Gamification In Upper Limb Stroke Rehabilitation

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Resumo

O acidente vascular cerebral (AVC) é uma condição debilitante que frequentemente resulta em deficiências motoras significativas, afetando severamente a capacidade do paciente de realizar atividades diárias e diminuindo a sua qualidade de vida. A reabilitação após um AVC é essencial para restaurar a função motora e melhorar a qualidade de vida, especialmente para pacientes com comprometimentos nos membros superiores. Embora os métodos de terapia tradicionais sejam eficazes, muitas vezes carecem de envolvimento, levando a uma diminuição da motivação e adesão dos pacientes. A gamificação, a aplicação de elementos de jogos em contextos não lúdicos, apresenta uma solução promissora ao aumentar a motivação e tornar o processo de reabilitação mais cativante. Esta tese explora a aplicação da gamificação na reabilitação de membros superiores após um AVC, enfatizando o papel dos exercícios interativos, baseados em jogos, na melhoria dos resultados dos pacientes. Ao integrar feedback em tempo real, níveis de dificuldade ajustáveis e mecanismos de recompensa, a gamificação transforma tarefas repetitivas de reabilitação em atividades mais dinâmicas e agradáveis. O estudo detalha o design e implementação de um sistema de reabilitação gamificado, utilizando a câmara Kinect V2 para criar um jogo sério na plataforma Unity 3D. Os resultados indicam que a gamificação tem um potencial significativo para melhorar a experiência de reabilitação e promover a adesão dos pacientes ao longo do tempo durante o processo de recuperação.

Palavras-chave: Reabilitação, Membro Superior, Gamificação, Jogos Sérios, Realidade Virtual, Unity

Abstract

Stroke is a debilitating condition that often results in significant motor impairments, severely affecting a patient's ability to perform daily activities and diminishing their quality of life. Stroke rehabilitation is essential for restoring motor function and enhancing the quality of life, particularly for patients with upper limb impairments. While traditional therapy methods are effective, they often lack engagement, leading to reduced patient motivation and adherence. Gamification, the application of game-like elements in non-game contexts, presents a promising solution by increasing motivation and making the rehabilitation process more engaging. This thesis examines the use of gamification in upper limb stroke rehabilitation, emphasizing the role of interactive, game-based exercises in improving patient outcomes. By integrating real-time feedback, adjustable difficulty levels, and reward-based mechanisms, gamification transforms repetitive rehabilitation tasks into more dynamic and enjoyable activities. The study details the design and implementation of a gamified rehabilitation system, utilizing a Kinect V2 camera to create a serious game in Unity 3D. The findings indicate that gamification has significant potential to enhance the rehabilitation experience and promote long-term patient adherence to recovery programs.

Keywords: Rehabilitation, Upper Limb, Gamification, Serious Games, Virtual Reality, Unity

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1. Introduction

Stroke represents a highly prevalent and life-threatening neurovascular emergency, ranking as the fifth leading cause of death globally and a prominent contributor to acquired disabilities in adults [1][2][3]. The number of stroke incidents is on the rise, driven by an increasingly aging population [1]. Approximately 101 million individuals worldwide have experienced a stroke, nearly doubling over the last three decades. Annually, an average of 12.2 million strokes are recorded, occurring at a rate of one every three seconds. Notably, statistics indicate that 1 in 4 individuals above the age of 25 will encounter a stroke in their lifetime. The estimated worldwide cost of stroke in 2017 amounted to 415 billion dollars, with 63% of strokes occurring in individuals under 70 years old in 2019 [4]. Survival rates following the initial stroke episode have increased significantly, leading to a shift in the primary health impact toward enduring consequences for both patients and their families. Concurrently, advancements in healthcare technology have resulted in a reduction in stroke fatalities. This positive trend, however, has given rise to a substantial and growing population of individuals living with permanent post-stroke impairments [1]. Numerous studies underscore the prevalence of post-stroke cognitive impairments (PSCI), affecting 25% to 80% of stroke survivors [5]. The burden associated with stroke is expected to escalate in the next two decades [6]. Research findings reveal that 50% of chronic stroke survivors grapple with upper limb (UL) motor impairments, significantly impacting their quality of life. Consequently, the restoration of UL function becomes a pivotal goal for stroke survivors, crucial for performing activities of daily living (ADLs) [6]. In addition to physical impairments, stroke survivors commonly experience emotion-based disorders, such as general anxiety disorders. Unfortunately, depressive and other emotion-related deficits often receive insufficient attention during post-stroke rehabilitation, despite their recognized significance as critical bottlenecks in transferring improved clinical outcomes to quality of living [7].

1.1. Motivation

Rehabilitation is recognized as a crucial factor in the recovery of patients affected by stroke, enabling them to resume normal life. The extent of improvement through physical or occupational therapy has clinically demonstrated an increase of five points on the Barthel Index [8] within a range of 0-15 values, as documented in well-designed rehabilitation trials. Evidence suggests that an early, intensive, repetitive, and task specific exercise program will improve neurological recovery, and improve UL function [9][10]. This type of training will lead to activation of the anterior cingulate and supplementary motor areas, and experienced more predictable and consistent UL motor recovery post-stroke than standard care [11][12].

Recently, it has been demonstrated that computer systems employing serious games, specifically tailored to enhance motor skills and learning, have shown effectiveness [13]. These systems involve exercises incorporating various levels of movement intensity, such as gripping, reaching, pointing, lifting, or throwing [14]. Game-based rehabilitation is an evolving therapeutic method characterized by a non-immersive environment that provides good motivation, feedback, and interactivity [15]. Housman *et al*. [16] demonstrated favorable outcomes, with 90% of the participants concurring that therapies involving robots or games were less perplexing, and enhancements were more readily comprehensible compared to conventional therapy methods. Furthermore, there is a prevailing belief that the integration of gamification may foster increased engagement and repetition within the rehabilitation framework [17]. These features will encourage the participants to spend more time in performing active UL movements, while concurrently fostering their involvement and commitment to task performance through mitigation of boredom or compliance challenges. This is likely to lead the participants to meet the high number of repetitions that would allow neuro-plastic adaptations and underlying behavioral improvement through motor learning [12].

1.2. Goal

The objective of this research is to develop a serious game for upper limb rehabilitation after stroke. This study aims to develop a rehabilitation systems that incorporate a variety of feedback mechanisms, both auditory and visual, and offer a diverse selection of games catering to the preferences of a wide range of users could be highly beneficial. Additionally, the implementation of varying difficulty levels, adaptable to all types of players, is an important consideration. The inclusion of friendly competition could also enhance the experience, preventing players from feeling isolated during the rehabilitation process. Furthermore, the system will allow therapists to monitor patient data, enabling them to track progress and gain valuable insights into the patient's preferred interactions with the game, ultimately contributing to a more effective and comprehensive recovery.

1.3. Thesis Structure

The chapter two provides a concise exposition delineating the nature of a stroke and the corresponding rehabilitation measures. The chapter three entails a comprehensive analysis of contemporary technologies and techniques explored and implemented by fellow researchers, encapsulating the current state of the art. The chapter four and five encompasses the carefully chosen and applied methodologies, accompanied by illustrative images depicting the project's implementation, the final application, and its procedural evolution. Following this, the chapter six will ensue a presentation, demonstration, and subsequent discussion of the obtained results.

2. Background

In this chapter, a concise definition of pertinent concepts will be presented for consideration prior to progressing towards the main objective and its implementation. First will be described the characteristics of stroke and its underlying mechanisms. After this, the rehabilitation process involved will be discussed, followed by an exploration of the role of games in stroke recovery and a description of the essential features required for their effective implementation.

2.1. Stroke

As per the World Health Organization, stroke stands as the second leading cause of global mortality and the third leading cause of disability [18]. In Portugal, the Directorate-General for Health (DGS - Direção-Geral da Saúde) identifies stroke as the primary contributor to both mortality and incapacity. According to the 2022 data released by DGS, the National Institute of Medical Emergency (INEM - Instituto Nacional de Emergência Médica) directed 6,876 patients suspected of experiencing strokes to the most suitable hospitals through the ”Via Verde do AVC”. This figure reflects an increase of 1,060 cases compared to the preceding year, 2021, equating to an average of 19 cases daily. Notably, in March of the same year, INEM referred 1,815 cases. The district of Porto recorded the highest incidence of cases through Via Verde AVC in 2022, with 1,456 patients, followed by Lisboa and Braga, with 1,267 and 537 cases, respectively. The average age of individuals registered in the Via Verde do AVC in 2022 was 73 years. Of the total cases, 49.3% were female, 46.8% were male, while gender information was unavailable for 3.9% of cases [19].

When a stroke occurs, the sudden interruption of blood flow to the brain, caused by either a blood clot blocking a brain vessel (Ischaemic stroke) or the rupture or leakage of a blood vessel in the brain (Haemorrhagic stroke), leads to the immediate death of brain cells, with up to 1.9 million cells per minute. Prompt intervention is crucial. The impact of a stroke depends on the affected area of the brain, influencing speech, comprehension, emotions, sensations, motor functions, and vital functions such as heart rate, swallowing, and breathing.

Consequences of a stroke may manifest as weakness, paralysis (hemiplegia), coordination difficulties (apraxia), changes in muscle tone (hypertonia or hypotonia), subluxation, contracture, swelling (oedema), and pain. Stroke is not limited by age, as it can occur at any stage of life, yet preventive measures are available. Factors within our control, such as high blood pressure, obesity, smoking, elevated cholesterol, excessive alcohol consumption, and diabetes, contribute to stroke risk and can be addressed for prevention [20].

2.2. Stroke Rehabilitation

Stroke rehabilitation is broadly characterized as any aspect associated with stroke treatment, with the overarching objective of mitigating disability and fostering engagement in everyday activities. Its objectives encompass the prevention of deterioration, improving of patient functionality, and the achieving of the utmost level of independence - both physically, psychological, social, and financial - within the enduring limitations imposed by the stroke [3]. The stroke rehabilitation process typically encompasses a cyclical sequence [21]: (1) assessment - identifying and quantifying the needs of patients; (2) goal-setting - establishing realistic and attainable objectives for improvement; (3) intervention - implementing strategies to facilitate the accomplishment of the established goals; (4) reassessment - evaluating progress in relation to pre-defined objectives. The predominant consequence of stroke is motor impairment, constraining functional movements and muscle mobility [6][22]. For upper limb rehabilitation, early and intensive engagement in active functional tasks within an enriched environment show more favorable outcomes. It has been suggested that such practices may stimulate neural reorganization within the cerebral cortex, thereby facilitating the recovery or partial recovery of upper limb function[23].

In stroke rehabilitation, various innovative approaches are being explored to improve patient outcomes, including traditional therapies, technology-assisted solutions, and gamification, which introduces interactive, rewarding activities to enhance engagement and motivation during recovery.

2.3. Gamification

Gamification can be characterized as a method of augmenting a particular activity through the incorporation of motivational elements. Huotari and Hamari [24] define gamification as the creation of a psychological experience that has the same positive impact as games. Deterding *et al.* [25], on the other hand, emphasize that the affordances implemented in gamification have to be the same as the ones used in games, regardless of the outcomes (Figure 2.1).

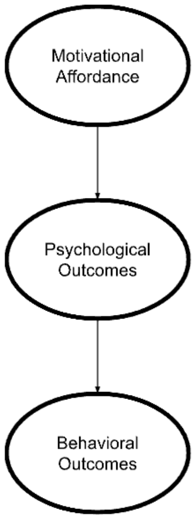


Figure 2.1: Gamification in a simplistic manner [26].

According to this conceptualization, gamification can be seen to have three main parts: 1) the implemented motivational affordances, 2) the resulting psychological outcomes, and 3) the further behavioral outcomes [26]. The primary objective is to increase motivation for prolonged gameplay by dynamically adjusting the game's difficulty and offering feedback throughout the progression. This strategy is implemented to redirect the patient's attention from the pursuit of complete recovery (a distant ultimate goal) towards a concentration on continual/emergent progression, characterized by observable minute-to-minute enhancements in game performance [27]. The utilization of gamification has garnered significance in augmenting intrinsic motivation and adherence [26]. This involves the deployment of diverse game design elements, encompassing game components, dynamics, and mechanics, to engender a sense of playfulness [25].

2.3.1 Serious Games

A Serious Game is delineated as a game designed with education or rehabilitation as its primary objective. Such games integrate elements of entertainment, attentional engagement, and problem-solving to challenge functionality and performance. Furthermore, they adhere to various motor relearning principles that form the foundation of effective interventions in neurorehabilitation [28]. For instance, certain devices adjust game difficulty to stimulate recovery and sustain motivation. Others incorporate functional tasks that emulate activities of daily living (ADL) within virtual environments, providing performance feedback during and/or after task completion. The characteristics of serious games vary depending on the targeted rehabilitation purposes and the technical specifics of the system on which they are implemented [15]. There are some crucial steps for success when creating a serious game. According to [29], involving therapists and caregivers in the game design development is a step in the right direction, involving them as co-players so they can positively influence the game on behalf of the patient. Contextualizing the game is also mandatory, so that each action in the game has meaning and relevance (can be achieved through diverse forms of feedback). Customizing, although more difficult to implement, is also important because it allows for easier adaptation according to the player due to the different characteristics of each patient (cognitive and motor). The simplicity of gameplay and prompt recovery mechanisms post-failure are deemed imperative, alongside fostering encouragement in positive interactions and progression through game levels. This approach is instrumental in averting sentiments of defeat, mortality, or failure.

According to [30], the majority of trials (60%) demonstrated significantly superior outcomes favoring the use of serious games intervention compared to conventional treatment. With regard to upper limb motor functions, serious games usage exhibits improvement compared to conventional treatment. Similarly, in terms of upper limb activity, serious games also yielded better results than conventional rehabilitation, albeit with a slight difference. Furthermore, concerning participation, serious games implementation led to significant increases, on a large scale, compared to conventional methods.

2.4. Virtual Reality

Virtual Reality (VR) can be implemented as a form of human-computer interaction (HCI), wherein individuals engage with a three-dimensional (3D) interface within a simulated environment comprising digital objects. Katz *et al* [31] observed that VR offers the potential to create a personalized environment for the user based on their interests, thereby fostering heightened motivation for sustained training efforts and improved focus during exercises, both of which are pivotal for enhancing the efficacy of rehabilitation. VR integration may manifest through gaming applications or alternative interactive modalities. Furthermore, it provides an interactive and motivational environment for patients to feel encouraged to participate in rehabilitation endeavors, whether within clinical settings or home-based programs. Presently, owing to technological advancements, video games are frequently selected for integration due to their notable efficacy in stimulating patient involvement in therapeutic regimens. It is also worth mentioning that interactions with VR can be non-gamified and non-playful [17]. The utilization of VR and games has demonstrated benefits in enhancing upper limb functionality and daily living, particularly when integrated with standard treatments or compared to an equivalent dose of conventional therapy [14].

2.4.1 Meaningful Play

Salen and Zimmerman [32] posit that the key to designing a successful game lies in the establishment of meaningful play. Meaningful play arises from the interaction between the player's actions and the resultant outcomes within the system. A player has to be able to perceive how their actions will affect the game, not only in the immediate state but also at a certain future part of the game. To facilitate this cognitive process, various feedback mechanisms are often integrated throughout the gaming experience. Such feedback serves to enable players to assess their progress towards set objectives and the development of their skills over time. Feedback can also be defined as the way the game reacts and responds to the choices made by the player and is crucial for creating and maintaining meaningful play. Common forms of feedback include progress indicators such as progress bars, numerical scores, and in-game character dialogue. In the case of rehabilitation, failure can be an important issue.

In the realm of rehabilitation gaming, the management of failure assumes heightened significance. Unlike in conventional gaming contexts where failure is an inherent and accepted aspect, its handling in rehabilitation scenarios necessitates a more deliberate and sensitive approach. Primarily, rehabilitation games should prioritize encouraging participation and rewarding successful engagement. Moreover, the constructive handling of errors and failures becomes imperative to sustain the motivation of rehabilitation participants, preventing feelings of defeat resulting from physical limitations post-stroke.

Furthermore, it is important to acknowledge that many rehabilitation participants may lack prior experience with video games, thus necessitating consideration for unfamiliarity with gaming equipment. Consequently, game structures must be meticulously designed to accommodate individuals with varying degrees of mobility impairment, ensuring equitable access and enjoyment of the gaming experience.

In conclusion, if there are few incentives when the player completes a task successfully and there are several disadvantages when there is weaker gameplay, the player tends to participate less in the game [23][27].

2.5. Principles of Neurorehabilitation

Neurorehabilitation denotes the medical subspecialty bridging rehabilitation medicine and neurology, encompassing a wide array of diseases and injuries that affect the nervous system, creating functional impairments that may be permanent or progressive, despite attempts at curative treatment. Research in neurorehabilitation strives to identify interventions that facilitate recovery and determine whether the occurrence or absence of improvement can be attributed to any neuronal changes within the post-stroke brain. To achieve this, there are certain principles that collectively contribute to the development of a comprehensive and effective neurorehabilitation program tailored to the unique needs of each individual. The key principles are [28]:

- Massed practice/repetitive practice - Concerning rehabilitation, it denotes the protracted and repetitive utilization of the affected limb;
- Spaced practice suggests that training should be organized with regard to time, incorporating intervals of rest between repetitions and sessions. Several studies indicate that extending the duration between learning periods can enhance performance in the final assessment. Conversely, excessively long intervals yield contrary results;
- Dosage/duration - The allocation of time spent in therapy, the frequency of sessions, and the duration of each session, or the volume of training required to facilitate learning, are crucial considerations. Typically, patients receive between 22 to 60 minutes of training per day. There is substantiated evidence indicating that augmenting the duration of therapy hours may contribute to expedited functional recovery;
- Task-specific practice - It advocates for consistency between the conditions experienced during training sessions and those encountered during testing. Conventional rehabilitation protocols prioritize training in activities of daily living (ADL), recognizing independence in these tasks as a paramount goal for patients. The main objective is for the patient to be able to perform daily tasks independently;
- Variable practice - It can be achieved in two different ways: (1) the implementation of variability in practice, characterized by a variety in a training sequence; and (2) the adoption of random practice, which entails the randomized arrangement of individual training sequences. Some researches on human subjects has evidenced

that the incorporation of varied exercises within practice leads to enhanced performance. While this principle is infrequently examined in isolation, its integration with complementary principles serves as a strategy to mitigate monotony;

- Increasing difficulty - The optimal escalation of difficulty occurs when the challenge posed by a task achieves a balance between the demand for information processing and performance. Significant enhancements in motor performance are achieved when users have the capability to adjust task difficulty. In stroke recovery, promote the utilization of the affected region is increased through progressive escalation in the complexity of the required movement. This strategy of increasing difficulty has proven successful in various domains, including robot-assisted therapy and virtual reality systems;

- Explicit feedback/knowledge of results (KR) - KR refers to feedback that is verbal, terminal, and augmented, specifically concerning the accomplishment of a goal. KR plays a pivotal role in the learning process through cognitive mechanisms. Explicit feedback can be presented either quantitatively or qualitatively, depending on the outcomes of a given task (e.g., success, failure). Notably, this feedback needs not always be verbal; for instance, if a task is executed poorly, the user might encounter auditory cues or visual changes in the target. While punishment feedback may expedite motor learning, rewarding feedback is conducive to long-term retention;

- Implicit feedback/knowledge of performance (KP) - KP refers to feedback provided regarding the execution of movement, typically in the form of verbal descriptions, demonstrations, or recordings. Implicit feedback fosters learning by utilizing sensorimotor prediction errors, which can aid in adapting to unexpected disturbances, contributing to implicit learning mechanisms. Despite the apparent benefits during training, there is evidence suggesting that users may develop a dependency on it, leading to decreased performance when deprived of this feedback. Stroke patients undergoing training with a virtual reality system incorporating implicit feedback on upper limb movement demonstrated significant motor recovery after four weeks, although this study also encompassed additional principles;

- Action observation/embodied practice - Individuals who observe another person performing a particular task demonstrate superior performance when executing the same task, compared to those who did not observe anyone performing it or observed a task with minimal differences. Consequently, action observation can facilitate movement execution and motor learning. There is some evidence that action observation therapy can reduce impairment.

2.6. Summary

As elucidated throughout this chapter, gamification offers promising avenues to enhance engagement, motivation, and outcomes in the rehabilitation processes subsequent to upper limb impairments induced by stroke. By leveraging principles of neurorehabilitation and interactive technologies, gamified rehabilitation approaches not only provide a stimulating environment for patients but also empower them to actively participate in their recovery journey. Furthermore, the integration of virtual reality and other cutting-edge technologies underscores the potential for personalized and immersive experiences tailored to individual patient needs. The incorporation of gamification will be an important pillar regarding innovation, promising transformative benefits for patients, clinicians, and researchers alike. Thus, this chapter sets the stage for a deeper exploration into the practical implementation and efficacy of gamified interventions in upper limb stroke rehabilitation.

3. Literature Review

In this chapter, an exploration is undertaken regarding the current state of the field, encompassing the latest research, technological advancements, and practical applications that influence gamified rehabilitation interventions. By scrutinizing evolving trends, literature, best practices, and empirical evidence, a comprehensive overview of the state of the art in gamification for upper limb stroke rehabilitation is provided. Through this examination, an endeavor is made to identify the mechanisms driving the effectiveness of gamified approaches, along with the challenges and opportunities inherent in their implementation. By comprehending the state of the art, the stage is set for a deeper understanding of how gamification can potentially revolutionize stroke rehabilitation practices, guiding towards the attainment of project objectives with optimal efficiency and effectiveness.

3.1. Hardware Used for Rehabilitation Targeted Serious Games

In the context of our analysis of case studies, it has consistently proven essential to have at least one screen for the reproduction of serious games, alongside a computer for processing the game content. Concerning visual aspects, certain researchers opt to employ a Head Mounted Display (HMD) (Figure 3.1a) [33][34][35] to enhance the immersive virtual reality experience in serious gaming applications. As discussed previously, the rehabilitation process for individuals affected by strokes typically involves executing a series of predetermined exercises aimed at facilitating the resumption of daily activities. To this end, various methodologies are utilized to integrate the exercises performed by the individual into computerized data. Examples include the utilization of a Leap Motion, sensor that is expressly designed for hand recognition, determining the position of the fingers and the orientation of the hand. The manufacturer provides a Unity Assets package that facilitates integration with the development of the mechanism [33][35][36]; Diverse hand-controlled joysticks for patient interaction [34][37], smart gloves equipped with sensors to relay movement data to the computer, and 3D printed structures augmented with sensors to transmit specific movement information relevant to the respective game [38]. Furthermore, a noteworthy case study incorporates a headband equipped with sensors to relay head movements and positioning, integrating the patient into a First-Person Controller interface [38]. The Microsoft Band 2 functions as a physiological sensor employed for the collection of two selected signals as a measure of engagement during the rehabilitation program: heart rate and electrodermal activity. It also incorporates a diverse array of built-in supplementary sensors (including GPS, skin temperature, ultraviolet sensor, among others). The integration with Microsoft Band 2 is executed through the utilization of the Band SDK for Universal Windows Platform, programmed in C# [36]. In the context of acquiring information regarding the movement of the upper body, Omar *et al*. [29] write that several open-source gaming platforms were employed in that study, including Microsoft Kinect (Figure 3.1b), Nintendo Wii , and Sony Playstation [39]. Microsoft Kinect is a motion sensing input device based on a high-resolution color camera and an infrared emitter for depth analysis, capable of concurrently tracking 3D motion across up to 25 essential joints of the human body [36] and a microphone for voice commands [40]. It boasts a wide field of view and detection range extending up to 4.5 meters from the device. The establishment of an interface linking the Microsoft Kinect V2 with the Unity3D engine is seamless owing to the provision by the manufacturer of a Software Development Kit (SDK) and a Unity add-on. These tools afford developers access to the precise positions and orientations of body joints, directly applicable in the development of rehabilitative gaming applications [36]. Studies examining the Kinect's capacity to accurately record upper limb motions have affirmed its adequacy for clinical application in monitoring elbow and wrist articulations. However, the consistency of shoulder movements has been questioned. Nonetheless, the overarching conclusion indicates that the Kinect offers adequate precision for assessing whole-body kinematics, serving the purposes of postural control and diagnostics. Despite the quadratic increase in the average standard deviation of spatial errors with distance, it has been observed that the Kinect maintains a satisfactory level of precision within distances endorsed by manufacturers for its utilization in rehabilitation contexts [41]. In contrast to Sony's Eyetoy and Nintendo's Wii, Kinect surpasses these two tools for three primary reasons: Firstly, Kinect offers the most natural form of human-computer interaction. Secondly, Kinect represents the most feasible technology for a widespread gaming system targeting the elderly due to its utilization of vision-based data capture, eliminating the need for additional hardware. Thirdly, the freedom of data acquisition provided by the controller-free system and the accessibility of the Kinect platform for developers facilitate the creation of high-quality rehabilitation systems [41].

Pham *et al*. [42] have identified three principal findings: Older participants exhibit a preference for fewer or no physical control devices; the necessity for larger physical movements does not diminish Kinect's appeal as the most desirable system; and older adults must acquire new knowledge and skills to fully utilize Kinect.

Gerling *et al*. [43] conclude that Kinect-based games yield a positive impact on users' emotional well-being. Such games have the potential to enhance quality of life across various metrics, including emotional state, physical function, level of bodily pain, skill performance, reaction time, and hand-eye coordination. In contrast, alternative studies made use of tracking or sensing technologies, such as 3D cameras. Burke *et al*. [44] also mention that the utilization of EyeToy games demonstrates potential efficacy in enhancing upper limb motor function therapy [45].

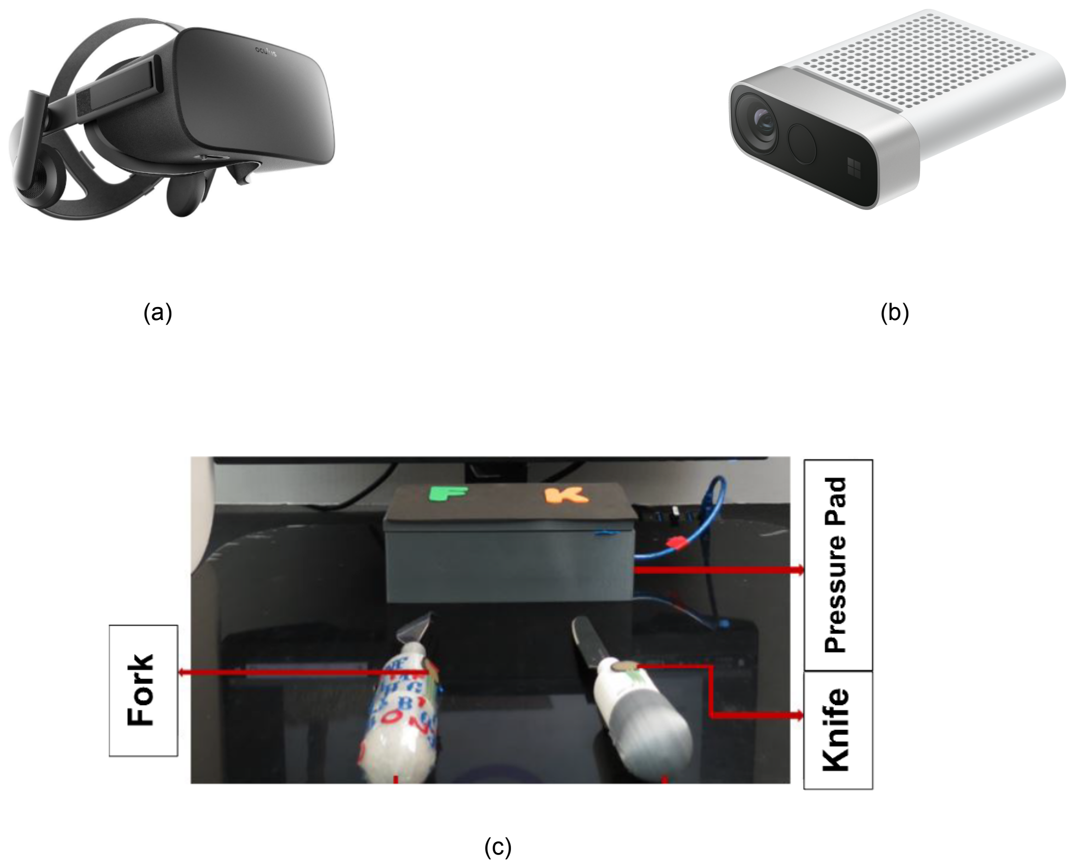


Figure 3.1: Hardware used for rehabilitation: (a) Oculus Rift VR [46]; (b) Microsoft Azure Kinect [47]; (c) Rehab-Fork Hardware [48].

3.2. Software Used for Rehabilitation Targeted Serious Games

Throughout our study, Unity [49] has emerged as one of the predominant software tools utilized. Its primary function lies in the creation of 2D or 3D structures employed within serious games set in virtual environments [33][34][35][38][48], as well as in facilitating interactions between these structures and users through the utilization of C# [38]. Within the domain of virtual reality, both the Virtual Reality Toolkit [34] and Oculus SDK [33] have also been leveraged. Additionally, C# has been instrumental in establishing connections between serial ports and web games, among other applications [37]. Furthermore, the development of serious games has extended to the utilization of Python in conjunction with the pygame library [13]. In the context of applications designed for data collection and synchronization, MatLab has proven to be an effective tool [13]. Finally, in the creation of supplementary mobile applications, the combination of Microsoft Xamarin with the C# programming language offers a viable solution [38]. Burke *et al.*[44] employed Microsoft's XNA framework, in conjunction with the C# programming language, supported by the .NET framework. Furthermore, they elected to utilize DirectShow libraries to enable seamless communication between the games and the Universal Serial Bus (USB) interface of the webcam.

3.3. Exercises/Gameplay

A pivotal consideration for individuals afflicted by stroke is their capacity to reintegrate into normalcy and carry out daily tasks with ease. This fundamental aspect underscores the development of serious games tailored for stroke rehabilitation, where application developers strive to inspire patients by integrating serious games centered on daily life activities. Jayasree-Krishnan *et al.* [48] advocate and support stroke patients in undergoing repetitive training of sub-functional tasks associated with eating, including (1) grasping eating utensils; (2) lifting utensils used for eating; (3) utilizing kitchen utensils to hold and cut food as part of rehabilitation exercises (Figure 3.1c). The utilization of fork and knife (Figure 3.2e) constitutes a bilateral task featured within the FunctionTaskBattery [50], that lists 20 essential Activities of Daily Living (ADLs) necessitating upper body engagement. John *et al.* [34] and Song *et al.* [13] similarly concentrate on executing kitchen-related chores, such as preparing toast, operating the refrigerator, inserting or removing items, brewing coffee, and retrieving a cup. Activities often taken for granted, such as eating an apple or washing dishes, can be repurposed as games [35] to facilitate patient recovery. Additionally, instances exist wherein movement is advocated to bolster ADL performance, albeit without employing a daily-life milieu as the game's foundation. Additional games that also allude to activities occurring throughout the day were considered like retrieving items from shelves (Figure 3.2c), lifting specific weights (Figure 3.2a). Ardakani *et al.* [37] elected to employ pre-existing internet games for patient rehabilitation. By substituting the mouse with a joystick, users could partake in existing games while concurrently benefiting from rehabilitation efforts. Postolache *et al.*[38] and AlMousa *et al.* [33] also directed their efforts towards crafting visually independent games derived from ADL, with a focus on aiding in recovery (Figure 3.2b). This study's findings [17] suggest that stroke-affected patients exhibited a heightened interest in engaging with multiplayer games over single-player alternatives, citing the interactive opportunities afforded by collaboration with their peers as a significant factor. Acosta *et al*. [51] used coordination training incorporating a 3D arm in conjunction with video games, and concluded that this combination holds potential utility in stroke rehabilitation. In this study [52] , the author considers these requirements necessary to take into account for the creation of a game for rehabilitation:

- Short-term memory: Given its prevalence among older individuals, it is commonplace for them to experience difficulty retaining information, such as instructions, during gameplay. Consequently, there is a need to repeat information consistently throughout gaming sessions. On-screen messages should be should be short and concise.
- Visual requirements:Literature review indicates that low vision is common among individuals aged 70-75. Thus, they may encounter challenges in reading or deciphering body language. Additionally, visual cues, including icons and illustrations, should be straightforward and easily interpretable (e.g., the symbol ♪denoting music). When crafting the game's graphical interface,it's important not to rely on a single color to convey information but to use black and white or colors with high contrast between them.
- Hearing requirement: Hearing impairments are frequently observed among older individuals and can significantly impact their quality of life. As such, the volume of in-game messages should be adjusted accordingly, and auditory messages should be kept as brief as possible.
- Technological requirements: It is a well-established fact that older individuals often encounter challenges when adapting to new technologies. In this regard, the Kinect system offers a notable advantage, enabling patients to engage in gameplay and navigate menus using body movements.
- Fun Requirement: Older women tend to derive enjoyment from social interactions, whereas men often prefer competitive gameplay experiences.
- Feeling and Emotional Requirement: It is imperative that the game does not overtly expose patients' shortcomings to other residents. Rather, the staff should actively encourage individuals to view the game as a social facilitator, fostering connections within the community.

Burke *et al.* also achieved success in the development of a serious game designed for upper body rehabilitation. This game is adaptable for both standing and seated play. Patients are instructed to utilize either a colored glove or grasp a colored object in their hand. Utilizing a Red-Green-Blue (RGB) color segmentation algorithm on the image feed from the webcam, the position of the marker can be accurately tracked in 2D space. The game encompasses several features pertaining to data processing, including assessment of the affected side of the body, evaluation of the patient's skill level, monitoring the duration of each gaming session, tracking total playtime, analyzing the percentage of hits and misses in target areas, presenting a graphical representation of skill progression over time, recording total time expended per day and per week, and facilitating review of each gaming session at customized intervals. Moreover, it underwent testing with individuals affected by stroke, who generally expressed satisfaction with the game [44]. These were the games he used within the scope of this study:

- ”Rabbit Chase” - can be played with the left or right hand with the objective of catching a rabbit as soon as it enters inside any of the 4 holes displayed on the screen Figure 3.2d. The duration of the rabbit's stay within a hole diminishes with increasing difficulty, after which it moves randomly to another hole. Players are able to observe the rabbit's movements between holes. Successful interaction with the target at the appropriate moment results in a change of color for both the hole and the rabbit, accompanied by an audible cue. Conversely, failure prompts the hole to turn red, accompanied by the display of the message ”miss” and an associated sound effect indicating an unsuccessful attempt.
- ”Bubble trouble” presents two gameplay variants: single-handed and two-handed. The primary goal is for the participant to touch the bubbles before their disappearance and subsequently burst them. In the two-handed variant, bubbles are presented in distinct colors corresponding to each hand (determined by either a glove or other held object), with visual cues indicating the appropriate hand for interaction. Interaction with the incorrect hand yields no effect; however, players retain the option to utilize the correct hand, thereby being rewarded for reacting with correct action instead of being penalized for the error.
- ”Arrow attack” features two arrows, each denoting left and right directions (representing the left and right arm, respectively), which move between 4 boxes displayed

on-screen. Participants must try to touch both boxes simultaneously with the appropriate hand. Arrows are color-coded to signify the associated hand. Notably, complete crossing of both arms is intentionally avoided to mitigate unnecessary complexity and alleviate player stress.

Based on the scoping review [29], it becomes apparent that numerous pivotal factors contribute to the attainment of optimal success and quality in game development. These factors encompass the engagement of therapists and caregivers as stakeholders in the design process, allowing for real-time influence over gameplay on behalf of the patient. Additionally, the imperative need for a well-contextualized game is underscored so that players' actions have meaning and relevance. Despite the inherent challenges, customized profiling emerges as a beneficial aspect in terms of rehabilitation. Simplicity in gameplay and the capacity to swiftly rebound from game failures are also highlighted as essential elements. Furthermore, the dissemination of feedback through diverse channels is identified as a means to enrich the player's experience.

3.3.1 Management of Difficulty

Within the domain of rehabilitation gaming, addressing failures must be taken even more seriously, particularly due to the technical inexperience of most post-stroke patients, which increases the likelihood of encountering setbacks. Consequently, these setbacks necessitate careful management to foster patient encouragement and facilitate their training regimen. Rather than terminating the game following a failure or defeat, or ascribing negative connotations to such instances such as loss of points, patients should instead be incentivized for their participation. This approach encourages renewed engagement with the games, enabling them to strive toward achieving rehabilitation objectives more effectively. It is imperative to maintain a balance in the management of difficulty, ensuring that tasks are not overly simplified, which could lead to user boredom. Similarly, tasks should not be excessively challenging, as this may result in user frustration and disillusionment. In both scenarios, demotivation ensues, ultimately impacting the effectiveness of rehabilitation. One viable method entails conducting an initial evaluation before gameplay to ascertain the patient's capacity in executing specific exercises integral to therapy. Subsequently, leveraging collected data alongside algorithmic analysis enables the customization of therapy exercises to suit the patient's medical condition [13]. Alternatively, employing standardized tests to evaluate the patient's current status, such as the Enjalbert Test [53], offers insight into their capabilities across a spectrum ranging from 0 (minimal upper body movement) to 5 (precise finger dexterity), contingent upon the task performed (e.g., hand-to-mouth movement, sustained hand positioning) [35]. These exercises may already be integrated into the game as a tutorial, with the data input into the system for automated assessment of the patient's condition [44]. After the patient's diagnosis is made, the game can diverge into two main gameplay paths in terms of difficulty control for the player: levels and adaptivity. The implementation of diverse difficulty levels is commonly observed across all genres of games. Level progression should be contingent upon the patient's performance status [29]. Upon the completion of a level, patients advance to the subsequent level, motivating them to achieve success in the new stage. Successful level completion depends on the player's comprehension of fundamental game mechanics and the acquisition of required knowledge and skills to successfully navigate the level to its conclusion [44][54] or accomplish the task within a specified time frame [29][54]. Adaptivity is a strategy grounded in an algorithm that dynamically adjusts the difficulty of the game in real-time, based on the performance and skills of the patient. This ensures an appropriate level of challenge that can result in the game becoming either easier or harder, depending on the player's performance [44]. [13][37][48], task level or the adaptivity's intensity can be set or changed by healthcare professionals based on statistical data regarding the patient's performance and well-being [33][34][35][38][44]. The difficulty of the levels can be achieved in various ways ([13][33][34][35][37][48]), which may escalate via diverse mechanisms including heightened exercise repetitions [33][34][35], increased task complexity (e.g., extending arm reach distance, prolonged positional holds) [13][33][35][37][48], shortened task execution time frames [33][34][35][37][48], or hand synchronization [44]. The utilization of unpredictable elements within the gameplay or subtle distractions throughout the game not only enhances engagement but also presents increased challenges to the patient [29]. The game should start off at a slower pace and with minimal difficulty to align with the player's initial level of skill or familiarity with the game, thereby mitigating the risk of catastrophic outcomes. As the player becomes more accustomed to the game and his skills improve through ongoing gameplay, they will seek increasingly advanced and challenging levels to sustain enjoyment and satisfaction [44].

3.3.2 Feedback

Feedback represents the manner in which the game reacts to alterations or decisions executed by the player, and it is indispensable for the creation and maintenance of meaningful gameplay [44]. In the realm of rehabilitation, heightened attention is placed on

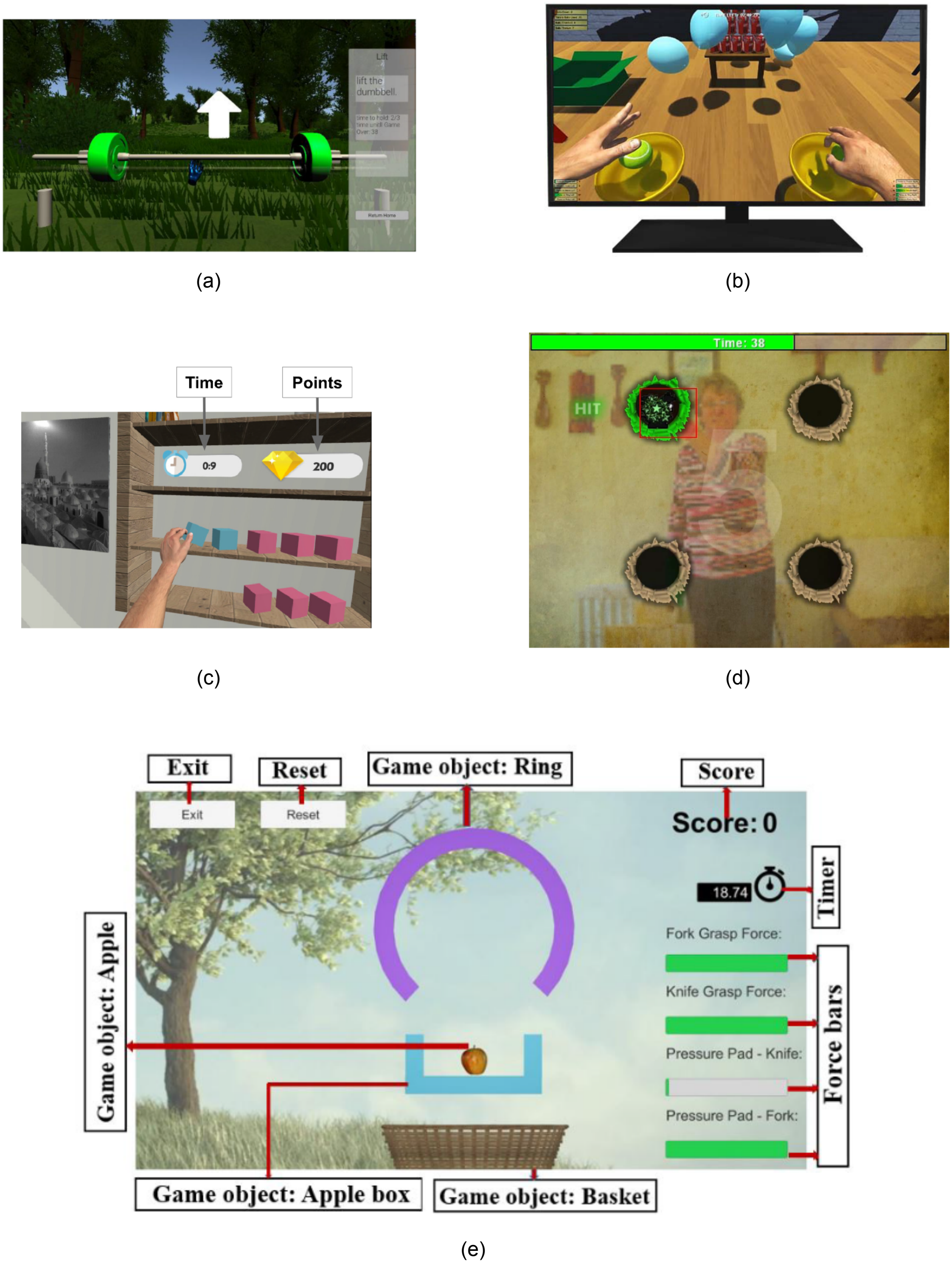


Figure 3.2: Game Interfaces: (a) Lift Game [35]; (b) Cans Down Challenge [38]; (c) Move-it Game Interface [33]; (d) Rabbit Chase Game [44]; (e) Rehab-Fork Game Interface - Level 1 and 2 [48].

positive feedback, given its pivotal role in fostering patient motivation and engagement. Negative feedback should be used very cautiously, or not at all, as it may provoke feelings of demotivation and frustration, particularly among post-stroke individuals grappling with motor impairments and potentially experiencing depression. Also the decrease in tolerance or motivation often leads to intentional or unintentional cheating, or in the worst-case scenario, avoiding performing the rehabilitation exercises altogether [41]. Such adverse reactions can ultimately impede the effectiveness of the rehabilitation process [29][44][54]. A method to enhance positive feedback involves rewarding not only the primary task but also subsidiary tasks that contribute to the overall objective. For instance, successfully shooting a ball into the basket may be rewarded through various actions, such as catching the ball (subtask), throwing the ball (subtask), and scoring in the basket (primary task) [44]. Typically, feedback manifests in three modalities: visual, auditory and haptic. Visual feedback mechanisms encompass score displays [33][38][48] or graphs (Figure 3.3) [33] that dynamically adjust based on task performance, preset messages congratulating the patient upon successful achievement of a sequence of objectives [38], graphical representations quantifying specific biological metrics obtained from integrated hardware sensors (such as force exerted or angle of rotation) [38][48], countdown timers indicating remaining game duration [13][33][38][48], task completion times recorded by the patient [13][33][34][35][38][48], interactions among characters, player's acquisition of new abilities or elements within the game, enhancing the game's longevity or their arsenal. Utilization of patient representations (avatars) or affected members within a simulation, has garnered favorable feedback due to its continuous and instantaneous nature, enabling them to consistently monitor their movements or periods of rest[44]. Auditory feedback methods entail the emission of sound cues signifying task completion and fostering a sense of accomplishment [13][35][38], along with in-game instructions designed to enhance exercise execution [13]. In a haptic context, there exists the potential for vibration of the input device [44]. In this study [17], after the patients played the game, feedback was gathered from them through questionnaires.

3.3.3 Limitations

In the realm of game-based rehabilitation interventions, while there are notable advancements and promising outcomes, it is imperative to acknowledge and address potential limitations. These limitations provide crucial insights into the effectiveness, feasibility, and applicability of such interventions within clinical settings. The utilization datagloves and

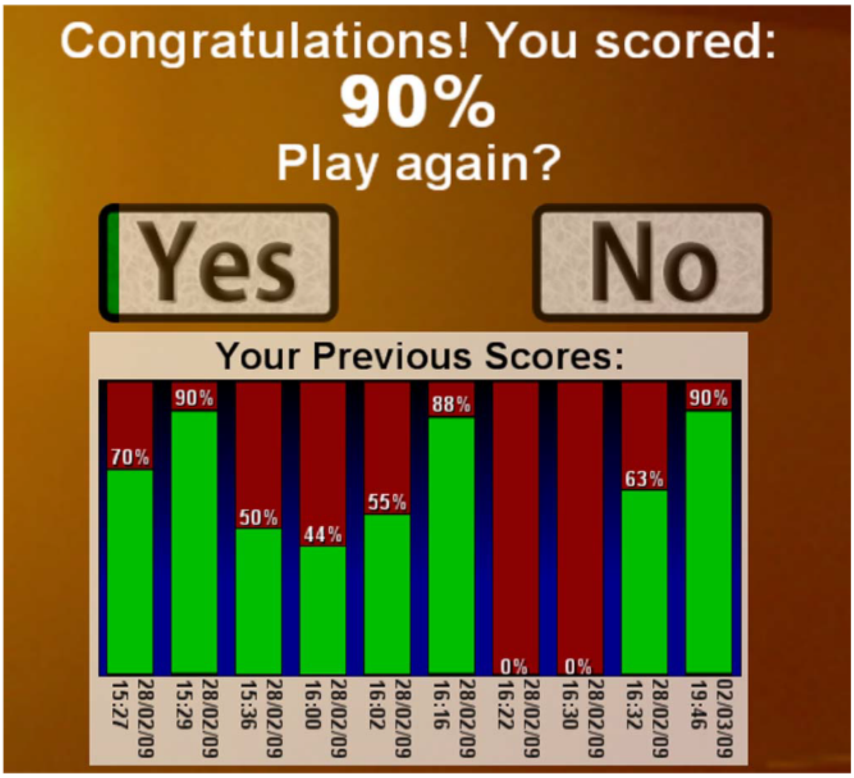


Figure 3.3: Example of feedback after playing [44].

HMDs by stroke-affected patients to interact with virtual environments may present challenges due to their physical impairments. Placing and removing the glove may present challenges, HMDs can cause discomfort [44][54]. Additionally, disposable plastic bags were utilized to mitigate the transmission of infections, resulting in dissatisfaction among the patients [34]. Some of the limitation of the Kinect are [41]:

- The studies concentrate exclusively on movements that are favorable for the Kinect. It is imperative to conduct more realistic assessments and/or assessments involving specific movements.
- The clinical viability of employing Kinect for shoulder-specific functional requirements remains unproven.
- Delicate motor skills are beyond the Kinect's capability for sole capture; nevertheless, certain studies propose that integrating Kinect with inertial sensor systems could present a viable alternative.
- Delicate hand and foot movements surpass the Kinect's capture sensitivity.

Furthermore, the considerable expense associated with attaining an immersive virtual reality experience may pose a disadvantage when compared to more economical alternatives. The displacement of electromagnetic sensors due to patient movement requires someone to repositioning them [13]. Games specifically designed for stroke rehabilitation demonstrate a tendency to exhibit greater efficacy compared to those intended for entertainment purposes or the general population [37][44]. The percentage of score may not adequately represent skill progression, as users advancing at a slower pace may achieve a higher percentage, such as 90%, compared to those progressing at a medium pace, who may attain 80%, even though the medium pace user performs everything at a slower pace without any errors [44]. The utilization of the Leap Motion device at a distance (for instance, positioned on top of the table) proved excessively challenging for patients in the initial phases of recovery to reach and play the game. Additionally, the patient's head remained static within the game interface, requiring precise positioning to validate movements (such as simulating the action of eating an apple) which was difficult because they had to perform other movements that would require them to change position, such as reaching for an apple in a basket [35]. The utilization of excessively aggressive adaptivity, predicated on the user's performance, even with minimal increments, may quickly lead to a misalignment between the user's skill level and the game's difficulty [44]. Moreover, certain applications lacked a diverse range of games capable of sustaining motivation and different rehabilitation exercises tailored to patients with different levels of disability [33][48]. In the literature review, it is observed that current rehabilitation games have not fully capitalized on the entertainment features that games can offer. Therefore, it is necessary to enhance motivation levels in rehabilitation programs. Additionally, games frequently undergo testing with a limited number of users/patients [54].

3.4. Summary

To sum up, serious games demonstrate a growing interest and investment in leveraging technology for improving upper limb rehabilitation outcomes. Researchers and developers have explored various game-based interventions tailored specifically for upper limb rehabilitation, utilizing technologies such as motion sensors, virtual reality, and gamification techniques. These serious games offer interactive and engaging experiences designed to facilitate motor recovery, enhance patient motivation, and provide real-time feedback to therapists. Studies have shown promising results in terms of improving motor function, range of motion, and overall quality of life for patients undergoing upper limb rehabilitation. However, challenges remain, including enhancements in failure management, cost reduction of hardware and software, expansion of feedback alternatives, adaptability, augmentation of the system's capacity to store patient data, among other factors.

4. Methodology

This chapter will cover the technologies proposed for the development of the game, the required hardware and software for its use, the optimal environment for ensuring the best possible execution, and an explanation of how the application's interface will be structured.

4.1. Questionnaires

This chapter presents a series of brief questionnaires developed to gather insights from healthcare professionals, aimed at informing the application's development. Two distinct types of questionnaires were designed for this purpose. The first was a Google Forms survey, primarily consisting of multiple-choice questions with one open-ended question. This questionnaire was structured to take no more than five minutes to complete, with the goal of reaching a broad audience, particularly healthcare professionals. The second was a more detailed document containing open-ended questions, solely dedicated to healthcare professionals, to gather in-depth information.

4.1.1 Google Forms Questionnaire

In this section, we present the results of a questionnaire conducted with a total of seven participants, aimed at gathering information about the application prior to its implementation. The questionnaire did not collect any personal data beyond gender, age range (18-39, 40-59, and 60+), and the respondent's role in stroke rehabilitation, which was used to confirm that the respondent was a therapist. For the statistical analysis, we focused solely on the responses provided by five therapists (four female aged between 40-59 years old and one male aged between 18-39 years old).

The questionnaire consisted of 15 questions (4.1), 14 of which were multiple-choice. Of these, 12 questions employed a five-point scale, with 1 representing the most negative response and 5 representing the most positive. Two additional questions were yes/no, and all 14 multiple-choice questions included the option ”No opinion.” The final question was open-ended to gather therapists' views on the most important characteristics of the game.

The graph in Figure 4.1 presents data from the 12 questions using the five-point scale. As depicted, the majority of responses were rated 4 or higher, indicating that the topics addressed by these questions are perceived as important, with the exception of Question 1, which assessed familiarity with computer games. Here, older respondents (ages 40-59) reported lower familiarity, which is to be expected. Question 9 yielded a mean score of 3.8, indicating some uncertainty about the importance of social interaction between participants.

For the yes/no questions (Questions 13 and 14), all responses were affirmative, except for one case where the respondent expressed no opinion. From the open-ended responses to Question 15, several key insights emerged. These included the importance of real-time feedback, the need for session result storage, the inclusion of varying difficulty levels, and the significance of user-friendliness, particularly given the generally older age of the patient population.

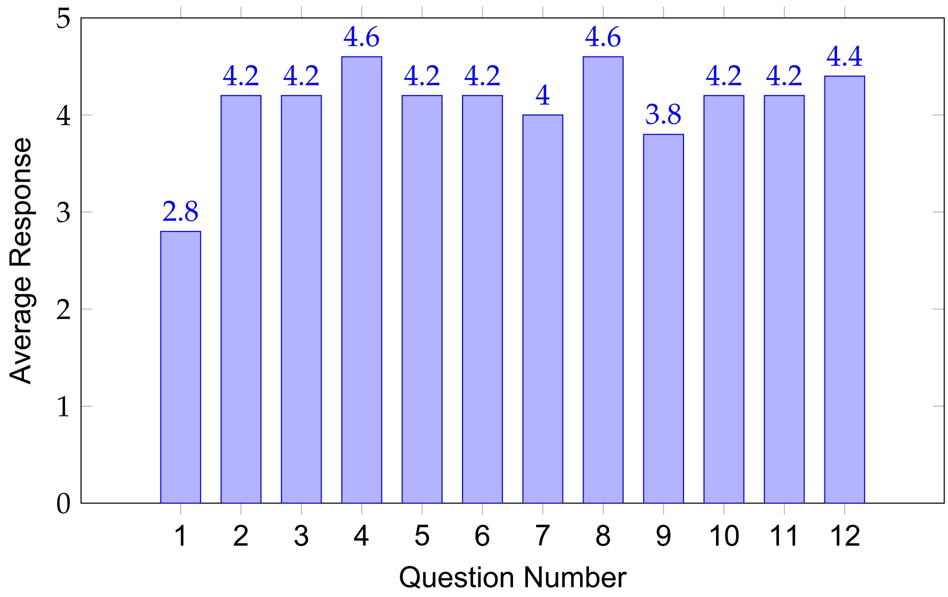


Figure 4.1: Bar Graph with 14 Points

Regarding a stroke rehabilitation application or game, how important do you consider the following aspects:	
No.	**Question**
1	How would you assess your level of familiarity with using computers and video games?
2	To what extent are you open to integrating technology-based solutions, such as games and applications, into stroke rehabilitation therapy?
3	How interested would you be in utilizing a stroke rehabilitation application that incorporates Virtual Reality technology?
4	The use of personalized exercise plans tailored to the individual needs and progress of each patient?
5	The incorporation of gamification elements (e.g., points, rewards, levels) to enhance patient engagement and motivation?
6	The provision of feedback (e.g., success messages or sounds) based on the patient's performance and progress?
7	Offering real-time feedback during exercises to guide proper form and technique?
8	Ensuring ease of use for both patients and healthcare professionals?
9	Incorporating social interaction features, such as sharing progress with other participants and connecting with the broader stroke survivor community?
10	Accounting for the cultural and linguistic diversity of users in terms of content and interface design?
11	Including relaxation techniques to address patient stress and anxiety?
12	Providing progress reports and data tracking capabilities for both patients and healthcare professionals?
13	Do you believe that stroke rehabilitation applications should offer customizable settings to adjust difficulty levels and various abilities?
14	Is it possible for a patient who has experienced impairment in both arms to undergo post-stroke rehabilitation for both limbs?
15	What are the key features that the application or game should include to offer optimal support in upper limb stroke rehabilitation?

Table 4.1: Google Forms Questions

4.1.2 Questions

This subsection addresses a series of open-ended questions on key issues relevant to the development of this project, specifically directed at therapists. A response was received from one female therapist, providing the following insights on various topics:

- **What exercises and activities are recommended for upper limb rehabilitation based on the patient's pathology?** The intervention should be individualized and rooted in the clinical reasoning process tailored to each specific case. Physiotherapy procedures must be selected according to the identified compromised functions, with a focus on enhancing motor relearning through the incorporation of functional activities meaningful to the patient. In upper limb rehabilitation, reaching movements are central to most functional activities.

- **What are the most effective strategies for motivating patients to join to the rehabilitation program?** Motivation is closely tied to the patient's perception of their progress and the connection they make between the frequency of therapy sessions and their recovery. Encouraging this understanding can greatly improve adherence.

- **How is the correct and safe execution of exercises ensured?** During one-on-one sessions, the physiotherapist, as an expert in human movement analysis, identifies compensatory movements and provides feedback to the patient, primarily through somatosensory and proprioceptive cues, to ensure proper performance.

- **What functionalities or tools are essential for an upper limb rehabilitation game to effectively support recovery?** The game should facilitate motor relearning by allowing patients to safely practice movement patterns, minimizing compensatory strategies while providing appropriate challenges to promote progression.

- **What game mechanics or interactive elements could enhance patient motivation and participation?** For many patients, game elements related to sports may be engaging, while others may find activities connected to daily tasks more motivating.

- **How can the balance between challenge and progression be maintained while minimizing the risk of frustration in a rehabilitation game?** Offering a broad range of difficulty levels allows the challenge to be adjusted according to the patient's abilities and progress, ensuring a positive experience.

- **What strategies can ensure sustained engagement and interest in an upper limb rehabilitation game over an extended period?** The game should balance the need for challenge and progression with the risk of frustration, providing a motivating yet manageable experience for the patient.
- **What factors should be considered to make the upper limb rehabilitation game user-friendly and intuitive for both patients and healthcare professionals?** The game should be designed to minimize any learning curve, particularly for users with little experience in technology or digital tools.
- **What social interactions can be incorporated into the upper limb rehabilitation process, and how can they be integrated into the game?** Social elements, such as networked games or tournaments, can be included to enhance the patient's experience and provide opportunities for interaction.

4.2. Chosen Technologies

Based on the articles reviewed, Unity [55] was the best option to develop the application. Unity allows the creation of 3D game scenarios with ease, utilizing a highly user-friendly interface that simplifies all forms of testing and debugging in an efficient, rapid, and visual manner. The programming language selected for this project is C Sharp (C#) due to the readability and ease of implementation. It is a cross-platform programming language that is easy to learn, cost-free, and performs well in event handling processes and triggers. Moreover, it is highly reliable for artificial intelligence and machine learning processes. Furthermore, since Unity 3D has officially adopted C# as its primary language since 2017, repositories and libraries are more readily accessible online. Given that the majority of Unity 3D projects are written in C#, there is an increased probability of obtaining relevant information [56].

4.3. Required materials

In order to use the application, a computer is necessary to run the game, along with a display to present the application's interface, speakers for auditory feedback, and a Kinect v2 camera connected to the computer for motion detection. For Windows users, the Kinect SDK, available on Microsoft's website, must be installed to ensure proper functionality of the application. For macOS or Linux users, additional software packages are required to enable Kinect compatibility. The accompanying architecture diagram (Figure 4.2) visually represents the integration of the aforementioned equipment for the application's operation. For optimal application performance, the user should position themselves at a

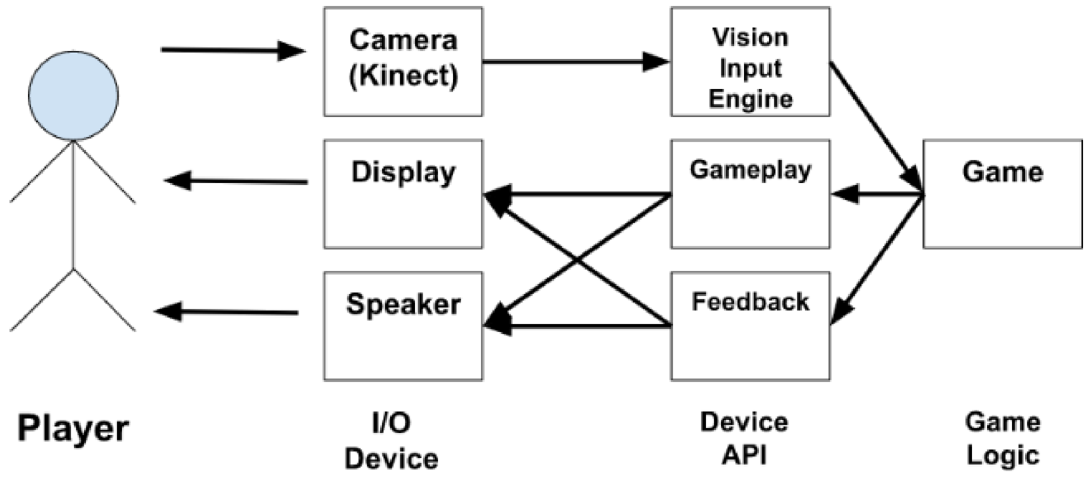


Figure 4.2: Architecture Diagram.

distance of 1.5 to 4 meters from the Kinect camera. The area of use should be moderately lit, avoiding direct exposure to sunlight, as this may interfere with the camera's depth detection capabilities. The camera should be mounted at a height of 1 meter above the user's base level. Additionally ensure that the camera's view is not obstructed.

4.4. Data Storage

Concerning the data and its storage method, the decision made was to go with SQLite. This database was chosen because, for this initial version, data storage will be managed locally, as there is no need for communication with external servers to fully enjoy the game. SQLite uses a file-based data storage system; it is atomic, consistent, isolated, and durable (ACID) even in the event of system crashes and power failures. Additionally, it is lightweight, straightforward to use, does not require external dependencies, and supports cross-platform environments such as Android, iOS, Linux, macOS, Solaris, and Windows [57].

Our database will likely consist of three primary tables: the first will store therapist information (including details such as login credentials), the second will hold patient information (covering profile characteristics and data for future applications), and the third will record patient game scores, ensuring that these data can be accessed for future reference.

4.5. Game Interface

The platform utilized for the development of the game will be Unity3D, which will be employed for the complete creation of the game's interface, encompassing all aspects from login menus and account creation to the gameplay itself.

For the creation of the therapist's account, password validation mechanisms will be implemented to ensure security during authentication. Furthermore, passwords stored in the database will be encrypted to protect credentials, even in the event of unauthorized database access. To further enhance security, a validation system will be added to prevent dictionary or brute force attacks by limiting the number of incorrect login attempts. After a set number of failed attempts, the account will be temporarily locked.

Following the login process, the system will verify whether the patient already has an account. If not, an account creation process will be initiated, requiring personal information (such as name, age, and gender) and relevant details for gameplay (including affected arm, difficulty level, session duration and username). The username must be unique to facilitate the therapist's ability to accurately identify the intended patient during the selection process.

Once the account is created, a mobility test for the affected arm will be implemented. This may involve displaying movement instructions for the patient to replicate. Based on the success of these movements, or the maximum range the patient achieves, this data will be stored. In future game sessions, this data will be used to adjust the required movements. If the patient completes the movements without difficulty, the games will proceed with predefined parameters. However, if the patient experiences challenges during the test, exercises involving those movements will be adjusted to avoid setting unattainable goals. This feature is designed to ensure that the game does not demotivate the patient. For instance, if objects were positioned at heights beyond the patient's reach in the lower levels, it could lead to feelings of discouragement and a loss of motivation to continue rehabilitation. This consideration is crucial, as it represents one of the primary objectives for the existence of this application.

After the tests or upon selecting the patient's account, the main menu will provide the following options:

- **Play**: This option allows the therapist to select a game level, initiating a session with the chosen difficulty. The patient will perform movements during gameplay, and data will be saved for future analysis by healthcare professionals.
- **Train**: A free play mode, where the therapist can customize all aspects of the game.

- **Statistics**: A panel displaying all relevant statistics from previous sessions for the selected patient.
- **Profile**: A section where the therapist can modify any settings related to the patient's profile.
- **Exit**: Returns to the patient selection menu.

The game's design will focus on the appearance of specific objects that the patient must touch with the previously selected arm to score points. As the difficulty increases, the objects will be assigned a limited lifespan, disappearing once the time expires. This added challenge is intended to maintain patient engagement and prevent boredom. Several key factors were carefully considered during the development of the game. One of the primary focuses was ensuring a variety of gameplay options for each player. For instance, players can choose which arm to use, even if only one is marked as injured in their profile. They can also select their playing position—either seated or standing—with an avatar that mirrors their posture accordingly. The game includes a broader range of levels to accommodate various patient needs, as well as a training mode that allows therapists to create custom levels, enabling an infinite combination of difficulty settings to tailor the experience to each individual. Additionally, players have the option to enable or disable a time limit and select the desired duration.

This activity diagram (Figure 4.4) provides a comprehensive summary of all the features included in the application, along with the sequence of their respective actions. Below is a summary of the previously discussed aspects of the game's interface, presented in the form of a Unified Modeling Language (UML) Class Diagram (Figure 4.3).

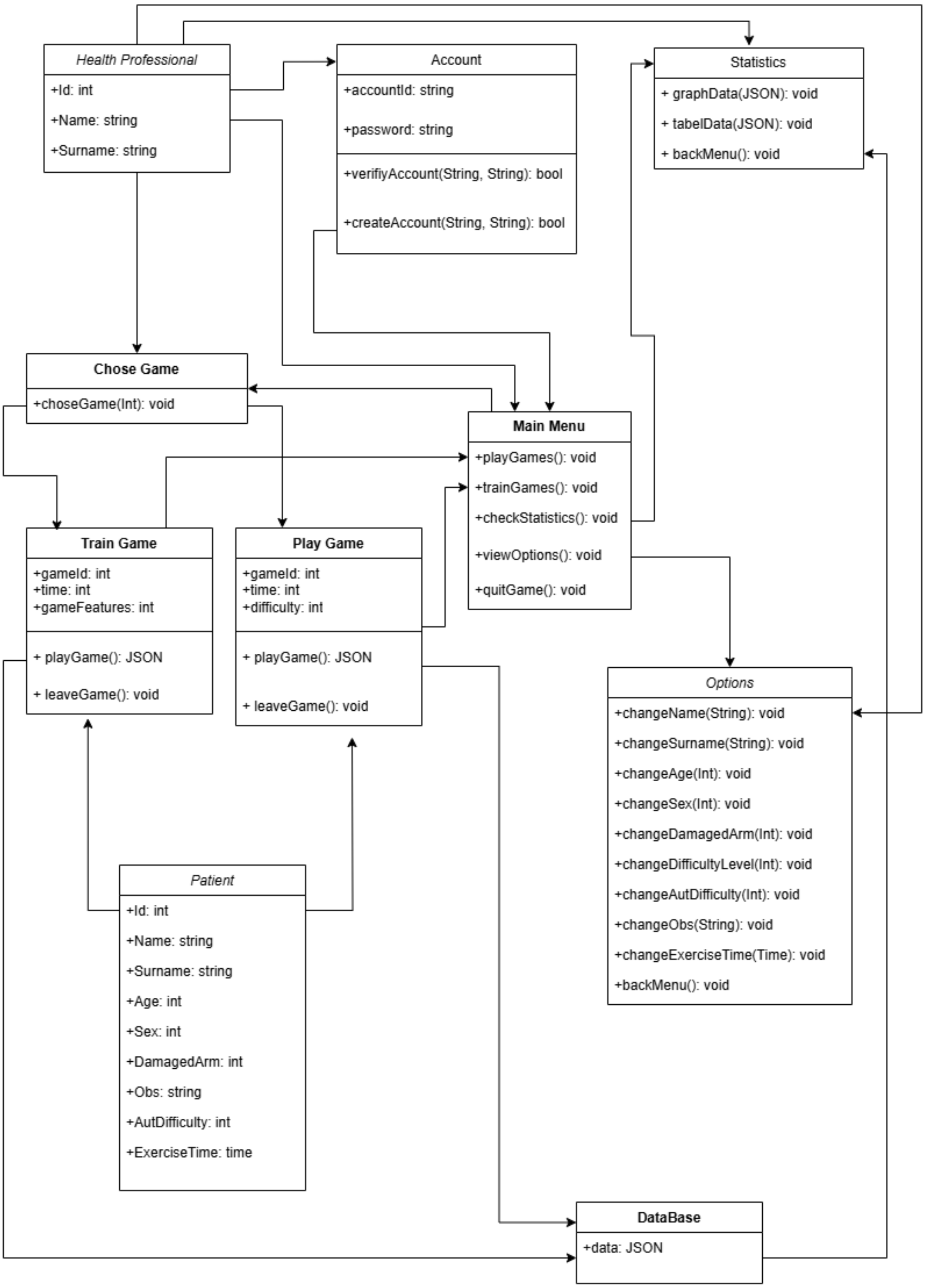


Figure 4.3: UML Class Diagram.

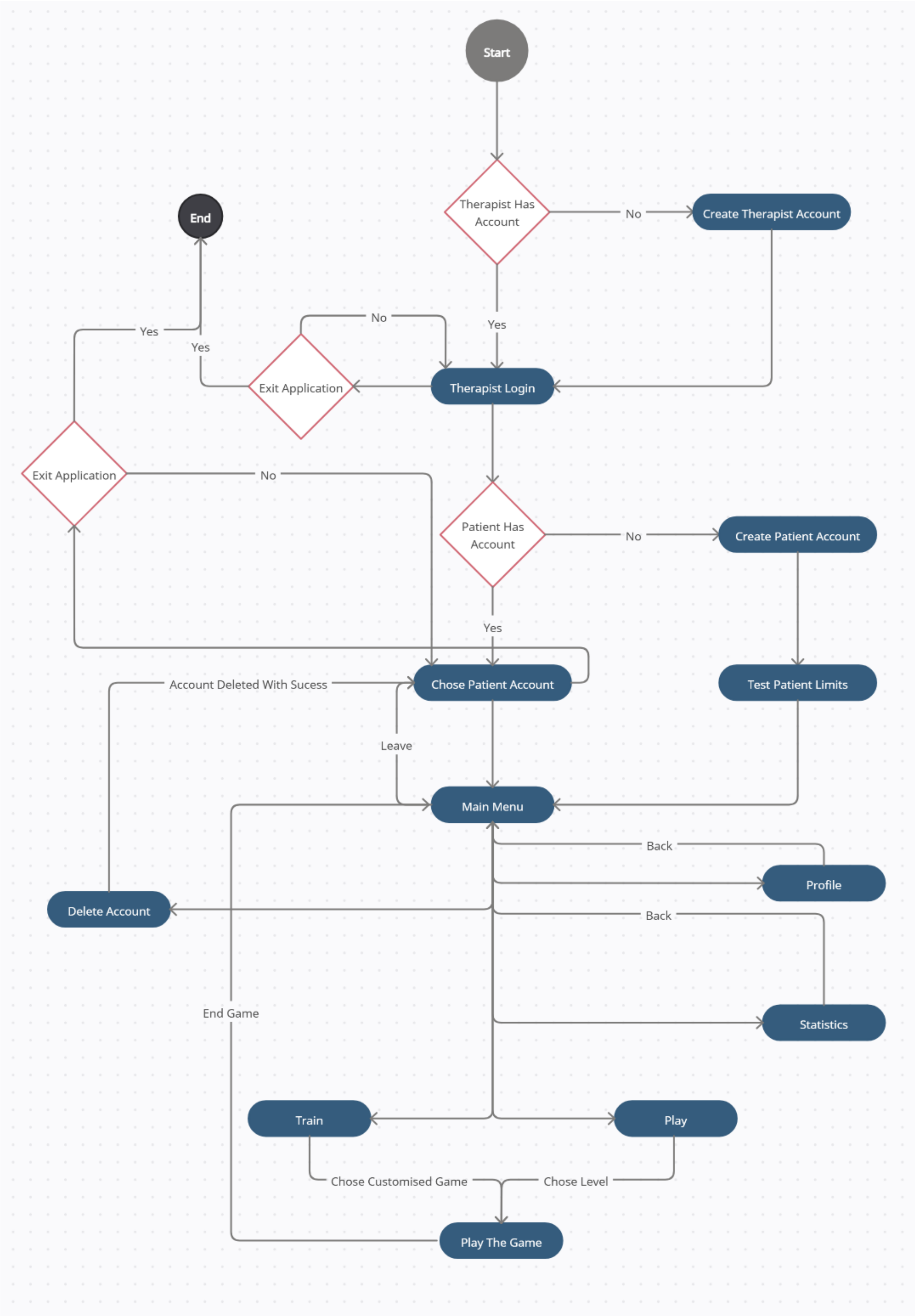


Figure 4.4: Activity Diagram.

4.6. Figma's Mockups

This section will present several mockups created in Figma [58] prior to the game's development in Unity (Figure 4.5 - Figure 4.10.

Figure 4.5: Initial Scene.

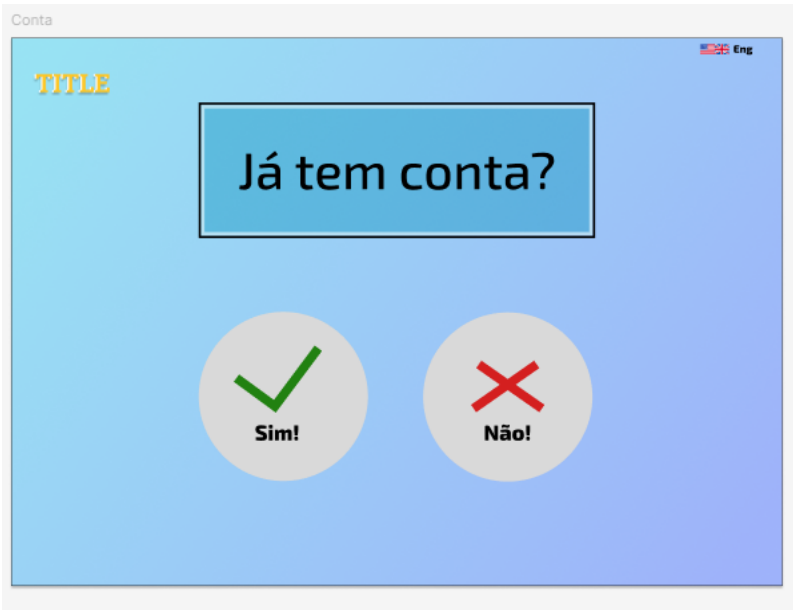


Figure 4.6: Check If The Patient Has Account.

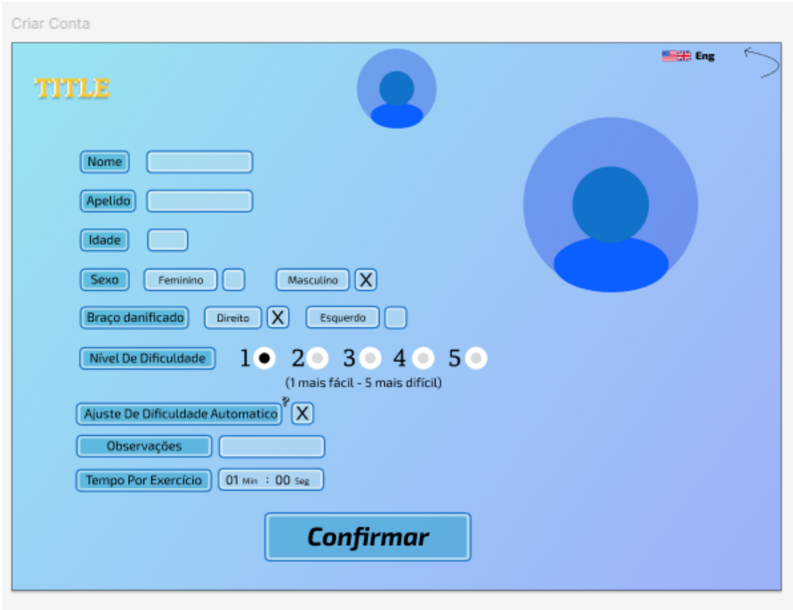


Figure 4.7: Create Patient Account.

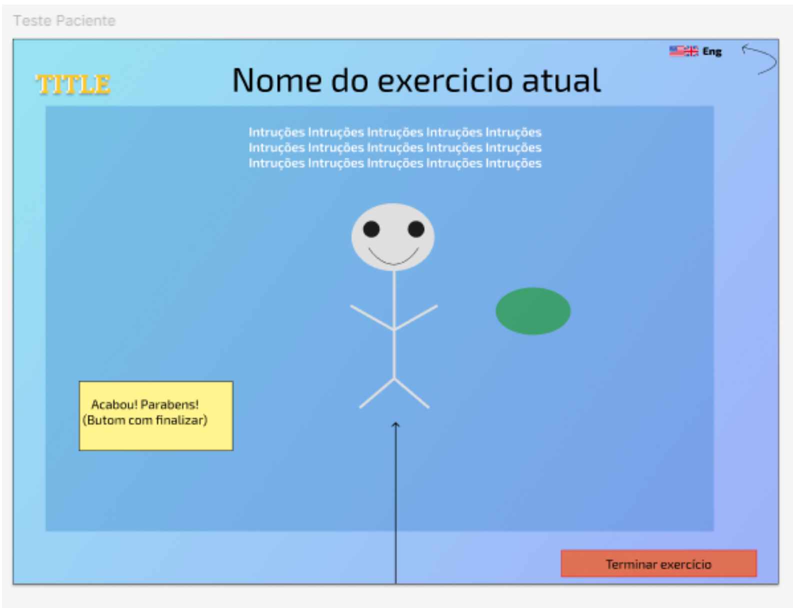


Figure 4.8: Test After The Patient's Account Creation.

Figure 4.9: Main Menu.

Figure 4.10: Patient Playing The Game.

4.7. Summary

In conclusion, this chapter has outlined the technologies selected for the development of the application, along with its tools and features, ranging from the game interface to gameplay mechanics. It also detailed the data-saving processes and the optimal environment to ensure the best user experience. The following chapter will demonstrate how these elements were implemented throughout the course of the project.

5. Game Implementation

This chapter begins by detailing the technologies and techniques employed in the development process, with each selection based on specific criteria and justifications to ensure the project's efficiency and effectiveness. Furthermore, a comprehensive overview of the project's creation and operational processes is provided. Throughout this project, we incorporated insights provided by a therapist on various aspects of the game, focusing on enhancements to help us achieve our objectives

5.1. Database Tables

The SQLite implementation utilized was sourced from the GitHub repository SQLite4Unity3d, developed by Roberto Huertas [59]. Our database will be organized into three tables: healthcare professional information, patient information, and game statistics.

5.1.1 Healthcare Professional Table's

The healthcare professional information table consists of seven fields:

- **Id**: This is the primary key, unique, not null, of type int, and is automatically incremented each time a new user is created.
- **UserName**: This is unique, not null, of type varchar, and will be used as the username in the application to authenticate the healthcare professional.
- **FirstName and LastName**: These are not null, unique, of type varchar, and are used to provide some information about the healthcare professional.
- **Password**: This is not null, of type varchar, and serves as the password that the healthcare professional must enter to authenticate. Before being inserted into the database, *BCrypt* is used to encrypt the password, transforming it into a hash to ensure authentication security.
- **PasswordTries**: This is not null, of type integer, and is used to store the number of times the password was incorrectly entered for a particular user. If the password is incorret to many times, the account will be locked to protect against potential attacks such as brute force.

5.1.2 Patient Table's

The patient information table comprises the following fields:

- **IdNumber**: This field serves as the primary key, is unique, not null, of type integer, and is automatically incremented with the creation of each new user.
- **UserName**: This field is unique, not null, of type varchar, and will be used as the username in the application to select the patient who will be playing the game.
- **FirstName and LastName**: These fields are not null, unique, of type varchar, and provide information about the patient.
- **Age**: This field is not null, of type integer, and stores the patient's age.
- **Gender**: This field is not null, of type integer, and records the patient's gender, where 0 denotes male and 1 denotes female.
- **DamagedArm**: This field is not null, of type integer, and indicates which arm the patient has damaged, where 0 represents the left arm and 1 represents the right arm.
- **LevelDifficulty**: This field is not null, of type integer, and records the difficulty level of the exercises, ranging from 0 (easiest) to 9 (most difficult).
- **Notes**: This field is nullable, of type varchar, and is used to record any important notes the therapist may have regarding the patient.
- **GameTime**: This field is not null, of type integer, and records the maximum duration per exercise in seconds.
- **Sitted**: This field is non-nullable, of integer type, and captures the player's position. A value of 0 indicates that the player will participate in the game while seated, whereas a value of 1 signifies that the player will be standing.
- **LastLogin**: This field is non-nullable, of DateTime type, and records the timestamp of the most recent login event.
- **XLeftArmLimit, XLeftArmLimit, XRightArmLimit and YRightArmLimit**: This fields are nullable, of float type, and records the maximum distance the patient can achieve with their arm during a lateral raise test, saving the position of x and y closest to the intended movement.

5.1.3 Score Table

The table regarding the patient's statistics has the following fields:

- **Id**: This field is a non-nullable integer, forming part of the composite primary key. It serves as a link between the score column and the players' column.
- **Level**: This field is a non-nullable integer, also forming part of the composite primary key. It represents the difficulty level within the game.
- **Game1MaxPoints**: This field is a nullable float and stores the player's maximum score for a specific level.
- **Game1PointsHist**: This field is a nullable string and stores all scores achieved by the player for that level.

Furthermore, the patient table is connected to the score table, such that for each patient, there may be multiple corresponding entries in the score table. In conclusion, Figure 5.1 illustrates the structure of the various tables within the database and their relationships.

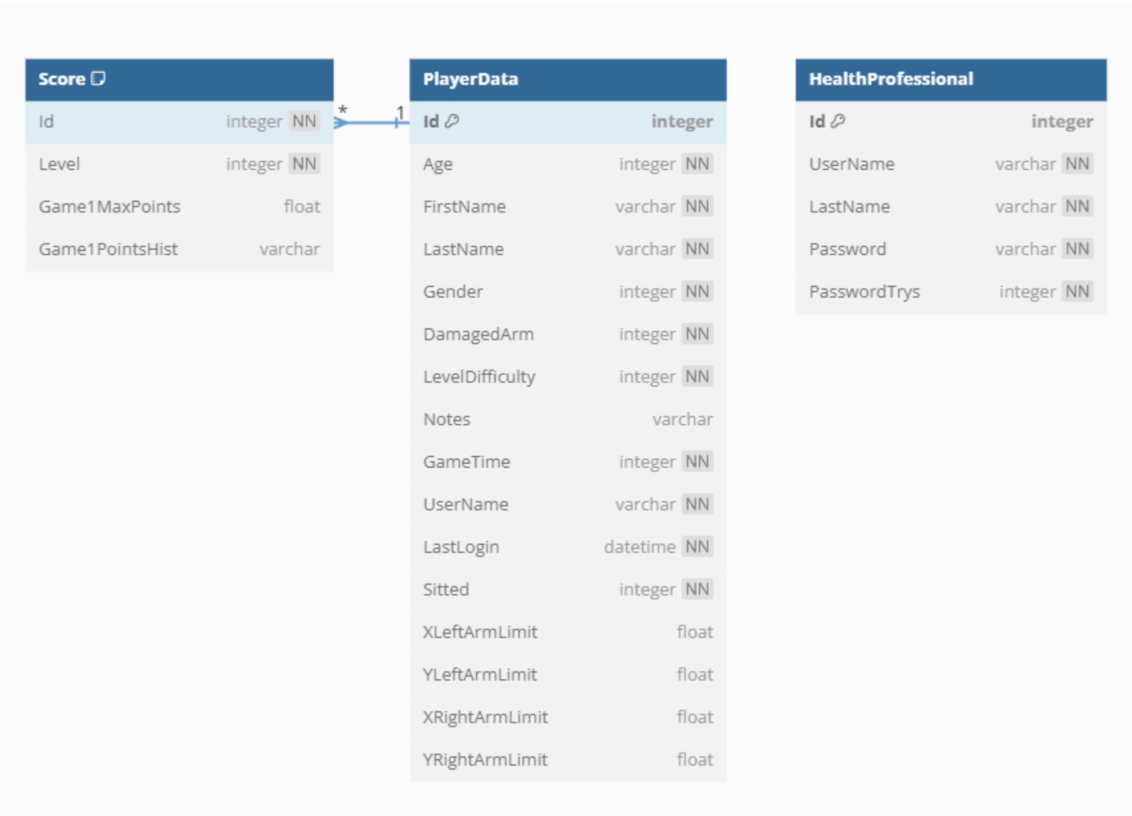


Figure 5.1: Data Base Diagram.

5.2. Avatar

This chapter examines particular features for integrating the avatar into the project, as well as enabling its movement in a manner suitable for the project's conditions.

5.2.1 Setup

For this project, two avatars were selected, one female (5.2a) and one male (5.2b), to replicate the patient's movements while using the application. The avatars were selected from Mixamo [60] due to their seamless integration with Unity and their suitability for accurately replicating movements.

To export an avatar from the Mixamo website to the Unity project, navigate to the Characters section, select an avatar, click the download button, and choose the 'FBX For Unity (.Fbx)' format. To import the avatar into the Unity project, simply drag it from the download folder into the project. Since the selected avatar has human characteristics, it is necessary to adjust the settings in Unity.Then go to the project area, click on the avatar, go to the Inspector, select the Rig option, and change it to 'Humanoid'. This setting allows the avatar to be recognized as a structure that includes at least 15 bones, organized to mimic the movements of a real human skeleton [61]. This configuration ensures animation compatibility across different avatars, as they share the same skeletal structure, and it facilitates the use of various animation techniques essential for movement replication, such as Inverse Kinematics (IK).

To obtain the textures and visual characteristics of the avatar, navigate to the Inspector, select the Materials tab, choose 'Extract Textures', and choose the folder named 'Textures' (if the folder does not exist, it must be created). To complete the avatar setup, access the Package Manager and download the Animation Rigging package (version 1.2.1, dated January 12, 2023, which was the most recent at the time of this project [62]) to enable the animation functionality that will be utilized later.

5.2.2 Characteristics

The initial enhancements made to the avatar included the implementation of a Bone Renderer, which facilitates the visualization of the avatar's bones. This addition simplifies the process of defining the avatar's positions, creating animations, and debugging by making it easier to identify issues such as incorrect rotations or bone movements. To add all the

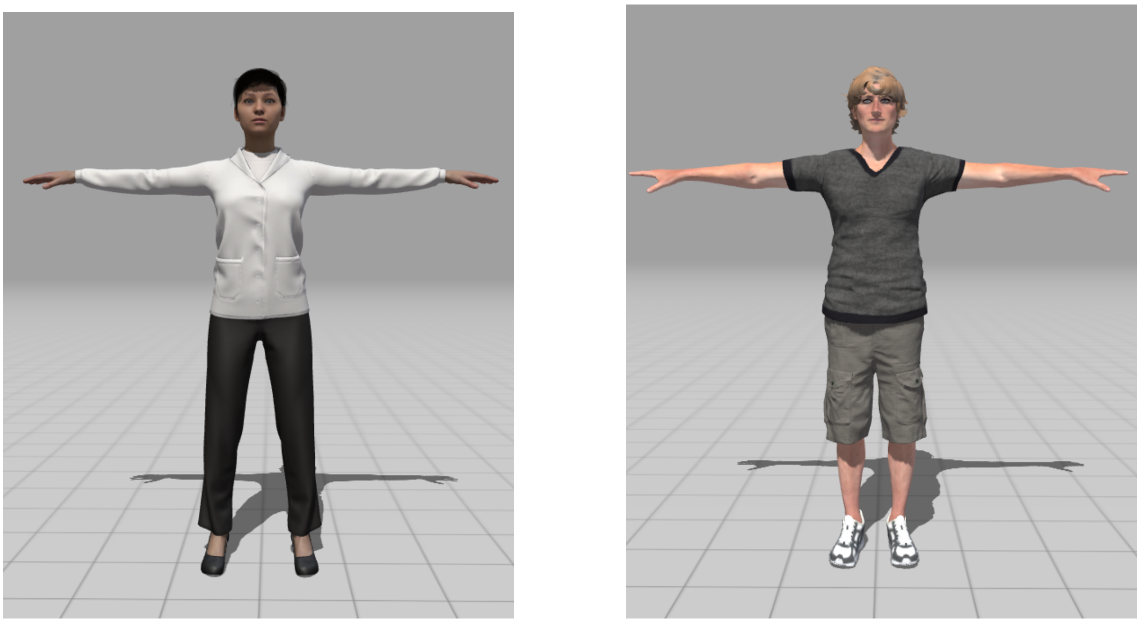


Figure 5.2: Avatars used in the game: (a) Female Avatar [60]; (b) Male Avatar [60].

avatar's bones to the Bone Renderer, select the avatar in the project, navigate to the Inspector, and choose all the bones (typically starting with the hips and labeled similarly to 'mixamorig') and drag them into the Transforms section within the Bone Renderer. It is important to note that the bones are not visible during gameplay.

Additionally, a Rig Builder was added to the avatar to manage the rigs used to control the avatar's animations and movements. Within the Avatar hierarchy, a Game Object with a Rig component was created, allowing control over the extent to which the avatar is influenced by this rig through the Weight parameter. Setting the Weight to 0 indicates that the rig has no influence on the avatar's movement, whereas setting it to 1 gives the rig full control over the avatar's movement for the selected bone or group of bones. For this project, the Weight was set to 0.893 to maintain the desired movements while allowing greater fluidity. This Rig contains four child objects, each equipped with a Two Bone IK Constraint component to control the movement of both arms and both legs. The leg movements are utilized solely to adjust the avatar's position between sitting and standing as chosen by the player, while the arm movements are applied in two scenarios: during gameplay and for creating animations.

Modifications were also made to the bones in the avatar's hands by adding three new components: Rotation Constraints, which match the rotation of the chosen Game Object (in our case it is the forearm [63]); Box Collider, which creates a box-shaped collider enabling interactions with other objects that have colliders [64]; and Rigidbody, which allows the GameObject (in this case, LeftHand/RightHand) to interact physically within the scene [65]. Without the Rigidbody, the Box Collider would remain static and immovable. This combination ensures that when the avatar's hand makes contact with a specified object in the game, it can detect the virtual contact and trigger a corresponding action. All child objects of both hands also have a rotation constraint linked to the parent's transform to keep the hand static and aligned with the forearm's movements, as finger movements are not considered in this game. With all configurations applied, the avatar prefab in the scene environment will appear as shown in Figure 5.3.

5.2.3 Inverse Kinematics

Inverse kinematics (IK) in Unity refers to the computational technique used to determine the necessary joint rotations and positions within a hierarchical skeletal structure to achieve a specific target position for an end effector, such as a hand or foot. Unlike forward kinematics, where joint angles are directly manipulated to compute the position of the end effector, IK works in reverse, calculating the required joint configurations to reach a predetermined position.

In Unity, IK is utilized primarily in character animation to ensure that parts of a character's body, like limbs, can dynamically and naturally interact with the environment [66]. The Two Bone IK constraint enables the inversion of control within a simple hierarchy of two GameObjects, allowing the tip of a limb to reach a designated target position. An additional Hint GameObject can be used to define the desired orientation of the limb when it bends [67].

5.2.4 Movements in animations

To create animations that move the avatar in the desired way, begin by opening Unity and navigating to **Window** → **Animation** → **Animation**. In the project, select the avatar for which the animation will be created, open the **Animation** window, and create a new animation clip. After creating the clip, click the **Preview** button, which will display a timeline where the duration can be set in either frames or seconds. To select the body part you wish to animate, go to **Animation** → **Add Property** and choose the appropriate property.

For this project, the animation created involved a lateral arm raise. For each arm, 4 frames were used, each containing a different target position to replicate the arm's upward and

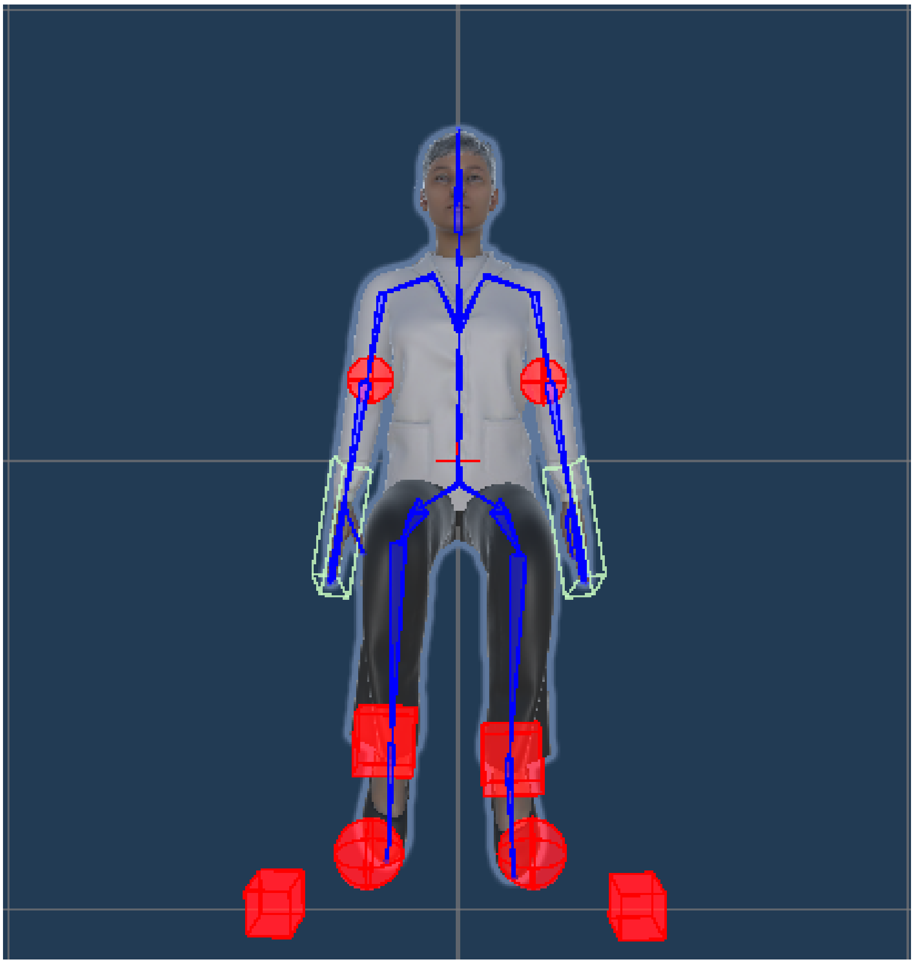


Figure 5.3: Avatar Structure: The blue skeleton represents the Bone Renderer; the red cubes indicate the Targets; the red spheres mark the Hints; and the green boxes in the hands are the Box Colliders.

downward movement. The first and last frames are identical, representing the resting position of the arm, while the second and third frames show the arm transitioning from rest to the target position (Figure 5.4).

This approach was also applied to determine the optimal positioning for the legs, whether seated or standing, depending on the patient's gameplay position. Instead of adjusting the target positions of the hands, the targets for the left and right legs were utilized. However, no animation was created for this, as these are static data points used solely for visualization in the game.

5.2.5 Movements in real time

As mentioned earlier, in order to achieve real-time motion capture, the Kinect system was used to record movements, and Unity, along with a human avatar, to visually replicate these movements. To achieve the objetive was implemented two distinct primary codes

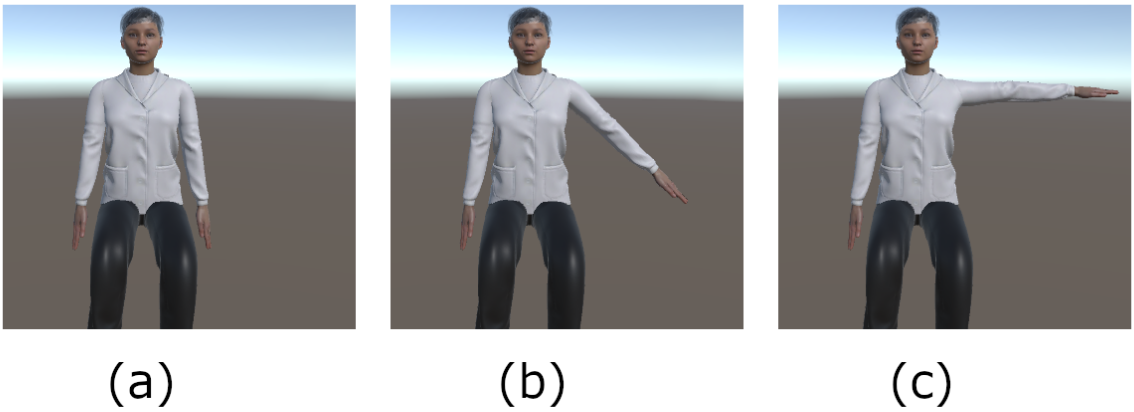


Figure 5.4: Animation of the avatar's lateral arm raise: (a) Initial and final frames; (b) Second frame; (c) Third frame.

to ensure that the avatar's movement is not reliant on data from the Kinect, but rather on spatial positions of the Vector3 type (representation of 3D vectors and points) **??**. This approach allows for greater flexibility, as future integration with different cameras or software would only require a spatial position to control movement, thereby enhancing the portability of the application.

5.2.5.1 Kinect Information

The Kinect system includes pre-built code that, using its camera, detects human bodies by creating a representation in which joints are depicted as cubes, with connections made between them using green renderer lines to facilitate the recognition of a human body as shown in figure 5.5. The process began by modifying the base code. First, the feature that allows the detection of multiple individuals simultaneously was disabled, ensuring that if the patient is detected, any other person, such as a therapist or someone passing behind the patient, will not be recognized. Second a new variable, JointToRig, was created and defined as a Dictionary<JointType, string>(). The JointType structure, utilized by the Kinect, is of integer type and is employed to identify the specific body part being detected. This structure includes 25 points, spanning from the head ("Head") to the feet ("FootRight" and "FootLeft"). This dictionary was created to map the required JointType — specifically targeting the wrists, elbows, and the "SpineBase".

Next, specific conditions were established to track and manage those joints to perform key tasks:

- **SpineBase**: SpineBase data was used to determine the avatar's position relative to the game environment. To maximize the game's potential and ensure more accurate position tracking, the player should always remain centered with the camera and with straight back.

- **WristRight/WristLeft**: These points provide the position of the patient's wrists at a given frame, which will inform the avatar's arm future positioning.
- **ElbowRight/ElbowLeft**: These points give us the position of the patient's elbows at a given frame, which is used to understand how the elbows should bend to ensure natural, humanly possible movements to the avatar's arm.

Using the spatial positions of each joint, the script responsible for controlling the avatar's movement will be invoked to transmit the extracted data to the game.

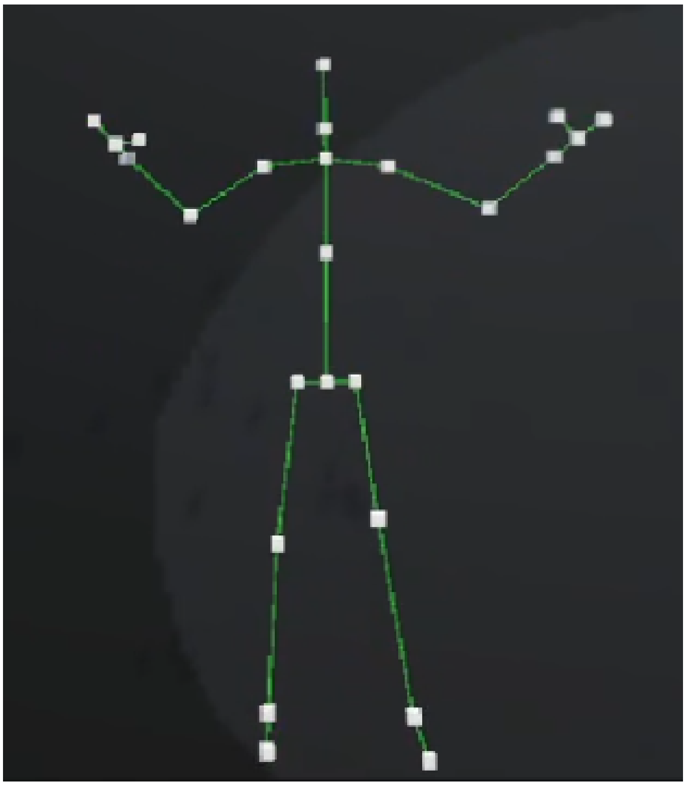


Figure 5.5: Kinect Skeleton.

5.2.5.2 Avatar Real Time Movement

In the avatar movement script, the process begins by determining the patient's gender, which dictates whether a male or female avatar will be used. Then, the script assesses the position in which the patient will play, adjusting the avatar's position and scale accordingly. Once these parameters are established, the script proceeds to the movement section, which involves two distinct types of transformations applied to the avatar in each frame. Initially, a function retrieves the SpineBase position from the Kinect and updates the avatar's transform position to align with it. Following this, another function takes as input a string representing the joint being moved, which could either be the elbows or wrists, along with the corresponding spatial position. Then a search is made for that string in the avatar's hierarchy. Upon locating the correct avatar's child for that string, it is moved in accordance with the provided spatial coordinates. If the joint pertains to the elbow, the script adjusts the Left/Right Arm Hint, influencing the elbow's bend and promoting natural, realistic motion. For wrist movements, it modifies the Left/Right Arm Target, thereby affecting the arm's movement based on the Kinect's positional data.

5.3. Unity Project

This chapter will discuss the creation of the various scenarios and highlight the key features and functionalities essential to their development.

5.3.1 Intro Screen

Initially, an infinite sky image environment was created as the background (Figure 5.6). To achieve this illusion, a script was developed to spawn a sky image at the start of the game, which moves to the left along the x-axis. Additionally, a timer was implemented to prevent images from being spawned every frame; instead, new images are spawned only when the current or previous image is about to exit the screen. To determine the position of the next image, the coordinates of the previous image were obtained, the image's width was added, and this value was set as the x-axis position. This ensures the new image appears seamlessly attached to the previous one. Furthermore, x-axis position was adjusted slightly to avoid a frame without an image. The new image is placed beneath the previous one to ensure a smooth transition, creating the appearance of a continuous infinite image rather than two separate images. Once an image moves off the screen, it is deleted to conserve game performance. To proceed to the next panel, simply press any key.

5.3.2 Healthcare Professional Account

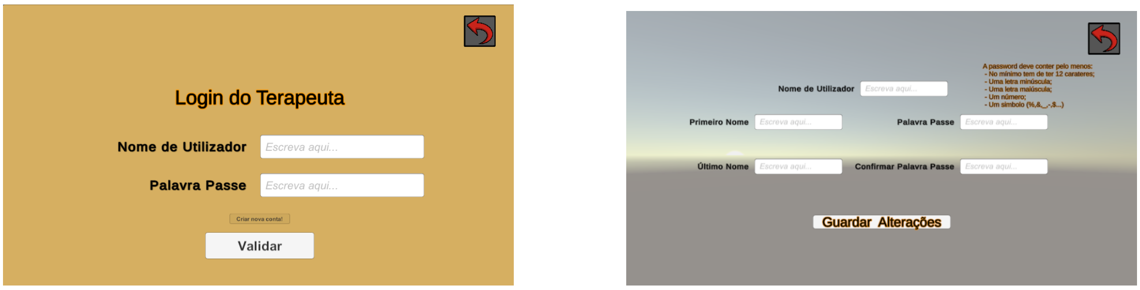
Following the initial scenario, a page appears requesting the healthcare professional's login credentials (Figure 5.7a). If the therapist enters an incorrect password three times for the same username, the account will be locked. This security measure is designed to protect the account from dictionary or brute force attacks.

Figure 5.6: Initial Scene.

If the therapist does not have an account, a button is provided to navigate to the account creation process. In this scenario (Figure 5.7b), the following five fields must be completed:

- **Username**: Must be between 5 and 15 characters to optimize database performance and facilitate memorability; If the value falls outside the specified range or the field is left blank, an error message will be returned.
- **First and Last Name**: These fields accept only alphabetic characters and provide identification of the therapist creating the account; If the field is left blank, an error message will be returned.
- **Password**: The password must meet minimum security standards, including a minimum of 12 characters, with at least one lowercase letter, one uppercase letter, one number, and one symbol [68].
- **Confirm Password**: This field ensures the password was entered correctly; If this field and the password field doesn't match an error message will be returned.

Upon clicking the save changes button and completing all required fields, a confirmation panel will appear, allowing the therapist to verify their decision to create the account. Once the account is successfully created, a confirmation message will be displayed indicating that the data has been saved successfully.



(a) (b)

Figure 5.7: Therapist Scenes: (a) Therapist login scene; (b) Therapist create account scene.

5.3.3 Patient Account

After the therapist has successfully logged in, a new panel appears to verify whether the patient already has an account in the application or if it is necessary to proceed with the account creation process (Figure 5.8).

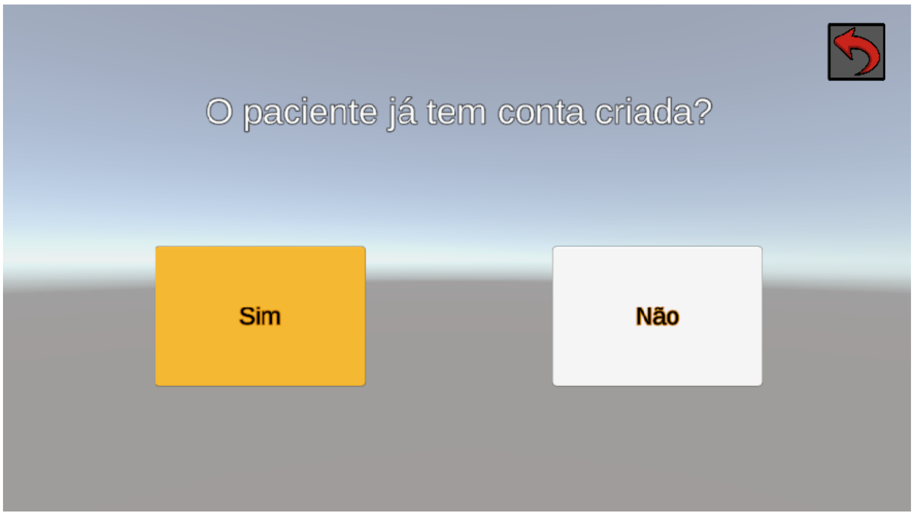


Figure 5.8: Scene to check if the patient has an account.

5.3.3.1 Patient Account Creation

Upon selecting the option indicating that an account has not yet been created, the user is directed to an account creation menu (Figure 5.9) with several required fields:

- **First and Last Name**: This field accepts only letters. If left blank, an error message is displayed.
- **Age**: This field accepts only numerical input, with a maximum of three digits. If the age is 150 or greater, or if the field is left blank, an error message is returned.

- **Gender**: A dropdown menu with two options: male or female.
- **Injured Arm**: Two checkboxes (left or right), with the option to select both. By default, the right arm is selected. If neither checkbox is selected, an error message will appear.
- **Mode of Play**: Two checkboxes (sitting or standing) that indicate the method by which exercises will be performed. A script ensures that only one option can be selected, with ”standing” as the default.
- **Username**: This field allows letters, numbers, and special characters. If the input is fewer than 5 or more than 15 characters, or if the field is left blank, an error message is displayed. The system also connects to the playerData database to verify if the username already exists; if so, or if the database is inaccessible, an error message is shown.
- **Difficulty Level**: A dropdown menu with 10 options, ranging from Level 1 (easiest) to Level 10 (hardest).
- **Game Time**: Two checkboxes (Yes or No) determine whether exercises will be timed. A script ensures only one option can be selected, with the default set to no option. If the yes option is selected, an additional field for ”Game Time” appears, containing two subfields for minutes and seconds. If either field is left blank, or if the seconds exceed 59 or the minutes exceed 10, an error message will appear.
- **Notes**: This field accepts letters, numbers, and special characters and is provided for the therapist to input relevant notes about the patient.

All fields, except for the notes, are marked with a red asterisk to indicate they are mandatory.

Upon clicking the red arrow in the upper-right corner, a warning message appears, notifying the user that returning to the previous scenario will clear the current entries, with an option to confirm whether the user wishes to proceed.

Upon clicking ”Save Changes”, the system validates the input fields for errors. If all fields are correctly completed, a confirmation message will appear, asking the user to verify whether they wish to save the data to the database. Upon confirmation, the selected data is inserted into the PlayerData table, with the lastLogin date set to the moment of the action and the idNumber assigned based on the next available value in the database. If the insertion is successful, a message will be displayed confirming that the data has been successfully saved, accompanied by a button to close the message.

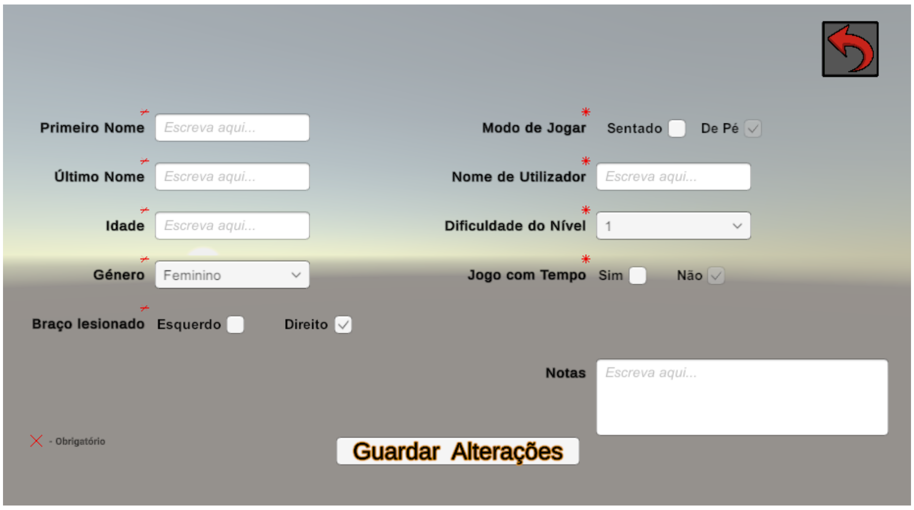


Figure 5.9: Create Patient Account Scene.

The system then transitions to a scenario designed to assess the patient's maximum lateral reach. In this scenario, an animation of an avatar performing a lateral raise is displayed on the screen, accompanied by a brief explanation of the expected movements and a "Ready" button, which prompts the patient to replicate the movements. A script utilizes a static variable that holds the ideal position, and as the patient performs the movement, their position is compared to this ideal. The system updates the recorded position to the best value achieved by the patient. This value is then stored in the database and later used as input for the game, ensuring that certain objects are not placed in positions where the patient is unlikely to reach. For instance, if the patient has significant difficulty raising their arm, game objects will not be positioned at great heights, as they would be unreachable. As the patient progresses through subsequent sessions, the objects will gradually appear at more challenging, yet attainable distances fostering realistic recovery and progression.

5.3.3.2 Patient Has An Account

Upon selecting the option indicating that the user already has an account, a query will be executed on the PlayerData database to retrieve all patients with existing accounts in the application. The resulting list of patients will be organized by the most recent login, ensuring that the most recently accessed records appear at the top (Figure 5.10). Once this list is sorted, a button will be generated for each user, displaying their first and last name. When the button is clicked it retrieves all relevant information about the selected user from the database, stores the retrieved data in a global variable, and, upon successful data retrieval, updates the user's lastLogin timestamp in the database.

Figure 5.10: Patient's Accounts Scene.

5.3.4 Main Menu

Upon selecting the patient, the system navigates to the main menu (Figure 5.11), which presents the following options:

- **Play**: Initiates a level-based game session.
- **Train**: Opens a game session where the therapist configures the game's characteristics.
- **Statistics**: Displays the player's statistics based on their progress across levels.
- **Profile**: Provides access to edit all fields within the player's profile.
- **Delete Account**: Deletes the selected patient's account.
- **Exit**: Returns the user to the patient account selection screen.

Additionally, each time this menu is accessed, the global variable with the patient information is refreshed to ensure that any updates from the database are synchronized with the system.

Figure 5.11: Main menu scene.

5.3.4.1 Game

This application currently features a single game, which involves the patient interacting with touch-sensitive objects. These objects are equipped with a capsule collider to enable the patient's selected hand to collide with the object. Upon creation, the object is blue, and once the patient's hand detects the touch, the object changes to green, then disappears. To prevent actions such as arm-crossing, which are not recommended for rehabilitation purposes, the capsule will award a point and disappear only when touched by the designated hand, chosen before the game, regardless of any attempts to use the opposite hand. A new capsule, identical in characteristics, subsequently appears in a different location. Depending on the level, the capsule may be subject to a time limit; after a predetermined number of seconds without the patient making contact, the object begins to blink, alternating between white and red, before disappearing and reappearing elsewhere (Figure 5.12). This feature is designed to enhance the level of difficulty and challenge, ensuring that the patient remains engaged and does not become disinterested due to the game being too easy. Upon successfully interacting with all the objects for a given level, the patient receives a congratulatory message, and the system returns to the main menu. The game may also conclude if the healthcare professional selects the "finished" button displayed on the screen. Following each game, the system verifies whether the score achieved is the highest for the respective level. If it is, the database is updated to record the new best score. Furthermore, regardless of the outcome, the score and date of each game are stored in the database for future use in statistical analysis. In training mode, the same game is used, but the therapist has the flexibility to select both the number of objects the patient must interact with and the time limit for each capsule's disappearance.

It can also select options such as game duration and preferred hand, as these settings are already available in standard gameplay mode.

Figure 5.12: Example of a game at the highest difficulty level - the capsule is red because is close to disappearing.

5.3.4.2 Statistics

In statistical analysis, the values of points and their corresponding dates, stored within the score database, are utilized to generate these graphs. There are two types of graphs: Level-specific graphs: These display the score, level, and date for each individual level; General graph: This presents the points achieved along with their respective dates, regardless of the levels (Figure 5.13).

5.3.5 Scripts

In this project, it is important to note that all scripts are written in English and thoroughly commented, facilitating modifications and code reviews by making the underlying logic more easily understandable. This key files deserve more attention due to their importance: GameConstants.cs is a critical file as it contains all static variables for the game, including scenario names, level information, and avatar positions, as well as certain global variables that store player information; DBQueries.cs includes all SQL scripts and database operation codes, such as SELECT, INSERT, and DELETE queries.

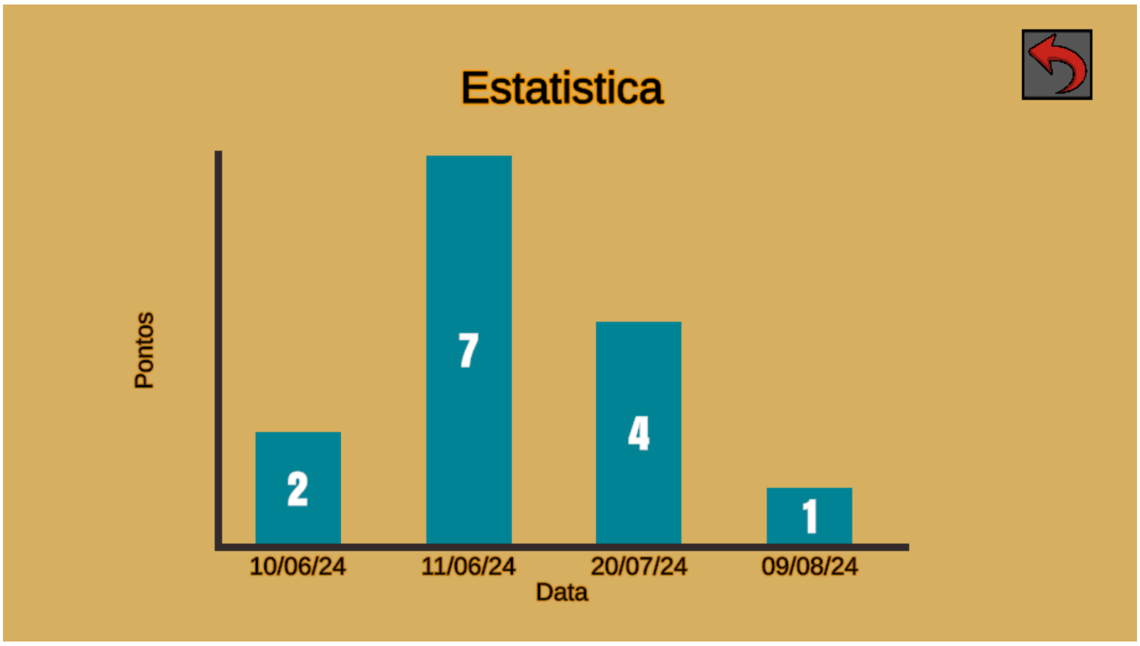


Figure 5.13: Statistics Graph.

5.4. Summary

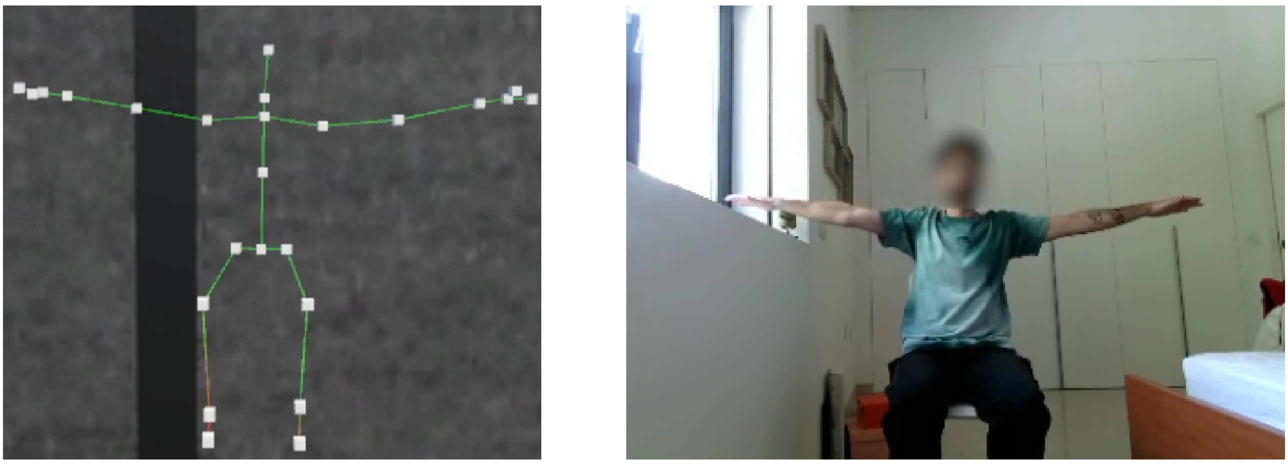
In conclusion, based on the information provided, the objective of ensuring that the people that read it can comprehend the implementation of this project has been successfully achieved. This includes a detailed explanation of the technologies employed, the characteristics of the database, motion detection via Kinect, the setup and movement of the avatar, as well as the development of the project in Unity3D. With this information, they should be well-equipped to replicate and modify the project with ease.

6. Results

Results are a crucial component of any project, and a game is no exception. To facilitate a more comprehensive analysis, this section into structure in two parts: Therapist - this section focuses on the actions a therapist would undertake in the rehabilitation process, with particular emphasis on the use of the game's interface; Patient - this section centers on the gameplay experience, including the execution of movements, the patient's feedback on their physical and emotional experience during gameplay, and their overall evaluation of the game.

6.1. Visual Representation

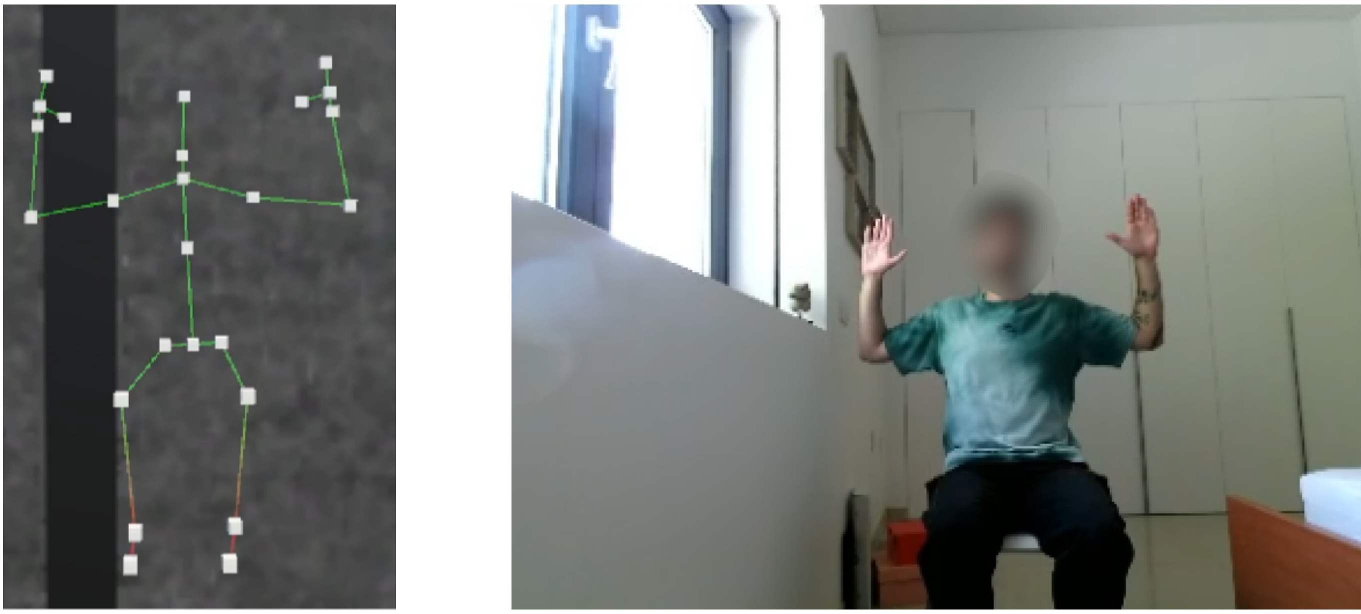
In this section, we present a series of images to illustrate the results of keypoint detection by the Kinect, which are subsequently transformed into an exoskeleton model. In the Figure 6.1, the exoskeleton replicates a pose in which both arms form a 90-degree angle with the body. In the figure 6.2 shows the exoskeleton mimicking a pose where the elbows are bent at a 90-degree angle upward. In the figure 6.3, the exoskeleton represents a position with both arms fully extended overhead .



(a) (b)

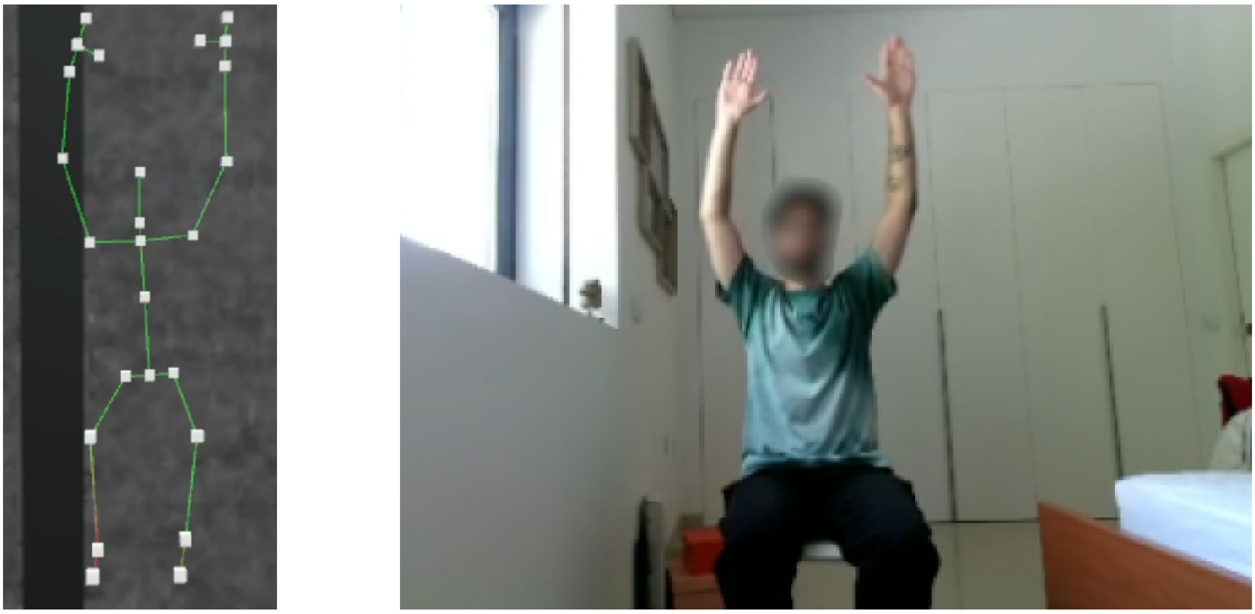
Figure 6.1: Pose 1 - Both arms form a 90-degree angle with the body: (a) Kinect's exoskeleton position; (b) Human position.

Additionally, a visual representation is provided here, illustrating the movements of the Kinect, the individual, and the avatar during gameplay (Figure 6.4 and Figure 6.5).



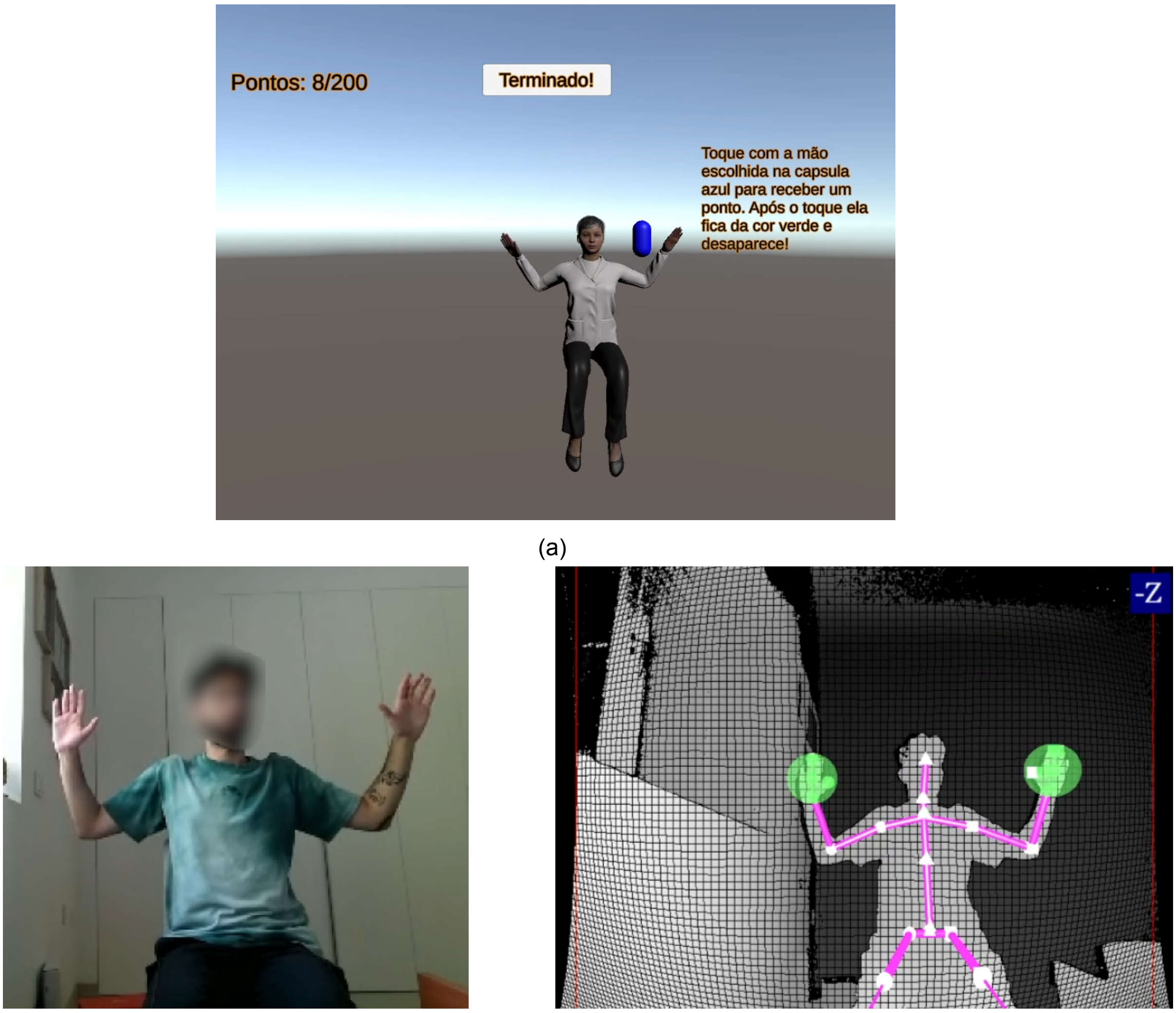
(a) (b)

Figure 6.2: Pose 2 - Elbows are bent at a 90-degree angle upward: (a) Kinect's exoskeleton position; (b) Human position.



(a) (b)

Figure 6.3: Pose 3 - Arm's Up: (a) Kinect's exoskeleton position; (b) Human position.



(a)

(b)

(c)

Figure 6.4: Pose 1 - Elbows are bent at a 90-degree angle upward: (a) Avatar position; (b) Human position; (c) Kinect's exoskeleton position.

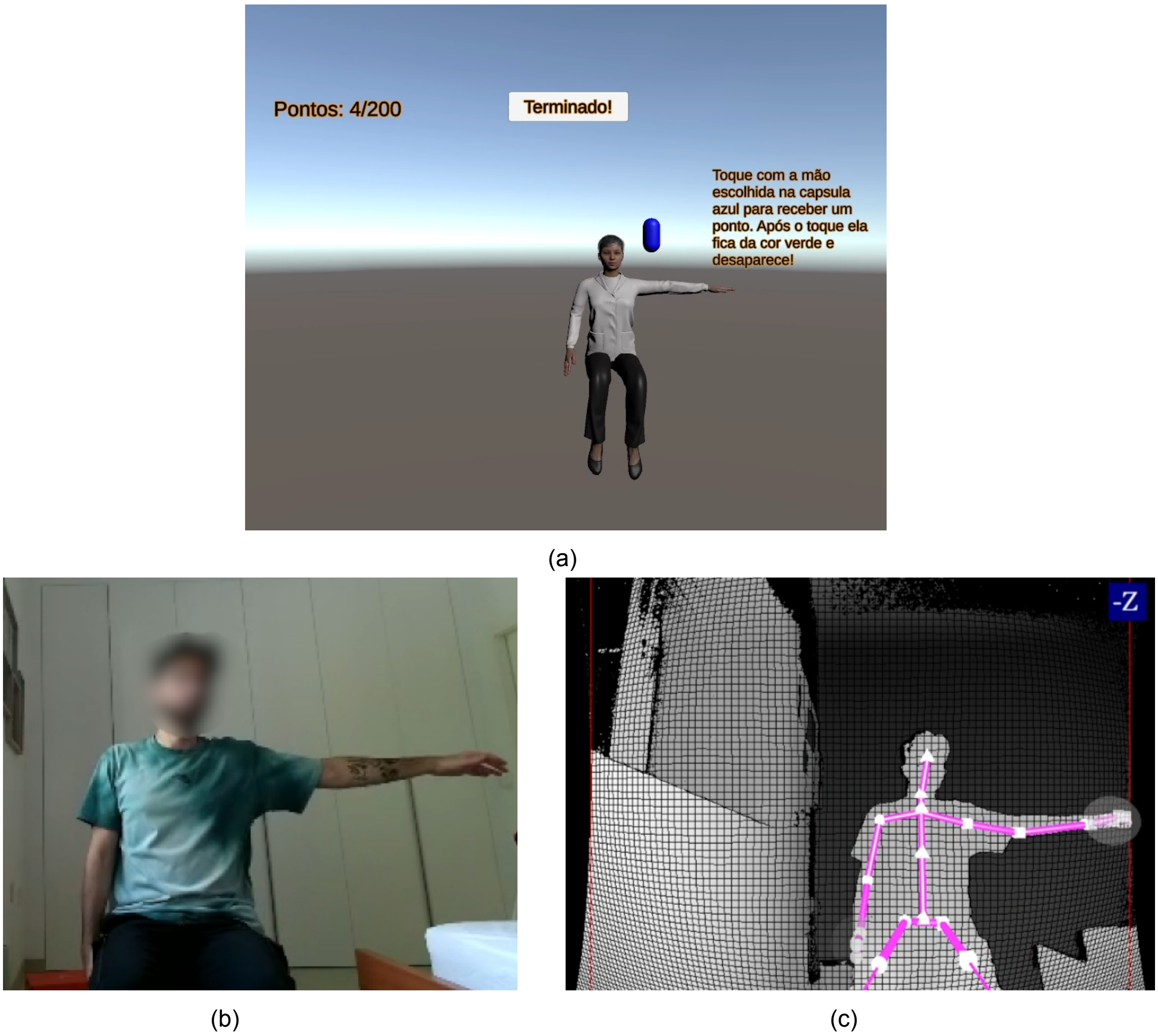


Figure 6.5: Pose 2 - Right arm up and left arm resting: (a) Avatar position; (b) Human position; (c) Kinect's exoskeleton position.

6.2. Therapist

For the therapist's section, the primary focus is on the therapist's interactions with the application, specifically in relation to data entry, error validation, data monitoring, and overall ease of use. To assess these aspects, a brief questionnaire was developed, administered after the person tested the application, consisting of the following questions:

- Is the application user-friendly and intuitive to use?
- Did any errors occur while using the application?
- What recommendations do you have for improving the application in the future?

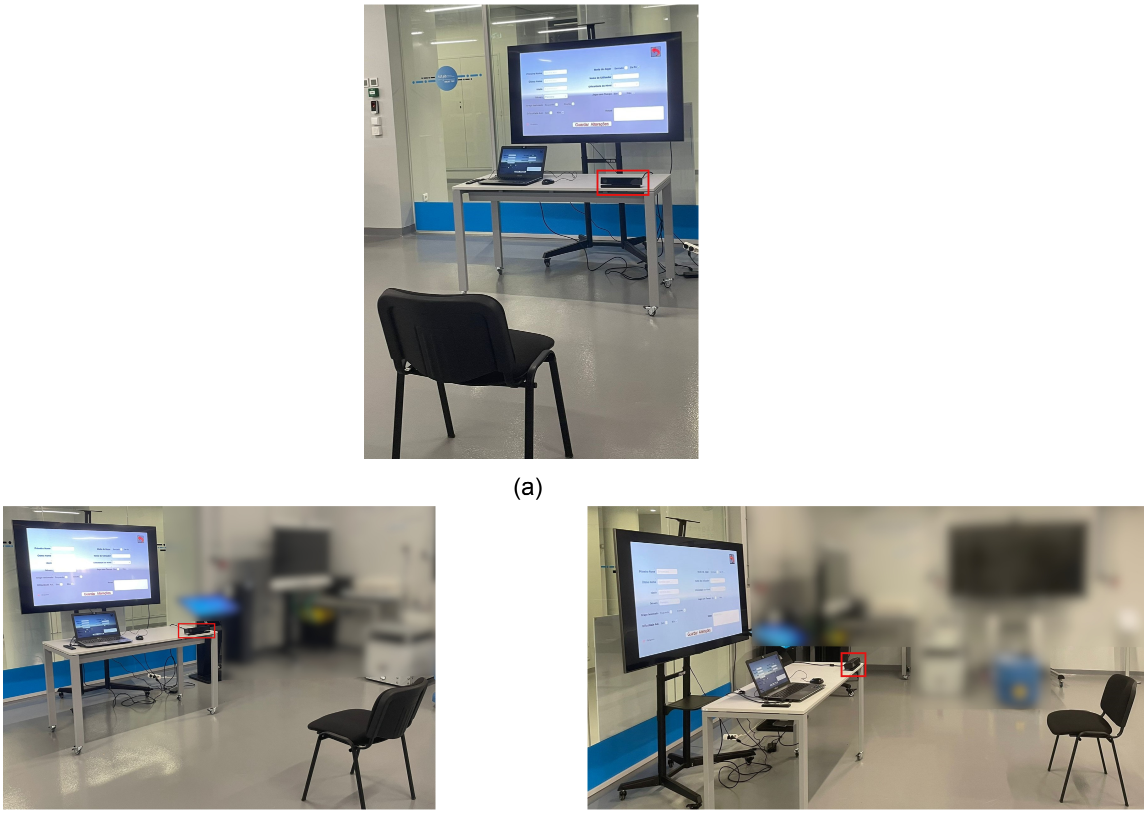
For this test, four individuals participated: three women and one man, with ages ranging from 19 to 55 years. All participants (100%) found the application to be easy and intuitive to use, and no errors were encountered while interacting with the game interface. One participant recommended enhancing the connection between the avatar and the user for a more immersive experience.

6.3. Patient

In the patient testing phase, it is important to consider the conditions under which the tests were conducted. All tests took place in a well-lit environment, with the patient either seated or standing 1.5 meters away from the Kinect v2 camera. The camera was positioned approximately 80 centimeters above the ground at the edge of a table, ensuring no objects obstructed its view, as shown in image x. This section will primarily focus on the gameplay experience, and to gather comprehensive feedback from the participants, each individual was asked to respond to the following questions after completing the session:

- **1**: On a scale from 0 (no familiarity) to 5 (a high level of familiarity), how familiar are you with using computer games?
- **2**: Have you ever used a virtual reality (VR) game?
- **3**: On a scale from 0 (not motivating) to 5 (very motivating), how motivating did you find the game?
- **4**: Do you think the difficulty settings were appropriate for any person?
- **5**: Did you encounter any errors/limitations while playing the game?

- **6**: What recommendations do you have for improving the gameplay in the future?



(a)

(b) (c)

Figure 6.6: Images of the environment where the tests were conducted, from three different angles (the red square is used to highlight the Kinect).

A test was conducted with 18 participants seated 1.5 meters from the Kinect camera, which was positioned at a height of 80 cm. Among the participants, the majority reported a high level of familiarity with computer games. On a scale of 0 to 5, twelve participants rated their familiarity as 5, one rated it as 4, one as 3, one as 2, and two as 1. Additionally, two-thirds of the participants had prior experience with virtual reality games. Approximately 77% of the participants rated the application as highly motivating, giving it a score of 4 or 5. The most critical feedback related to the visual environment, which was perceived as lacking in appeal, rather than the gameplay. All participants agreed that the application offers a versatile range of difficulty levels, suitable for a wide variety of users.

In terms of issues, four participants noted that the capsule's position was too far back, making it difficult to see clearly on the screen. One participant observed that after touching the object just before it disappeared, the object only turned green for a single frame and continued alternating between red and white, instead of remaining green. Another reported limitation was that, on occasion, the object spawned in the hand's zone, automatically awarding a point.

Several participants offered suggestions for improvement, including: increasing the number of games available, as most enjoyed the current game but desired additional options; introducing a friendly competition feature or a mode for two players to play simultaneously; displaying the level below the date in the general statistics section; and beautify the overall game design.

6.4. Limitations

The project presents several limitations. First, the requirement for the user to maintain a straight back poses a challenge, particularly for older individuals who may have spinal issues and are unable to keep their back completely straight. This limitation can negatively affect the avatar's interaction with the capsules. Additionally, due to the avatar's fixed back position, arm movements may appear unnatural when the arms are extended behind the body.

From a visual standpoint, the project lacks aesthetic appeal, making it somewhat difficult to perceive the depth of the capsules, which hinders the ability to determine whether they are near or far. A more defined visual environment, incorporating shadows and varied camera angles, could alleviate this issue.

Another limitation is the lack of a variety of games, which could impact the overall effectiveness of the application. Offering multiple game options would cater to different user preferences and prevent the experience from becoming monotonous. This variety could also extend the duration of rehabilitation, as patients may feel more motivated by having the ability to select from different games and engage in diverse activities.

Lastly, the randomness in the creation of capsules presents a potential issue. Capsules may occasionally appear within the patient's scoring area, resulting in automatic points being awarded without any movement. This undermines the reliability of the scoring system and statistics.

6.5. Summary

In conclusion, the majority of cases had positive outcomes, with participants reporting increased motivation and a stronger determination to continue rehabilitation with the assistance of the game. Furthermore, the ability to adjust certain features that influence the game's difficulty introduces two significant advantages: for more experienced players, reducing the capsule's lifespan and the game time makes the game more challenging, thereby maintaining their engagement. Conversely, for players encountering more difficulty, extending the capsule's lifespan and reducing the number of capsules simplifies the game, enabling them to achieve success and fostering motivation.

It is important to note that, in order to obtain more accurate and realistic results, future tests should primarily involve individuals undergoing stroke rehabilitation, or at the very least, those with a history of rehabilitation to provide a meaningful basis for comparison. Additionally, it would be essential to increase both the number of tests and participants to enhance the reliability of the findings.

7. Conclusion and Future Work

This chapter presents the conclusions derived from the topics explored throughout this project and outlines potential improvements that could enhance the project's effectiveness in achieving its defined objectives in the future.

7.1. Conclusion

In conclusion, this project integrated features required for a rehabilitation game designed for upper-body stroke recovery, demonstrating the potential to enhance patient motivation. By fostering increased motivation, the system may improve patient engagement in exercises, potentially contributing to a full recovery. By developing the game, we successfully enabled a humanoid avatar to replicate the movements performed by an individual, detected solely through a camera, within an engaging environment. The game features a points-based reward system, where the patient, upon visualizing the object on the screen, simply moves their arm to the designated area to earn points.

The research conducted throughout this project, both through the literature review and the evaluation of the game's functionality, supports the notion that gamified rehabilitation offers a compelling alternative to traditional methods. It reinforces the vision of a future where rehabilitation can become a more enjoyable and fulfilling experience for patients.

The use of cameras, such as Kinect, instead of VR headsets, has proven to be a cost-effective and practical solution. This approach is particularly beneficial for older patients who may struggle to adapt to VR systems, while still providing an experience that closely mirrors virtual reality. However, it is important to acknowledge that further refinements are necessary, and significant progress must be made before gamification in upper limb stroke rehabilitation can fully meet the needs of all patients in an affordable and accessible manner.

In summary, gamification offers a transformative approach to upper limb stroke rehabilitation by improving patient engagement and supporting the recovery process. As technological advancements continue, the integration of gamification into rehabilitation protocols holds the potential to revolutionize the field and enhance the quality of life for stroke survivors. Ongoing research and development in this area are essential to fully realize its potential in clinical practice.

7.2. Future Work

In the future, this program has the potential to serve as a strong foundation for addressing motivational challenges and increasing patient engagement in upper body rehabilitation exercises.

Transitioning the database to a server-based system, rather than a static one, could enhance competitiveness among patients across various rehabilitation centers or hospitals. This shift could foster a sense of community and motivation among players, driving better performance and engagement.

To strengthen the patient's connection to the game, the introduction of a customizable avatar that resembles the patient's physical appearance would be highly beneficial. This would allow the player to feel more immersed in the game, as the virtual reality experience would be enhanced by having a realistic representation of themselves while performing rehabilitation exercises. Additionally, including that avatar's face image in each patient's profile would assist therapists in easily identifying and selecting the correct profile for treatment. Furthermore, incorporating an option for the game to be available in English would significantly increase the application's accessibility to a larger number of people.

Upon account creation, data could be collected from the player's lateral arm lift to accurately capture the patient's range of motion. Beyond this, incorporating movements such as elbow flexion and circular arm motions could provide a more comprehensive understanding of the patient's capabilities, facilitating a faster and more effective recovery by tailoring exercises to their specific needs.

Lastly, developing additional games would offer patients a wider variety of choices, increasing their desire to participate. A potential improvement for the development of a new game could involve utilizing the existing one and adapting it to more realistic environments, such as simulating the action of picking apples from a tree. By designing games that target specific areas of the arm, the rehabilitation process could be further optimized, potentially accelerating the patient's recovery.

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