Question 2

What are the requirements for a prototype of a Multiplayer Serious Game in the context of stroke rehabilitation?

Various studies have already shown that multiplayer serious games reduce the feeling of social isolation and depression in stroke patients. Social interaction helps motivate patients to continue with their rehabilitation exercises. Game modes can be collaborative, competitive, cooperative, or co-active and depend on the individual's preferences, which may vary. Patients with severe impairments may prefer the collaborative game mode [76] [77].

The user-centered design process was applied, which included generating an understanding of the application context, specifying requirements, providing a design solution, and finally, to evaluate it by test users and experts. The literature research in chapter 2 revealed various theories and studies from which initial requirements emerged. These requirements formed the basis for the concept of an application for stroke patients and were further used for the expert interviews. In addition to the results of the literature research, requirements also emerged from the requirements elicitation in 4.2.1. The requirements elicitation included several expert interviews with occupational therapists, physiotherapists, a nurse, a speech therapist, and a doctor-to-be. Most of the interviews could only be conducted on the phone, except for one person who was met regularly and another interview was conducted over Skype. An interview guide served as a guideline for the questions on the game, matchmaking, and gamification elements.

This work focuses on individuals with mild impairments. Therapists would not anticipate a person with severe impairments to be able to use such a mobile application. They do not expect the patients to be able to operate a cell phone by themselves well, let alone interpret or play the game. Patients who are severely affected would need the help of someone else who can guide them.

The game of the prototype for this work is of competitive nature where two patients are matched with each other in order to play the game poker dice on their smartphone in the browser. Each player has to try to roll a better dice combination than their opponent does to win the game. The competitive mode was chosen since Pereira et al. showed in a study that stroke patients with better cognition, higher motor skills, or introverted personalities prefer the competitive mode [77].

Personas and low-fidelity prototypes (pencil sketches, wireframes) were identified as part of the first iteration (see chapter 4.1.3), to elaborate the requirements for poker dice. Pencil sketches were created during the brainstorming phase, and relevant excerpts were further processed into wireframes. The pencil sketches were evaluated in a one-on-one meeting with an occupational therapist, and various experts evaluated the wireframes. The analysis summarizes the resulting requirements in the table 4.2. The defined requirements concern the matchmaking, game, and gamification elements that contain the prototype.

A weak point of the developed multiplayer serious game is that players do not have the option to communicate with each other via chat or to see each other via the smartphone's front camera. As part of possible future work, this issue is also addressed in chapter 6.2.

5.3 Research Question 3

What is the best way to design a multiplayer serious game to ensure good usability?

Usability is critical for stroke patients since they have impairments that do not allow them to grasp things as quickly as a healthy human. Since no actual patients were available to test the application for this work, four independent volunteers were approached to

perform a usability test on the game and matchmaking on-site (see chapter 4.4). After finishing the game rounds, the System Usability Score (SUS) and Post-Study System Usability Questionnaire (PSSUQ) were handed over to the test users to evaluate the application's usability. The SUS is a standardized questionnaire used for quantitative analysis of the usability of an application. The PSSUQ is a standardized questionnaire that measures end users' perceived satisfaction with an application.
A perfect application in terms of design and usability is an application that achieves a SUS score of 100 on the test. Excellent usability is achieved with a score of 80 and good usability scores between 70-80. The PSSUQ is subdivided into three additional subgroups: system usefulness (SYSUSE), information quality (INFOQUAL), and interface quality (INTERQUAL). Each of the subgroups has its own score.

The average score of the SUS survey for the application presented in this work is 82.5. However, it should be noted that healthy people were used for the test, and the result is not 1:1 transferable to a test with stroke patients.

For the PSSUQ, an overall score of 2,828125 was achieved. The System Usefulness received the best overall score of 2,3975, Interface Quality is ranked as second best with an overall score of 2,65, and the worst score was information quality which had a score of 3,515.

Matchmaking was perceived as a good solution as it worked quickly, and the participants were satisfied with the match quality. The game was entertaining, but one of the four test users needed help understanding it at the beginning, which may be because the person did not read the game explanation. However, the test users had to explore the application without being told what to do.

Contrary to the demands of the interviewed and surveyed experts, the test users wanted more eye-catching images and pop-ups of newly received achievements. This also shows the limitations of interviewing healthy test users instead of stroke patients. Other feedback coincided with the experts, who wished for a start signal at the beginning of the game. Furthermore, there are significant differences in the perception of a healthy person. During the first interview, it was apparent that a game for stroke patients must not be overly graphically demanding. The user interface should not be too colorful or have bright flashes, nor should it contain many details. In addition, the patient should not have to deal with rules for a long time but instead follow the flow of the game.

The usability test shows the importance of testing the application on actual stroke patients in order to implement a design tailored to this target group.

CHAPTER 6

Conclusion and Outlook

This work aimed to develop a matchmaking of stroke patients in a multiplayer serious game. The game should allow patients to be matched with another patient, for example, from home, during waiting times, or while traveling, and to perform rehabilitation exercises playfully. This chapter summarizes the results of this thesis. An outlook into the future is given, which describes possible continuations of this work.

6.1 Conclusion

This work aimed to develop a prototype for a multiplayer serious game that includes a matchmaking solution for stroke patients undergoing rehabilitation. It is evident from the interviews with the stakeholders that therapists would like to use matchmaking for their stroke patients. According to the expert questionnaire, patients would benefit from being able to perform their rehabilitation exercises digitally and be matched with another patient without the need for a therapist to intervene. The experts suggested that in the future, as more and more people with an affinity for technology grow older and have a stroke, they will find it easier to use such an application in any case. Therefore, it is encouraging to develop such an application for stroke rehabilitation. Advocacy and actual utilization of digital applications among older generations can be achieved by integrating gamification elements and having a simple user interface.

The proposed solution encloses a matchmaking strategy that uses Elo as a ranking strategy, which compares the skill (success rate) depending on the game result. The time spent in the waiting queue is also addressed as part of the matchmaking solution. Analysis of the expert survey indicated that the current patient matching parameters based on success rate are sufficient but could be expanded to include risk tolerance measures and decision-making duration. The game includes cognitive skills such as risk assessment, estimating the opponent, recognizing moves and combinations, and making decisions. A patient's necessary motor skills include grasping the phone, clicking the dice, and shaking the phone by moving the hand. As a condition of being able to use the application, the patient must operate the cell phone independently and have the indicated cognitive and motor skills. The prototype implementation was preceded by an iterative approach using the user-centered design process. Outstanding usability is essential as it enables people to use digital applications and can even lead to their independent use, whereby individuals no longer depend on the help of others for operation. In a test session with four participants, the game and matchmaking solution was tested, and its usability was evaluated through standardized usability questionnaires.

6.2 Outlook

In the course of the work, several ideas for additional requirements for the game and matchmaking emerged, which, however, could not be considered in the current implementation as they would go beyond the scope of this work. The ideas collected are presented in this section as an outlook for future work.

One idea that emerged after development was to incorporate the phone's camera by displaying a small live image of each player at the bottom of the screen. A camera would make the game more personal for the players and possibly encourage engagement.
Settings should be implemented that allow the sound of the application to be muted and the volume and font size to be adjusted to the patient's individual needs.
The statistics could be expanded to comparatively show games won/lost by age group, and whether winning or losing games depends on the time of day. A mood barometer could also be integrated, asking the players after each game how they feel, and then statistics can be depicted according to the player's mood.
Another idea is to include an initial skills assessment phase with different tasks. This idea can be used for an application that consists of more games than just poker dice, where a mini-version could be implemented for each of the games to score the skills. In the assessment, one task could check the patient's motor skills, and the other could measure their cognitive skills. The mini-games could involve different necessary skills to complete the tasks. As a ranking value, one could define both a motor and a cognitive value and match the players separately instead of having one ranking value for all skills. In one game, motor skills might be required, and those with similar motor skills get matched when the player registers for this game. In the other game, cognitive skills are necessary, so those with similar cognitive skills are matched. Depending on what the patient should focus on during rehabilitation, they could choose whether to play a game that focuses on motor or cognitive rehabilitation.
Moreover, testing the application on a larger scale is needed for further evaluation. For instance, a test session with therapists who work with stroke patients instead of the test users employed in this work would be of great value. In a later test session, actual stroke patients could be used for usability tests. Continued evaluations with larger groups of healthy test users and actual patients over a prolonged period can provide more insights for the advancement of the presented prototype and serve as a foundation for further scientific work.

List of Figures

List of Tables

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Appendix A

Interview Guide - Translated to English

Date:
Name:
Age:
Education:
Current Workplace:

1. Do you know Serious Games?
2. Do you think patients are interested in playing a game (online) with others who have similar skills?
3. What do you think matchmaking for stroke patients should do differently than matchmaking for regular matches?
4. From a rehabilitative perspective, what do you think is important to keep in mind about the matchmaking algorithm?

   [Explanation of Game Idea and Matchmaking]
5. Matchmaking:
   a) Which matchmaking parameters are supposed to occur?
   b) Should this match people who fit cognitively as well as motorically?
   c) Should the matchmaking take into account the amount of shaking?
   d) What if patients want to shake less or take the better hand?
6. Would you prefer a new match, with new players, after every game or after every x game?
7. Should it display who the player's match is before the game starts?
8. Should a vibrating signal indicate a found match and that the game starts?

9. How long should someone wait for an opponent? How important is the waiting time for stroke patients - do they get impatient or such?

10. Shaking:

    a) Should the amount of shaking be included in the game result, or should someone with poor motor skills, for example, only roll dice ranging from 1-4?

    b) What should the shaking motion look like: should someone shake far out or make small, fast movements?

    c) Should a threshold be built in for people who are more motorically impaired?

11. What happens to players who leave the game early?

12. If a player leaves the game, should they be able to return to the game? If so, how long should they have the opportunity to get back to the game?

13. Should there be a limit to how long a player can play in a day (to prevent fatigue, for example)?

14. How long should someone in the round decide which dice to re-roll?

15. Which gamification elements motivate patients to train?

16. To what extent can patients grasp what they have rolled and what the best combinations are? How much is cognitive thinking required to do so?

17. Is it essential to have a game explanation that can always be accessed?

18. What color should the dice be when they are selected for re-rolling?

19. Should the player be able to give feedback on the match?

20. Should there be a vibration when the dice are shaken?

21. Should players be able to see what trophies are available to earn (grayed out) in the Achievements?

22. What statistics are interesting for the players?

23. Should there be the possibility for a Revenge game? Should someone be able to choose that they want to play again with the same player?

24. What do you think of the idea?

Interview Guide - Original

Datum:
Name:
Alter:
Ausbildung:
Derzeitiger Arbeitsplatz:

1. Kennen Sie Serious Games?

2. Haben PatientInnen Ihrer Meinung nach Interesse, mit anderen, die ähnliche Fähigkeiten haben, ein Spiel zu spielen (online)?

3. What do you think matchmaking for stroke patients should do differently than matchmaking for regular matches?

4. From a rehabilitative perspective, what do you think is important to keep in mind about the matchmaking algorithm?

   [Erklärung vom Spiel und Matchmaking]

5. Matchmaking:

   a) Welche Matchmaking Parameter soll es geben?
   b) Sollten dadurch Leute miteinander gematcht werden, die sowohl kognitiv als auch motorisch zueinander passen?
   c) Soll in das Matchmaking die Schüttel-Menge der PatientInnen miteinfließen?
   d) Was, wenn PatientInnen mal weniger schütteln möchten oder die bessere Hand nehmen?

6. Ist es besser, wenn ein neues Match, mit neuen Spielern, nach jedem Spiel oder erst nach x Spielen stattfindet?

7. Soll angezeigt werden, mit wem man gematcht wurde, bevor das Spiel startet?

8. Soll es ein vibrieren geben, welches signalisiert, dass ein Match gefunden wurde und das Spiel startet?

9. Wie lange sollte jemand maximal auf einen Gegner warten? Bzw. wie wichtig ist die Wartezeit für Schlaganfall PatientInnen, werden sie ungeduldig oder dergleichen?

10. Schüttelparameter:

    a) Soll die Schüttelmenge in das Ergebnis inkludiert werden, oder dass dann jemand, der motorisch schlecht ist, z.B. nur Würfel von 1-4 würfelt?
    b) Wie soll die Schüttelbewegung aussehen: soll jemand weit ausholen beim Schütteln, oder eher kleine schnelle Bewegungen machen?

c) Soll ein Threshold eingebaut werden für Personen, die stärker motorisch eingeschränkt sind?

11. Was passiert mit Spielern, die das Spiel vorzeitig verlassen?
12. Wenn ein Spieler das Spiel verlässt, soll er wieder zurück zum Spiel kommen? Falls ja, wie lange sollen sie die Möglichkeit haben, wieder zurück zum Spiel zu kommen?
13. Soll es ein Limit geben, wie lange an einem Tag gespielt werden darf (um Übermüdung zB zu verhindern)?
14. Wie lange soll jemand in der Runde Zeit haben, sich zu entscheiden, welche Würfel neu gewürfelt werden?
15. Welche Gamification Elemente motivieren PatientInnen zu trainieren?
16. Wie schnell können PatientInnen erfassen, was er/sie gewürfelt hat und was die besten Kombinationen sind? Wie sehr wird das kognitive Denken hierbei gefordert?
17. Ist eine Spielerklärung wichtig, auf die immer zurückgegriffen werden kann?
18. Welche Farbe sollen die Würfel haben, wenn sie zum erneuten Würfeln ausgewählt werden?
19. Soll der/die SpielerIn Feedback auf das Match geben können?
20. Soll es eine Vibration geben, wenn die Würfel geschüttelt werden?
21. Should players be able to see what trophies are available to earn (grayed out) in the Achievements?
22. What statistics are interesting for the players?
23. Soll es die Möglichkeit für ein Revenge-Spiel geben? Soll jemand auswählen können, dass er/sie mit dem gleichen Spieler noch einmal spielen möchte?
24. Was denken Sie von der Idee?

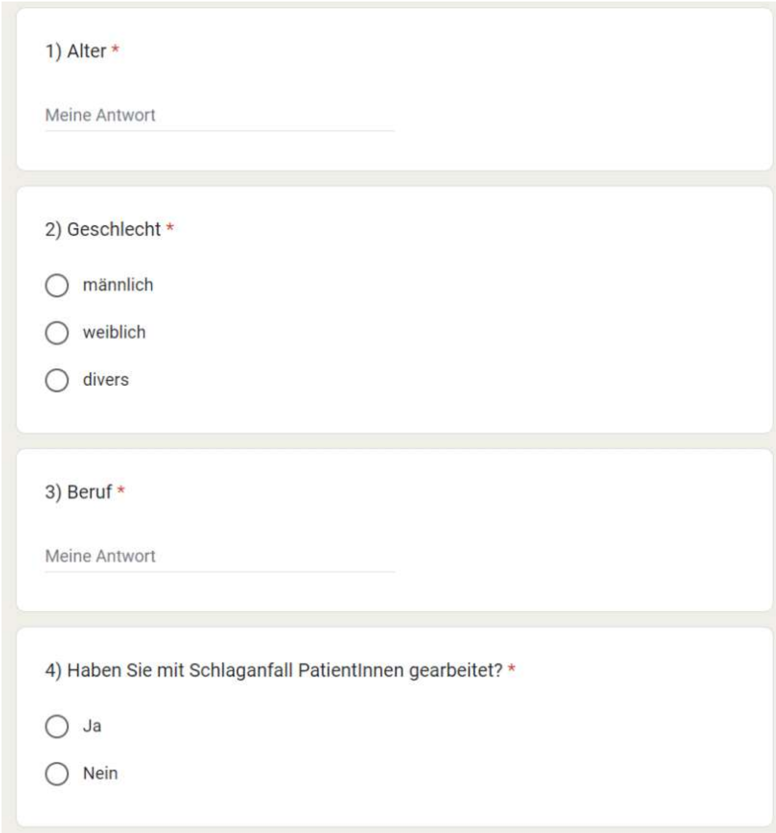
Appendix B

Questionnaire - Translated to English

1. Age
2. Gender
3. Occupation
4. Have you worked with stroke patients?
5. In your opinion, is the matchmaking described above suitable for this game?
6. In your opinion, is the waiting time and quality of the match sufficiently balanced?
   a) If not, why not?
7. Would you therefore include the shaking frequency of the players weighted in the result for this game?
   a) If yes, what should be taken into account?
8. Which of the following matchmaking parameters would you like to see in this game:
   a) Can you elaborate on your previous answer?
9. Is it acceptable if the ranking and thus the match of the player becomes more accurate only after 10-15 games?
10. In your opinion, is the game PokerDice suitable for stroke patients?
    a) If no, why not?
11. Is everything understandable?
    a) If no, what is not understandable?
12. In your opinion, is anything in the application superfluous?

13. Think about the video. Was there anything that can be distracting for some patients?
14. In your opinion, are more sounds needed (clicking buttons, match found, won/lost)?
15. Are the Achievements motivating for the patients?
16. What can be improved or extended about the Achievements?
17. Are the statistics (ranking development, shake development, how many matches won/lost, what dice results) motivating?
18. What can be improved or expanded about the statistics?
19. Do you think this application brings variety into the everyday life of stroke patients and motivates them to rehabilitation?
20. Which of the following age groups do you think get along best with the application?
21. How do you like the design of the application?
22. Would you use the matchmaking game and recommend it to your patients?
    a) If no, why not? If yes, why?
23. Do you have any other comments?

Questionnaire - Original


1) Alter *

Meine Antwort

2) Geschlecht *

- männlich
- weiblich
- divers

3) Beruf *

Meine Antwort

4) Haben Sie mit Schlaganfall PatientInnen gearbeitet? *

- Ja
- Nein

Figure 1: Questionnaire: Basic Questions

Fragen zum Matchmaking

Jede/r SpielerIn hat ein "Ranking". Beim Matchmaking wird das Ranking der SpielerInnen in der Warteschlange verglichen. Dieses Ranking wird nach jedem Spiel, basierend darauf ob gewonnen/verloren wurde upgedated.
D.h. der verwendete Matchmaking-Parameter ist die Erfolgsquote.

5) Eignet sich Ihrer Meinung nach bei diesem Spiel das oben beschriebene Matchmaking? *

- ◯ Ja
- ◯ Nein
- ◯ Sonstiges: ____________

6.a) Bezüglich der Wartezeit auf ein Match: *
wenn es genügend SpielerInnen mit unterschiedlichen Rankings gibt, wird die Person als GegnerIn gewählt, der/die am nähesten zum eigenen Rank liegt. Je näher, desto ähnlicher sind ihre Fähigkeiten.
Mit jeder Sekunde werden GegnerInnen mit weiter entferntem Ranking gesucht.
Bsp. Person X hat ein Ranking von 1200:
- Nach 5 sec. wird jemand mit einem Ranking zwischen 1280,53 und 1119,47 gesucht.
- Nach 10 sec. wird jemand mit einem Ranking zwischen 1329,69 und 1070,31 gesucht.
- Nach ca. 30 sec. wird mit "irgendjemanden" gematcht.

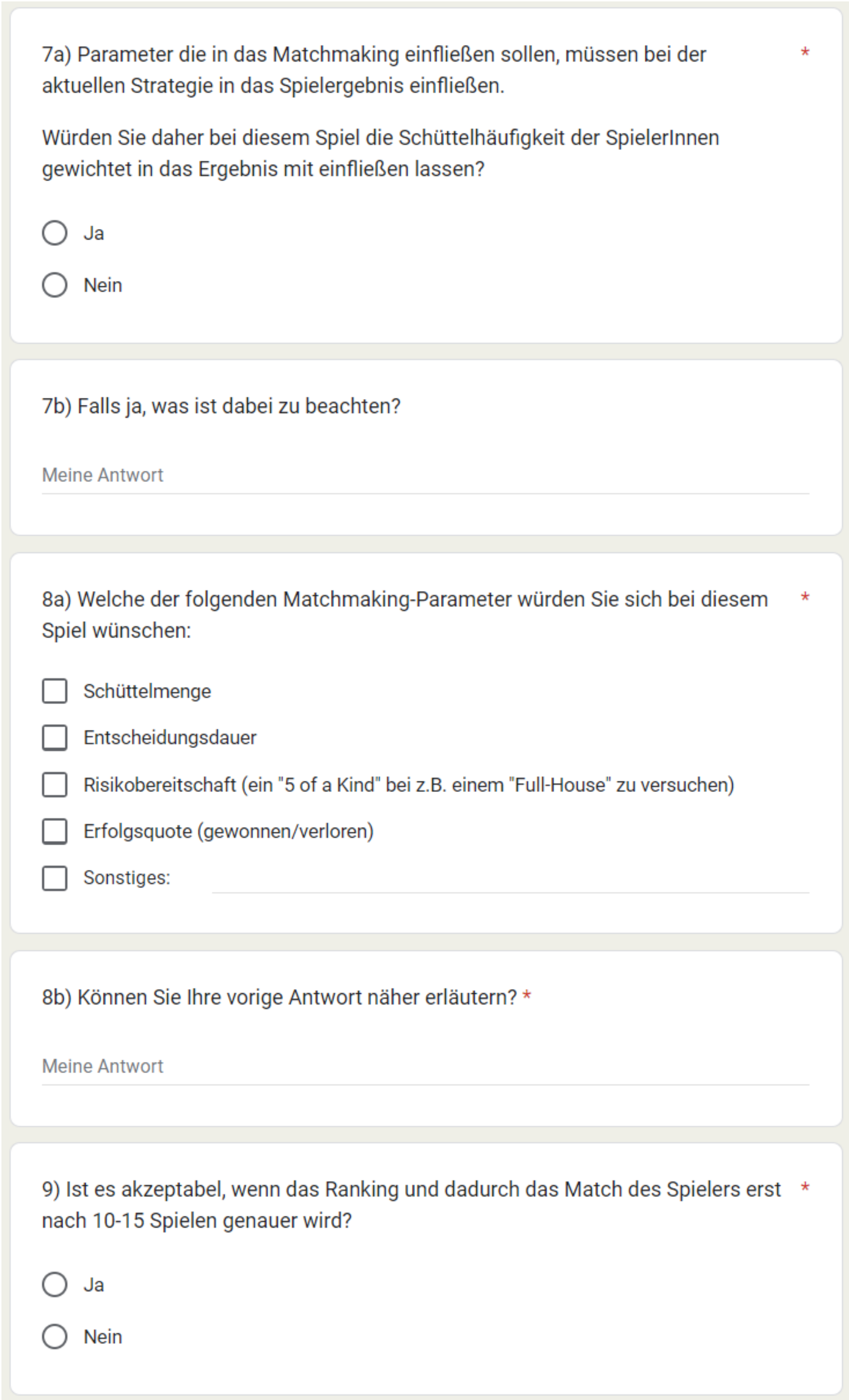
Ist, ihrer Meinung nach die Wartezeit und Qualität des Matches ausreichend balanciert?

- ◯ Ja
- ◯ Nein

6.b) Falls nein, warum nicht?

Meine Antwort ____________

Figure 2: Questionnaire: Questions on Matchmaking



7a) Parameter die in das Matchmaking einfließen sollen, müssen bei der aktuellen Strategie in das Spielergebnis einfließen. *

Würden Sie daher bei diesem Spiel die Schüttelhäufigkeit der SpielerInnen gewichtet in das Ergebnis mit einfließen lassen?

- ◯ Ja
- ◯ Nein

7b) Falls ja, was ist dabei zu beachten?

Meine Antwort

8a) Welche der folgenden Matchmaking-Parameter würden Sie sich bei diesem Spiel wünschen: *

- ☐ Schüttelmenge
- ☐ Entscheidungsdauer
- ☐ Risikobereitschaft (ein "5 of a Kind" bei z.B. einem "Full-House" zu versuchen)
- ☐ Erfolgsquote (gewonnen/verloren)
- ☐ Sonstiges:

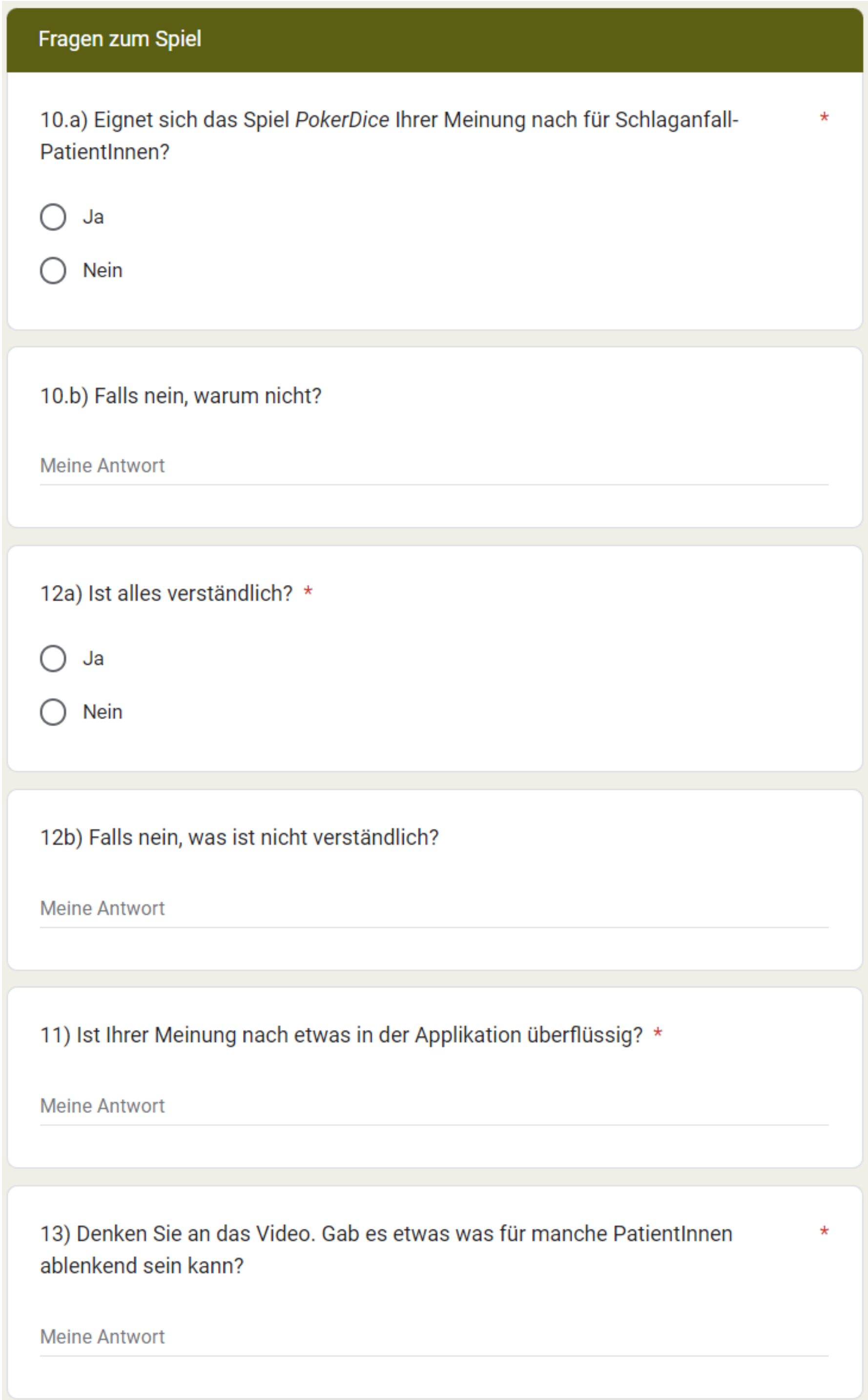
8b) Können Sie Ihre vorige Antwort näher erläutern? *

Meine Antwort

9) Ist es akzeptabel, wenn das Ranking und dadurch das Match des Spielers erst nach 10-15 Spielen genauer wird? *

- ◯ Ja
- ◯ Nein

Figure 3: Questionnaire: Questions on Matchmaking



Fragen zum Spiel

10.a) Eignet sich das Spiel *PokerDice* Ihrer Meinung nach für Schlaganfall-PatientInnen? *

- ○ Ja
- ○ Nein

10.b) Falls nein, warum nicht?

Meine Antwort

12a) Ist alles verständlich? *

- ○ Ja
- ○ Nein

12b) Falls nein, was ist nicht verständlich?

Meine Antwort

11) Ist Ihrer Meinung nach etwas in der Applikation überflüssig? *

Meine Antwort

13) Denken Sie an das Video. Gab es etwas was für manche PatientInnen ablenkend sein kann? *

Meine Antwort

Figure 4: Questionnaire: Questions on the Game

14) *Im Video nicht zu hören: es wurde ein "Schüttelgeräusch" beim Würfeln und ein "Klickgeräusch" beim klicken auf die Würfel eingebaut.* *
Sind Ihrer Meinung nach noch mehr Geräusche notwendig (klicken auf Buttons, gefundenes Match, gewonnen/verloren) ?

- ◯ Ja
- ◯ Nein
- ◯ Sonstiges: ______

Ein Ausschnitt aus den Achievements

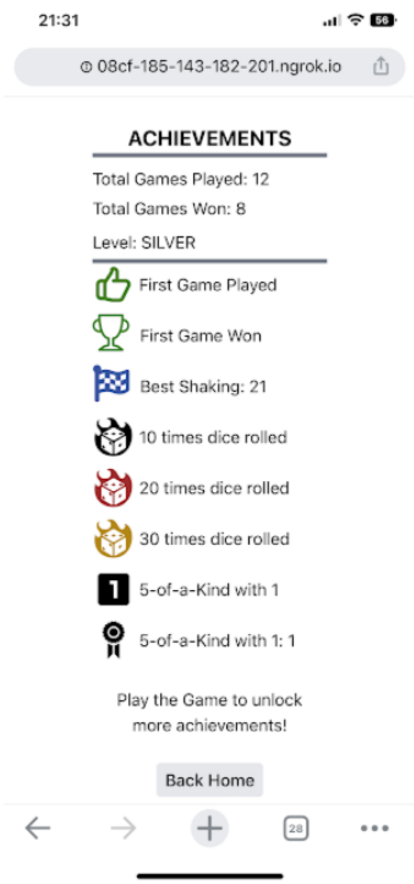
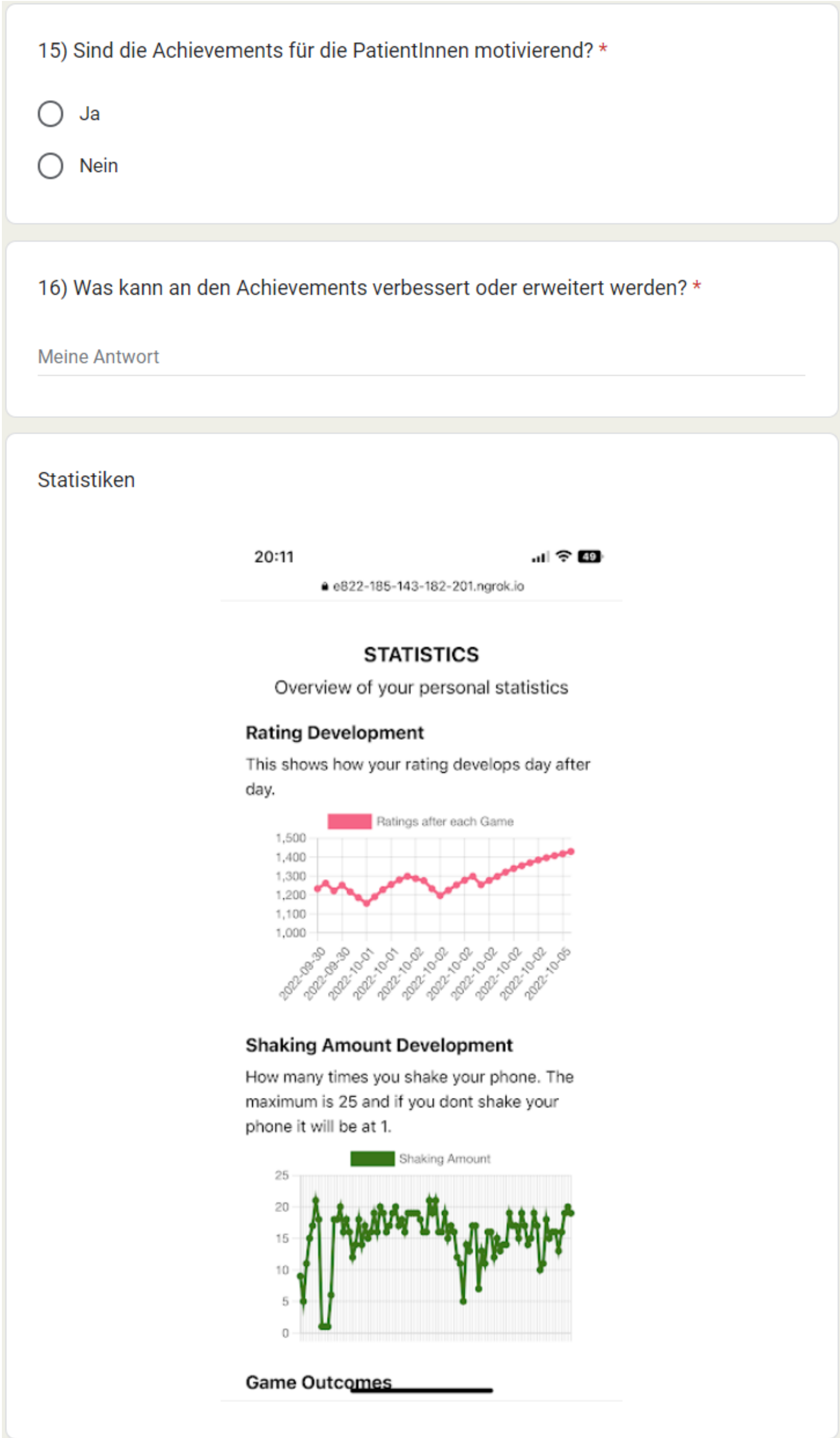


Figure 5: Questionnaire: Questions on the Game



15) Sind die Achievements für die PatientInnen motivierend? *

Ja

Nein

16) Was kann an den Achievements verbessert oder erweitert werden? *

Meine Antwort

Statistiken

Figure 6: Questionnaire: Questions on the Game

17) Sind die Statistiken (Ranking-Entwicklung, Schüttelmengen-Entwicklung, wie viele Spiele gewonnen/verloren, welche Würfelergebnisse) motivierend? *

- ○ Ja
- ○ Nein

18) Was kann an den Statistiken verbessert oder erweitert werden? *

Meine Antwort

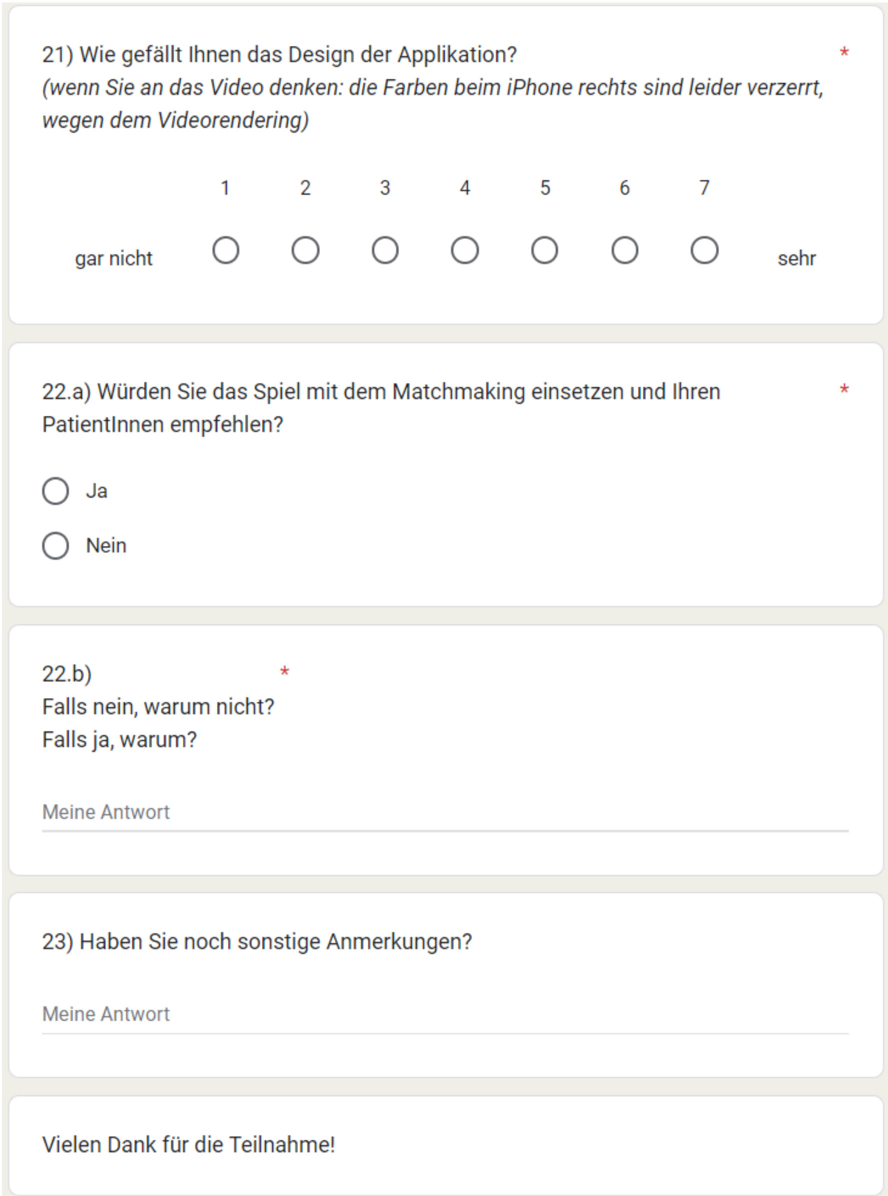
19) Denken Sie, diese Applikation bringt Abwechslung in den Alltag der Schlaganfall PatientInnen und motiviert sie zur Rehabilitation? *

- ○ Ja
- ○ Nein

20) Welche der folgenden Altersgruppen kommen Ihrer Einschätzung nach mit der Applikation am besten zurecht? *

- ☐ 0-10 Jährige
- ☐ 10-20 Jährige
- ☐ 20-30 Jährige
- ☐ 30-40 Jährige
- ☐ 40-50 Jährige
- ☐ 50-60 Jährige
- ☐ 60-70 Jährige
- ☐ 70-80 Jährige
- ☐ 80 Jahre oder älter

Figure 7: Questionnaire: Questions on the Game



21) Wie gefällt Ihnen das Design der Applikation? *
(wenn Sie an das Video denken: die Farben beim iPhone rechts sind leider verzerrt, wegen dem Videorendering)

	1	2	3	4	5	6	7	
gar nicht	○	○	○	○	○	○	○	sehr

22.a) Würden Sie das Spiel mit dem Matchmaking einsetzen und Ihren PatientInnen empfehlen? *

○ Ja

○ Nein

22.b) *
Falls nein, warum nicht?
Falls ja, warum?

Meine Antwort

23) Haben Sie noch sonstige Anmerkungen?

Meine Antwort

Vielen Dank für die Teilnahme!

Figure 8: Questionnaire: Closing Questions on the Game

Appendix C

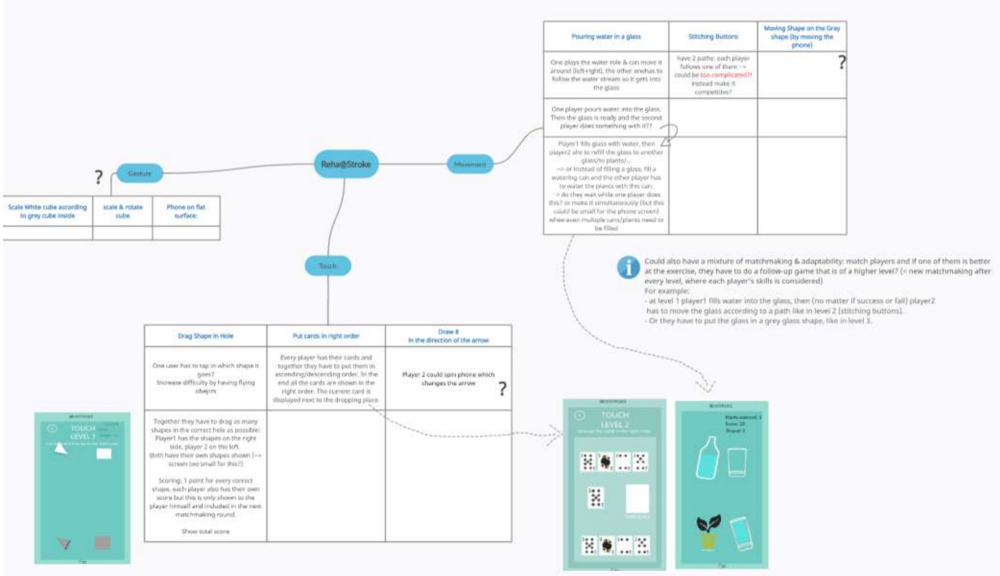


Figure 9: Mind Map 1: Adaption of Reha@Stroke

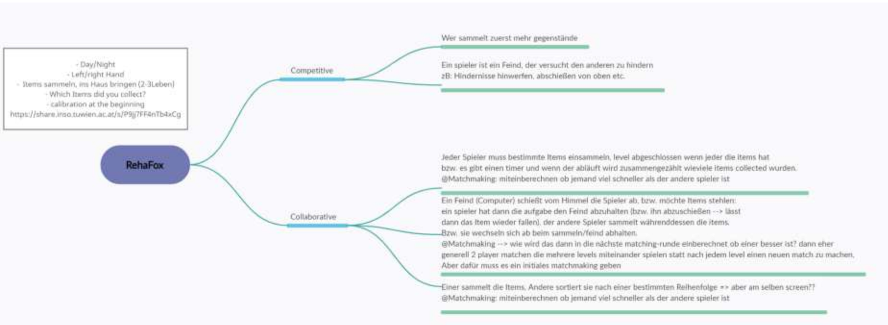


Figure 10: Mind Map 2: Adaption of FoxJump

Appendix D

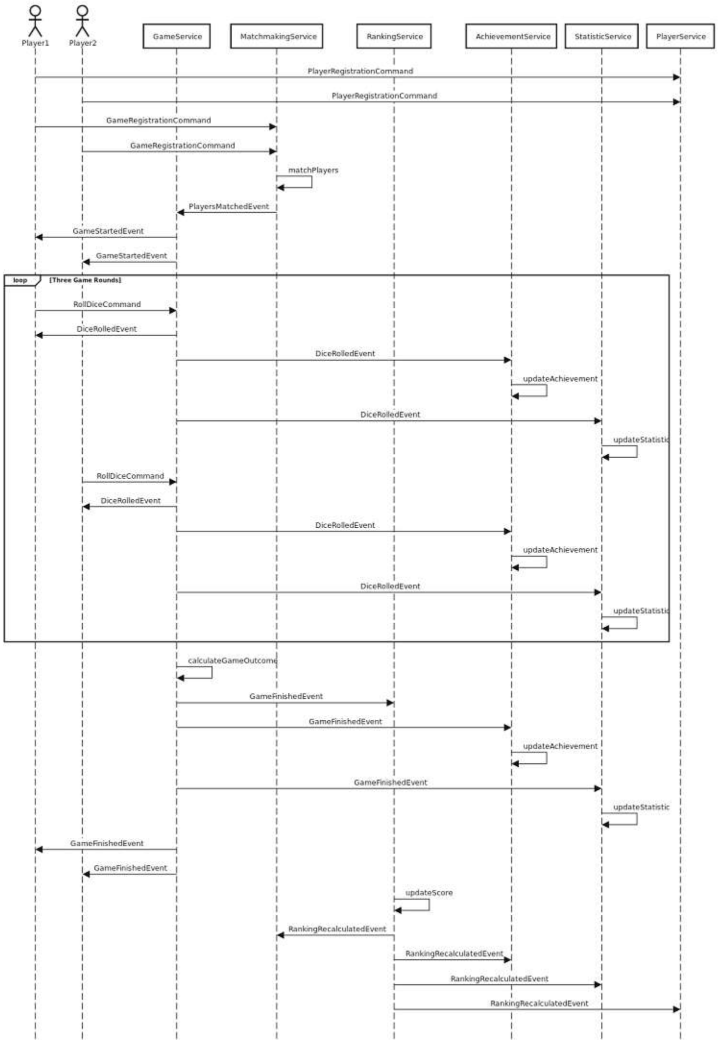


Figure 11: Sequence Diagram of all Services in the Backend