FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

A serious game for older adults' well-being: An Innovative Approach

Igor Monteiro de Andrade

Mestrado em Engenharia Informática e Computação

Supervisor: Doutora Eliana Silva

Second Supervisor: Professor Doutor Luís Reis

July 24, 2026

A serious game for older adults' well-being: An Innovative Approach

Igor Monteiro de Andrade

Mestrado em Engenharia Informática e Computação

Approved in oral examination by the committee:

President: Professor Letícia Seixas Pereira
Examiner: Professor Rogério Silva
Supervisor: Doctor Eliana Silva

July 24, 2026

Resumo

O envelhecimento da população mundial está a tornar-se uma preocupação cada vez maior. Tendo isso em conta, é necessário desenvolver uma estratégia para assegurar o bem-estar dos adultos mais velhos. Jogos sérios representam uma abordagem promisora que combina entretenimento com atividades que podem contribuir para o estímulo cognitivo, o bem-estar emocional e o envolvimento contínuo.

Esta dissertação foi desenvolvida em colaboração com a Universidade Lusíada-Porto e baseia-se no modelo PERMA de Seligman, focado-se principalmente em duas dimensões, Emoção Positiva e Envolvimento. Esta dissertação apresenta o projeto, desenvolvimento e avaliação de um jogo sério com o objetivo de promover o bem-estar de adultos mais velhos. O jogo foi desenvolvido na plataforma Unity e contém vários minijogos inspirados em atividades associadas ao bem-estar positivo, incluindo jardinagem, música e organização de pensamentos. Para projetar o jogo com a população-alvo em mente, foi realizada uma revisão sistemática centrada em jogos sérios para adultos mais velhos.

O jogo sério desenvolvido foi avaliado com a população-alvo, onde os adultos mais velhos participaram em sessões de jogo na qual completaram todos os minijogos implementados antes de avaliarem a aplicação utilizando questionários como o System Usability Scale (SUS), o Intrinsic Motivation Inventory (IMI) e o User Satisfaction Evaluation Questionnaire (USEQ), complementados por notas observacionais qualitativas sobre as interações dos participantes com a applicação, recolhidas durante a utilização do jogo.

Os resultados obtidos indicaram que o jogo desenvolvido foi recebido positivamente e registou nível satisfatórios de satisfação e de diversão por parte dos utilizadores. Os resultados também revelaram vários desafios em termos de usabilidade, particularmente em relação à compreensão de certas mecânicas do jogo. Os dados observacionais recolhidos demonstraram ainda mais a importância de instruções claras, interações e interfaces simplificadas especificamente adaptadas a adultos mais velhos com diferentes níveis de experiencia tecnológica. Esta avaliação reforçou ainda mais a importância de testar a aplicação com a população-alvo.

Esta dissertação demonstra a viabilidade de usar jogos sérios como intervenções digitais para promover o bem-estar de adultos mais velhos, identificando várias oportunidades para melhorias futuras. O jogo foi desenvolvido com o intuito de complementar estratégias de bem-estar existentes sem as substituir. Os resultados contribuem para a pesquisa na area de jogos serios acessíveis e fornece orientação no projeto de intervenções digitais com o objetivo de promover envelhecimento saudável e ativo.

Palavras-chave: Jogos sérios • Bem-estar • Adultos mais velhos • PERMA • Usabilidade • Acessibilidade

Abstract

The aging of the global population is becoming an increasingly worrying concern. Knowing this, a strategy must be developed to ensure the well-being of older adults. Serious games represent a promising approach by combining entertainment with activities that may support cognitive stimulation, emotional well-being, and continued engagement.

This dissertation was developed in collaboration with Lusíada-Porto University and is guided on Seligman's PERMA model, focusing in two main dimensions, Positive Emotion and Engagement. This dissertation presents the design, development and evaluation of a serious game intended to promote the well-being of older adults. The game was developed in the Unity game engine and contains multiple minigames inspired activities associated with positive well-being, including gardening, music, and thought regulation. In order to design the game with the target population in mind, a systematic review was also conducted focusing in serious games for older adults.

The serious game developed was evaluated with the target population, where the older adults participated in gameplay sessions in which they completed all implemented minigames before evaluating the application using questionnaires such as System Usability Scale (SUS), Intrinsic Motivation Inventory (IMI) and User Satisfaction Evaluation Questionnaire (USEQ), complemented by qualitative observational notes regarding participants' interaction with the application, collected during gameplay.

The evaluation results obtained indicated that the developed game was received positively and reported satisfactory levels of user satisfaction and enjoyment. The results also presented various usability challenges, particularly regarding the understanding of certain game mechanics. The observational data collected further highlighted the importance of clear instructions, simplified interactions and interfaces specifically adapted to older adults with varying levels of technological experience. This evaluation session further reinforced the importance of the testing the application with the target population.

This dissertation demonstrates the feasibility of using serious games as digital interventions to support older adults' well-being while identifying several opportunities for future improvements. The game developed aims to complement existing well-being strategies without replacing them. The findings contribute to the research in the accessible serious games area and provides guidance in the design of digital interventions aimed at promoting healthy and active aging.

Keywords: Serious games • Well-being • Older Adults • PERMA • Usability • Accessibility

The United Nations Sustainable Development Goals

The United Nations Sustainable Development Goals (SDG) provide a global framework adopted in 2015 as a part of the 2030 Agenda for Sustainable Development. It aims to achieve a better and more sustainable future for all.

The framework defines seventeen goals (https://sdgs.un.org/goals), addressing the world's most pressing challenges faced by societies worldwide, including poverty, inequality, climate change, environmental degradation, peace, and justice.

Although this dissertation focuses on the development of a serious game for older adults, the project still contributes to some of the goals from this framework, with these being:

SDG 3 Ensure healthy lives and promote well-being for all at all ages.

With the rapid aging of the human population and the increased declines of psychological well-being related to aspects such as social isolation and reduced leisure activities, the development of a serious game to promote well-being for this demographic contributes toward the promotion of this goal. Furthermore, with the exploration done via the systematic review, this project adopted design choices that make the serious game suitable for older adults with varying levels of technological experience, along with providing solid findings that could be used in future work in this area.

SDG 10 Reduce inequality within and among countries.

In a world that is rapidly evolving toward digital technologies, older adults tend to be left being, resulting in limited access to digital services due to their lack of technological knowledge. This project was specifically designed with older adults in mind, resulting in a serious games that focused on the needs of the older adults, with particular attention to accessibility and usability considerations. This reduces the technological barriers and support participation by individuals with limited gaming or digital experience, allowing all ages to be able to use the game, indirectly contributing to the reduction of age-related inequalities in access to digital technologies.

The following table synthesizes the Sustainable Development Goals that this project contributes to, along with the specific targets achieved. It also includes how exactly this targets are met and indicates what performance indicators and metrics can reflect this contribution.

SDG	Target	Contribution	Performance Indicators and Metrics
3	3.4	The development of a serious game for promoting well-being in older adults creates a serious game that provides general mental well-being support for older adults, such as mood, engagement and enjoyment	Increase in user engagement, satisfaction, and perceived usability of the serious game as an indicator of improved well-being experience among older adults
10	10.2	The development of a serious game for promoting well-being specifically for older adults encourages the participation of older adults in digital culture while being inclusive to participation regardless of age	Increase in perceived accessibility and equal participation in the serious game experience across older adult users, indicating improved digital inclusion
	10.3	Developing of a serious game for promoting well-being for older adults requires the need for accessible game design, which ensures equal opportunity for all the possible players, allowing age-friendly digital inclusion	Reduction in differences in usability and engagement outcomes across users with varying digital skills and abilities, indicating more equitable user experience

Acknowledgements

The completion of this dissertation would not have been possible without the support and guidance of several people, to whom I would like to express my sincere gratitude.

First and foremost, I would like to thank my supervisors for the opportunity to undertake this project and for the continuous guidance, encouragement and valuable feedback provided throughout the development of this dissertation. Their support, patience and expertise made the completion of this dissertation possible.

I would also like to express my gratitude to the PhD researcher collaborating on this project, whose guidance, availability and valuable discussions throughout the design and development of the game were greatly appreciated. Their support was instrumental in the completion of this dissertation.

To my family and friends, thank you for the constant encouragement, understanding, and support throughout my academic journey. Their confidence in me was the single most important source of motivation during the completion of this dissertation. A special thank you to my girlfriend, who helped me organize myself and encouraged me when I thought I would not be able to complete this dissertation, I wouldn't have been able to complete this dissertation without her.

Lastly, I would like to thank everyone who participated in the evaluation process of the serious game and took the time to either make the evaluations happen or directly participate and give feedback. Their enthusiasm, patience, and valuable feedback were fundamental to this dissertation.

To everyone who was a part of this journey, directly or indirectly, thank you. Without your presence this journey wouldn't be possible.

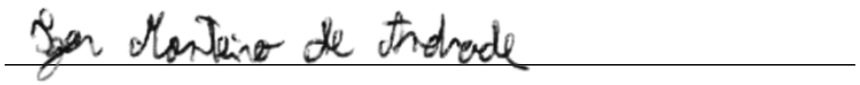
Igor Monteiro de Andrade

Declaração de Honra

Declaro que a presente dissertação é de minha autoria e não foi previamente apresentada e avaliada nesta ou em outra instituição. As referências a outros autores (afirmações, ideias, pensamentos), assim como a utilização de trabalhos publicados respeitam escrupulosamente as regras da atribuição, e encontram-se devidamente indicadas no texto e nas referências bibliográficas, de acordo com as normas de referenciação. Tenho consciência de que a prática de plágio ou de autoplágio constituem ilícitos académicos, conforme estabelecido no Código de Ética da U.Porto.

Declaro, ainda, que utilizei ferramentas de Inteligência Artificial para a realização de formalização de texto e ajuda na correção de erros de código na presente dissertação, e os seus resultados foram objeto de cuidada verificação para deteção de erros, imprecisões, atribuições infundadas ou outras formas de enviesamento de conteúdos e argumentos, bem como de determinação de autoria.

Igor Monteiro de Andrade



"We don't stop playing because we grow old; we grow old because we stop playing"

George Bernard Shaw

Contents

List of Figures

List of Tables

List of Acronyms

ADHD Attention Deficit Hyperactivity Disorder

GUI Game User Interface

IMI Intrinsic Motivation Inventory

MMORPG Massive Multiplayer Online Role-Playing Game

NA Not Applicable

PC Personal Computer

RCT Randomized Controlled Trial

SD Standard Deviation

SDG Sustainable Development Goals

SUS System Usability Scale

UI User Interface

URL Uniform Resource Locator

USEQ User Satisfaction Evaluation Questionnaire

Chapter 1

Introduction

1.1 Context

The aging of the human population is becoming an increasingly worrying concern. In some countries, such as Portugal, the situation is particularly alarming. According to Instituto Nacional de Estatística (INE) [1], the ratio between older adults (65 years and older) and the younger population (0 to 14 years) is continuously increasing. Data obtained from the Portuguese 2021 Censos [1] indicates that this ratio was 181 older adults for every 100 young people at the time, and, as of 2024, was estimated to be 192 older adults for every 100 young people [1]. The United Nations Population Fund [2] estimates that the number of adults over the age of 65 will double somewhere between 2024 and 2074.

Given this information, it becomes clear that some strategies must be developed to ensure the well-being of older adults. However, there appear to be few measures currently in place to address this. For other age groups and areas, such as the educational field, one method that has been gaining popularity and showing mostly positive results is the use of serious games [3]. The term serious game was first used in 1970 by Clark C. Abt in his book "Serious Games". According to Abt [4], serious games are games that have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for entertainment. They are designed to solve real-world problems, teach specific skills, or promote learning and behavioral change through game-based experiences.

1.2 Motivation

According to a systematic review, it is possible to conclude that very few games are developed in order to help the well-being of older adults [5].

This dissertation is framed in a PhD dissertation by the name of "Desenvolvimento de um Jogo Sério para Promover o Bem-Estar em Idosos baseado no Modelo PERMA" that has started being developed at Universidade Lusíada do Porto and current findings suggest that the creation of a serious game may contribute to improve their well-being, provided that the approach is correctly

adapted to the target population (older adults). This indicates that more research and development is required, leading us to the development of a serious game specifically designed for older adults, with this game being part of a project being developed in conjunction with the aforementioned dissertation. The creation of this game could lead to an increase in the adherence of the well-being treatment [6], reduction of depressing symptoms [7], cognitive stimulation [8] and accessibility and convenience [9].

1.3 Problem Identification

Based on the knowledge presented in the previous section, a problem arises. The well-being of the older adults is still an area that is not yet fully explored. Although there exist a current and successful strategy in other fields, which is serious games, to the best of our knowledge, very few have been implemented in this field yet. This reveals a research gap that can be addressed by developing a serious game that aims to enhance the well-being of older adults.

Aging is associated with changes not only to the body, but to the mind as well. Without adequate monitoring, aging can lead to social isolation and depression [10]. This dissertation aims to build upon previous findings in serious games, as well as existing studies on the well-being of older adults, to develop a serious game that tackles these challenges. The objective is to design a game that meets the needs and preferences of the target population while filling the gap currently present in this area of research.

1.4 Design Challenges and Considerations

Working with the older population is important for ensuring that the final product is aligned with their needs and capabilities. However, it also presents some challenges:

- The older population has little experience with technology, meaning that every interaction must be simple, intuitive and easy to make/replicate. The game should not rely on common knowledge and should be designed in the device most comfortable for this demographic;
- With aging, some health problems such as bad vision and poor hearing tend to appear. The game should therefore accommodate these conditions by implementing appropriate accessibility measures;
- Each person identifies different needs and preferences in this style of game, so identifying common themes through research is needed, to ensure that the final product is a compelling serious game that reaches the intended objective.

1.5 Research Questions

The challenges mentioned in 3.3 can then be simplified into the following research questions, which will guide the development of the product:

Q1: How do different types of interactions affect usability and engagement when designing a serious game for older adults?

Q2: Which accessibility features have the most positive impact in a serious game for older adults?

Q3: What gameplay mechanics are more effective at keeping engagement and improving the well-being of older adults?

Q4: Does device familiarity impact adoption and usability of serious games for older adults?

Q5: Can a serious game developed in this area improve the well-being of older adults?

Chapter 2

Theoretical Background

2.1 Serious Games

A serious game is a game, digital or physical, that was developed with the main purpose being educational, informative or training rather than entertainment. The first formalization of the term serious game was by Clark C. Abt, who defined serious games as games designed with explicit and carefully thought-out objectives. Serious games are created to achieve measurable outcomes, often related to learning, skill acquisition or health improvement [4].

The combination of game design and domain-specific knowledge represents the core of serious games. These take mechanics such as feedback systems, rewards, goals, rules and challenge for game design and intertwine them with tasks with a real-world benefits, such as improvement of cognitive abilities, teaching concepts and promoting behavioral change. This duality is recognized in the literature as a defining characteristic of serious games [3]. This addition of game mechanics make it so serious games can produce positive effects on engagement and learning when compared to more traditional approaches [3].

As mentioned before, serious games have a main purpose different from just entertainment, allowing them to be classified by said main purpose. Some common classifications are educational games, training simulations, health and rehabilitation games, awareness games and behavioral change games. Inside each classification there is the possibility to further divide them, such as in health related games, where they can be further subdivided into categories such as physical rehabilitation, cognitive training, mental health support and patient education. This diversity allows serious games to be adapted to different populations and goals, making them a versatile tool for intervention design [5]. For example, in educational contexts, a very well-known example is Minecraft Educational Edition, which is used in classrooms to teach multiple subjects such as programming, mathematics, chemistry and collaborative problem-solving. Studies such as Nebel, Schneider, and Rey [11] show that that game-based environments like the one mentioned can enhance engagement as well as support learning outcomes. Another situation where serious games can be applied is in training and simulation contexts, with a very known example being Microsoft

Flight Simulator. Even thought it was designed with entertainment as the main purpose, the realistic simulation it provided has been since used for pilot training and skill development [12].

2.2 Serious Games as Digital Health Interventions

Digital health interventions are using more and more digital technologies to achieve multiple objectives, such as health promotion, disease prevention, treatment and well-being. These technologies are varied and include mobile applications, web-based interventions, telehealth systems, wearable technologies and serious games [13]. From these, serious games have gained increasing attention due to their ability to deliver health-related interventions in an engaging and interactive way [14].

There are some very well-documented examples showing the effectiveness of serious games in Health contexts. One example of this is the serious game Re-Mission, which was developed to support young cancer patients by improving treatment adherence and knowledge about the disease. The game takes cancer-related tasks such as destroying cancer cells and incorporating them in the gameplay of the game, while teaching players about chemotherapy and immune responses, allowing them to better understand their condition. Studies by Kato et al. [15] showed that playing the game demonstrated an increased adherence to oral medication regiments, which resulted in improved health-related behaviors.

Another very well documented example is EndeavorRx, which is the first video game to be approved by the United States Food and Drug Administration as a treatment for Attention Deficit Hyperactivity Disorder (ADHD) [16]. In the clinical trials conducted by Kollins et al. [17] demonstrated significant improvements in the attention of children who used the game as part of their treatment.

Other than clinical outcomes, serious games can also contribute to to emotional well-being and quality of life. Studies such as the PhD dissertation this dissertation is framed in and the study by Abd-alrazaq et al. [18] show that serious games can positively influence mood, reduce stress, and increase overall well-being. However, other studies suggest that the success of the interventions depend on usability, accessibility and alignment with user needs [19].

Older adults represent a growing population for digital health interventions due to global population aging and the increasing demand for scalable solutions that support healthy aging. According to the World Health Organization, healthy aging is defined as the process of developing and maintaining functional ability that enables well-being in older age [20]. Regarding serious games in this context, some game-based interventions have been done and showed that they can contribute not only for clinical rehabilitation but also for promoting cognitive stimulation, emotional well-being, and social engagement [5]. As such, serious games are considered a promising approach to support both health-related outcomes and broader well-being in aging populations.

2.3 Accessibility and Usability Design for Older Adults

Designing any type of digital system for older adults requires taking into consideration the changes observed with age, such as changes in cognition, perception and motor abilities. These can present themselves in multiple ways, such as reduced visual sharpness, slower reaction times, memory limitations and lower familiarity with digital technologies, all of which can affect the user interaction and should guide the design of the technologies for this population from the beginning [21].

With that in mind, some researches have been made that highlight the importance of some design principles, such as large and readable text, simple and high contrast interfaces, simple navigation structures, clear instructions and lower cognitive load. These elements turn the experiences provided by the technologies more intuitive and inclusive, which reduces frustration and increases user confidence [22, 23].

Another important aspect of design of digital systems of older adults is ensuring that usability and accessibility are considered in relation to users' needs and capabilities, as highlighted in human-centered design literature [24]. User feedback is crucial in this process, as it allows a better understanding of usability challenges, preferences, and potential technological barriers experienced by the target population, particularly through co-design approaches that improve usability and acceptance [25]. In this dissertation, older adults were involved in a final evaluation phase to provide feedback on the developed system. This input is valuable for identifying areas for improvement and informing future iterations of the design, particularly in terms of usability, accessibility, and user acceptance.

For this dissertation, the principals that were just mentioned are fundamental, as the development of a serious game aimed at the improvement of the well-being of older adults requires understanding of game design and health interventions as well a strong focus on accessibility, usability, and user engagement.

Chapter 3

Systematic Review

Designing a serious game specifically for older adults comes with some challenges that most other games do not have to deal with. A serious game for older adults must take into account a lack of familiarity with new technologies and common standards of interaction, so it must be as simple as possible and be self explanatory. Furthermore, accessibility features like different font sizes, colour themes, and higher contrast options must also be present in order to make the game usable and enjoyable to the target demographic.

A systematic review of the current literature would then be helpful in obtaining information about current best practices and designs for this type of serious game, as well as the learnings from what could be improved regarding previous attempts in this area. The methodology for this systematic review follows the PRISMA guidelines

3.1 Objectives and Scope

This systematic review has the objective of finding not only the current best practices and designs, but also determining what game design elements where previously tried and determining their outcomes in the serious games for older adults area. Taking this into account, the results must be limited in some ways in order to find the best possible results for this application, so the inclusion criteria for selecting a study is the following:

1. Studies published in English.
2. Studies must specifically address games and older adults.
3. Studies must have game design information or findings about games for older adults or both.
4. Studies must have access to the respective full text.
5. Studies must use standard controls for the platform (controllers, keyboard and mouse or touch screen controls)
6. Studies must describe a digital game if a game is involved.

7. Studies must specifically address the well-being area.
8. Studies must be primary empirical research.

And the exclusion criteria would be the following:

1. Studies published in any language other than English.
2. Studies that do not address either games or older adults.
3. Studies that do not have neither game design information nor findings about games for older adults.
4. Studies that are locked to full text visualization.
5. Studies must not make use of non standard controls for the platform, such as virtual reality, augmented reality or sensor/motion controls
6. Studies must not describe board games or any other game that is not a digital game.
7. Studies that are in any other area than the well-being area.
8. Studies that are not primary empirical research (e.g., systematic reviews, literature reviews, meta-analyses, or mapping studies).

Every study that met all these criteria was reviewed and information was retrieved regarding these key features:

- **Usability:** What was used or suggested to be used in order to make apps more easily used by older adults and their outcomes.
- **Engagement Strategies:** What strategies did the studies make use or suggest to use to keep the end-user engaged and their outcomes.
- **Well-Being Strategies:** What strategies did the studies make use or suggest to use to enhance the older adults well-being and their outcomes.
- **Interaction type:** What interaction types like tap and drag were used or suggested to be used and their outcomes.
- **Platform:** What platform was the game developed in.
- **Core gameplay:** What does the game loop consist off.

3.2 Search methodology

In order to do the search, five databases were selected to be used, all of them being digital libraries, shown in Table 6.1. These databases were chosen because they provide access to publications in the areas of health, computer science, and human–computer interaction, which are the most important areas for this research.

PubMed was included due to its focus on biomedical and health-related research. IEEE Xplore and ACM Digital Library were selected because they contain a large number of publications in computer science, serious games, and human–computer interaction. Scopus was included as a large multidisciplinary database that allows broad literature coverage. Finally, ScienceDirect was selected for its collection of journals in health sciences, psychology, and technology.

Table 3.1: Databases with respective links

Database	**URL**
PubMed	https://pubmed.ncbi.nlm.nih.gov
IEEE Xplore	https://ieeexplore.ieee.org
ACM Digital Library	https://dl.acm.org
Scopus	https://www.scopus.com
ScienceDirect	https://www.sciencedirect.com

A query was designed with the intention of focusing on the inclusion parameters, so must be describing games, must involve older adults, must have information of game elements and must be related to mental health/well-being. Each of this sections is present in the query separated by the ANDs. It was then passed through two iterations, with the results of each iteration being analysed using the PubMed Library. PubMed was selected for this preliminary testing due to its comprehensive indexing of health-related literature and its advanced search functionalities, which facilitate the evaluation of search terms and result relevance. The first iteration is present here:

> ("serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population") AND (feedback OR "goal tracking" OR reward* OR "social interaction") AND (well-being OR "mental health")

This iteration presented few results, so broadening was necessary. The next iteration added one term in the game section and as well as two more terms in the design features. It also detected a possible problem with variation with United Kingdom English and United States English in the "aging population" term so the "ageing population" term was also added:

> (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population") AND (feedback OR "goal tracking" OR reward* OR "social interaction" OR GUI OR "user interface") AND (well-being OR "mental health")

This iteration appeared to have few results related to well-being/mental health, so that section was expanded with more terms resulting in the final iteration:

> (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population") AND (feedback OR "goal tracking" OR reward* OR "social interaction" OR GUI OR "user interface") AND (well-being OR "mental health" OR accomplishment OR meaning OR "positive emotion*")

Then, the same query was applied to each of the databases except for science direct which imposed a connector limiter so query was tweaked to fit the parameters by removing some less critical terms in each section and broadening the terms into concepts in order for more results to be present, resulting in this query:

> (games OR gamification) AND ("older adults" OR seniors) AND (feedback OR rewards OR "user interface") AND (well-being OR "mental health")

In each of the databases some filters were also applied, displayed in Table 3.2:

Table 3.2: Databases with what filters were applied

Database	**Filters**
PubMed	Language: English; Title/Abstract: (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population")
IEEE Xplore	Document Title OR Publication Title OR Abstract: (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population")
ACM Digital Library	Title AND Abstract: (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population")
Scopus	Language: English; Article AND Abstract: (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population")
ScienceDirect	Language: English; Title AND Title/abstract/keywords: (game* OR "serious game*" OR "digital game*" OR gamification OR "video game*" OR "video-game*" OR videogame*) AND ("older adult*" OR elderly OR senior* OR "aging population" OR "ageing population")

3.3 Data Extraction

In total, 398 results were found following this spread in the databases represented in Table 3.3, as well as with the percentages in figure B.3.

Table 3.3: Databases with number of results

Database	**Nº of studies**
PubMed	45
IEEE Xplore	30
ACM Digital Library	90
Scopus	173
ScienceDirect	60

From these the duplicates were removed, which represented 45 studies. Then the remaining 353 studies were screened based on their title and abstract, which excluded a total of 338 studies for not following the inclusion criteria mentioned in Section 3.1, leaving us with 15 studies. Most of the studies removed in this stage where removed due to not being related to mental health/well-being, with most of them being either related to exercise or cognitive ability. These 15 studies where read and assessed for eligibility and 5 more studies where removed, one for not being in English, two for not being related to the mental health/well-being area and two more for using non standard controls, one used virtual reality and the other used sensor controls. This process can be viewed in Figure 3.1.

After this selection of studies, Table 3.4 was built with the information collected according to what was said in the key features in Section 3.1.

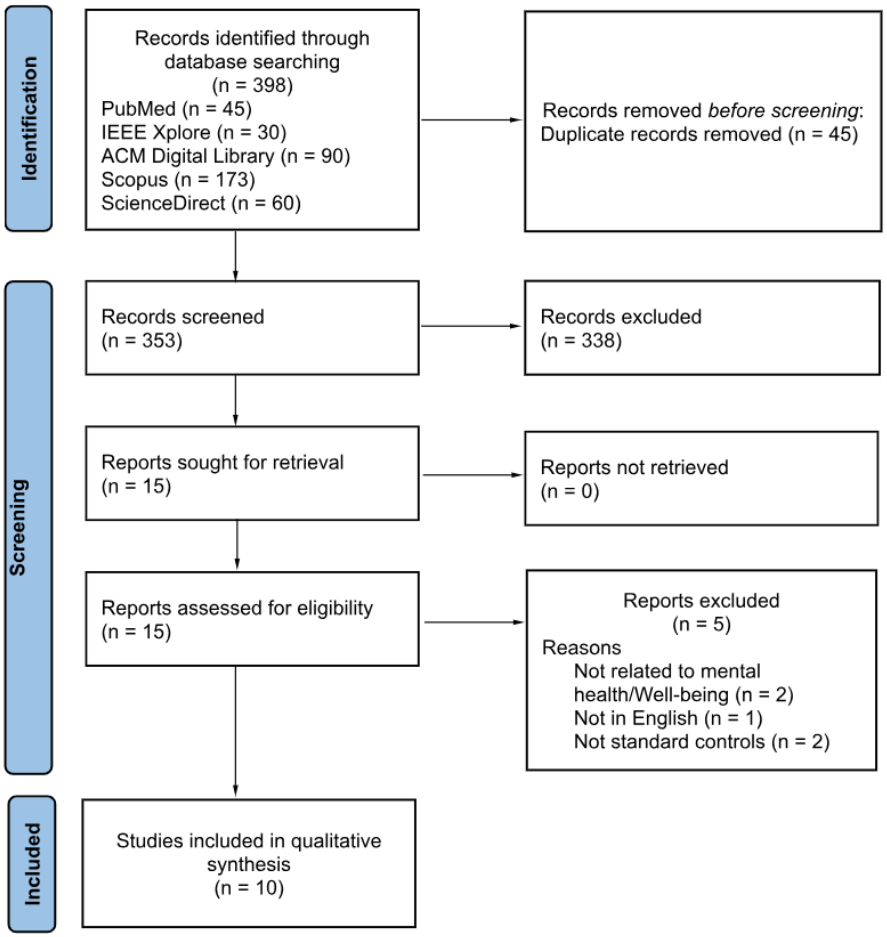


Figure 3.1: Flow diagram of review process

Table 3.4: Information collected about each study

Study	Game	Core gameplay	Platform	Co-design	Older Adults Age	Sample	Interaction	Engagement Methods	Wellness Activities	Usability Methods	Study Type	Usability Results	Clinical Effectiveness
Li and Chen [26]	*Custom Gobang Application*	Chinese game gobang	Mobile	6 older adults	65+	*N*=6	Tap, pinch	Self-improvement, small competitiveness, increasing difficulty, entertainment	Socialization, feeling of accomplishment, reminiscence due game choice (common Chinese game for demographic)	Simplified menu, game instruction, theme selection, font size selection, adjustable difficulty	User evaluation (pre-post usability study)	Elderly participants engaged with the game; design supported social and cognitive play	Suggested improvements in well-being, social interaction, and cognition, but not rigorously tested in an RCT
Janssen et al. [27]	*Playing Together (SamenSpelen)*	Party games with group chat and chatbot	Mobile	NA	65+	*N*=33	Tap, keyboard inputs	Small competitiveness, in-app socialization, entertainment	Socialization, reminiscence due game choices (common party games like hangman)	Chatbot game explanations, younger population in-app help	RCT	Low engagement and adherence; some enjoyed games but usability barriers (many steps, low retention)	No clear clinical effect measured due to low participation and adherence

Continued on next page

Table 3.4: Information collected about each study

Study	Game	Core gameplay	Platform	Co-design	Older Adults Age	Sample	Interaction	Engagement Methods	Wellness Activities	Usability Methods	Study Type	Usability Results	Clinical Effectiveness
Janssen et al. [28]	-	-	-	NA	50+	*N*=29	-	Challenge, diversity of games, entertainment	Socialization, feeling of accomplishment, trigger creativeness and knowledge	Simple rules and mechanics, native language of the user, large font size, high contrast, use of colors	Qualitative study (focus groups, interviews)	Need for intuitive, user-friendly social games enabling communication	Potential to improve social interaction; not clinically tested
Kolthoff, Spil, and Nguyen [29]	-	-	-	NA	65+	*N*=36 (older adults and young adults)	-	Entertainment, in-app socialization, short games, learning component	Socialization, reminiscence of some tasks	Simple to use	Usability study (experimental user evaluation)	Older adults were able to use the system with generally positive usability and interaction experience	No clinical outcomes assessed; focused on usability and interaction performance

Continued on next page

Table 3.4: Information collected about each study

Study	Game	Core gameplay	Platform	Co-design	Older Adults Age	Sample	Interaction	Engagement Methods	Wellness Activities	Usability Methods	Study Type	Usability Results	Clinical Effectiveness
Zhou et al. [30]	*Old Li*	Emotional challenging game with meaningful choices to the outcome of the story	PC	NA	50+	*N*=32	Click	Entertainment, narrative drive	Emotion driven narrative, reminiscence of past histories	No time limit on decisions, higher amount of hints in way-finding	Experimental user study (game play evaluation)	Older adults reported positive gameplay experience; meaningful choices increased autonomy satisfaction	No clinical outcomes assessed; improved psychological need satisfaction (autonomy, competence, relatedness)
Kaufman and Zhang [31] and Zhang and Kaufman [32]	*World of Warcraft*	MMORPG focused on leveling characters, looting better gear, and conquering raids with a guild	PC	NA	55+	*N*=222	Click, keyboard inputs	Progression, Social pressure	Socialization	UI Scaling, High Contrast	Cross-sectional survey	MMORPGs were generally usable for older adults; social interaction and guild participation were engaging and enjoyable	Enjoyment of relationships and quality of guild play were associated with lower loneliness and depression and higher social support; gameplay time alone had little impact

Continued on next page

Table 3.4: Information collected about each study

Study	Game	Core gameplay	Platform	Co-design	Older Adults Age	Sample	Interaction	Engagement Methods	Wellness Activities	Usability Methods	Study Type	Usability Results	Clinical Effectiveness
Ballesteros et al. [33]	*Lumosity*	Cognitive training games	PC	NA	57+	*N*=30	Click or keyboard input	Self-improvement	Feeling of accomplishment	Adaptive Difficulty, clean visual interface	RCT	Older adults successfully completed non-action video game training with good engagement	Video game training improved processing speed, attention, and visual memory and showed trends toward better wellbeing vs control
Palacio et al. [34]	-	-	-	NA	60+	*N*=794	-	Entertainment	Reminiscence of preferred leisure activities	Big font, simple indications with voice	Design/guideline development (qualitative)	Simple, age-appropriate interfaces improve engagement	No clinical outcomes; may support wellbeing indirectly
Châtel et al. [35]	*Playing Together (SamenSpelen)*	Party games with group chat and chatbot	Mobile	NA	65+	*N*=25 (older adults and young adults)	Tap, keyboard inputs	Small competitiveness, in-app socialization, entertainment	Socialization, reminiscence due game choices (common party games like hangman)	Chatbot game explanations, younger population in-app help	Feasibility / mixed-methods	Games childish, low retention	Inconclusive; high dropout, no clear effect on loneliness

3.4 Study Characteristics

Before the analysis of the studies and the results, a quick analysis on the study characteristics was done to contextualize the studies and the results that were obtained.

The studies analyzed in the review were published between 2012 and 2025, which indicates that research in the area of serious games for older adults well-being is still very recent and to this day still being developed. The earliest study was by Palacio et al. [34] in 2012 and the latest was by Zhou et al. [30] in 2025, but the biggest amount of studies falls after 2017, indicating growing interest in the area in the last decade.

Relative to the publication type of the studies, various types were identified, with these being journal articles, conference proceedings, and mixed-methods digital health publications. The focus of the sources (journals, conferences and publications) is also different between the studies, with some being published in sources focused in digital health and social well-being and others being published in sources focused in human–computer interaction and serious games, which shows the interdisciplinary nature of this topic, which combines health, usability and game design.

The area covered by these studies is also wide, covering multiple continents. There are studies focused in the older adult population of China [26, 30], the Netherlands [27–29, 35], Spain [33] and Mexico [34], as shown in figure 3.2. This diversity strengthens the relevance of the review, but also means that some cultural aspects and habits could have influences the outcomes observed in each study.

Finally, with this early information it is possible to understand where the information comes from and what could be some possible problems with the data retrieved. Understanding these characteristics is crucial to analyzing the outcomes of these studies, which will be discussed in the following result analysis.

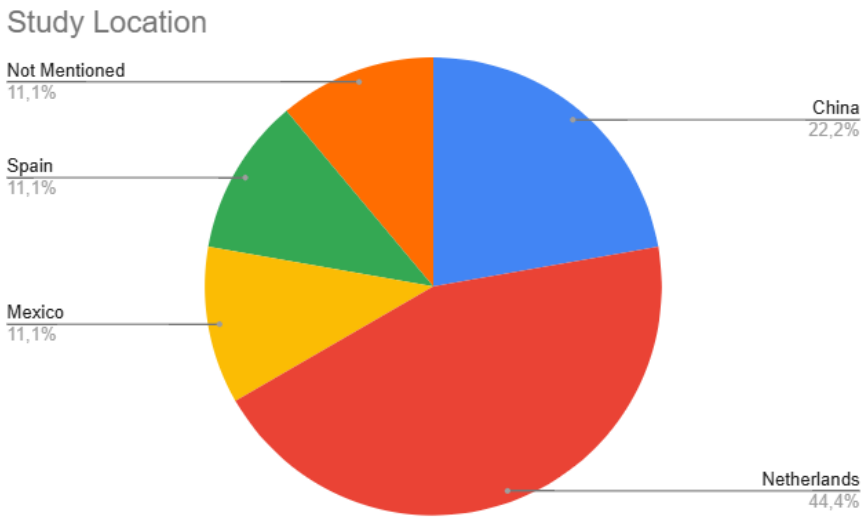


Figure 3.2: Graph with study locations

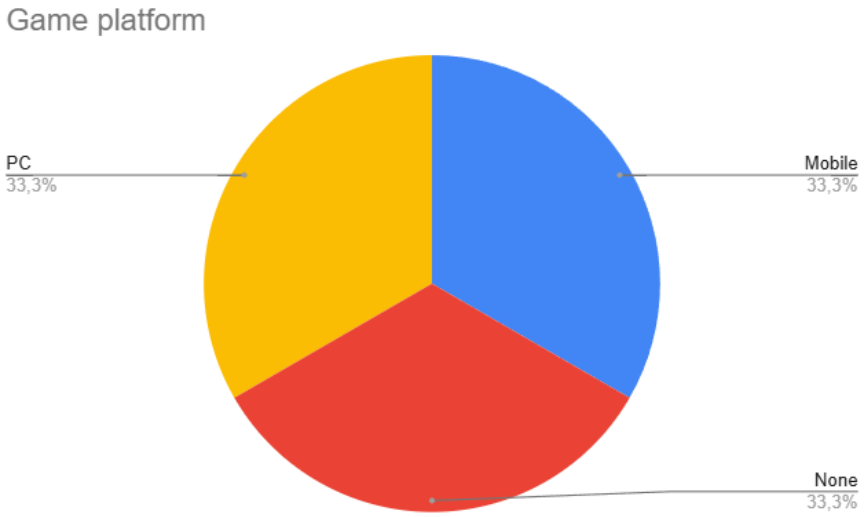


Figure 3.3: Graph with platforms used in the studies

3.5 Results Analysis

The studies included present different approaches of designing a serious game for older adults. As shown in Table 3.4, all studies are related to digital games to promote social interaction, cognitive stimulation, or emotional well-being. Due to the fact that the inclusion criteria chosen limited the studies included to being in the well-being area, the low amount of results further demonstrate that this area still needs more exploration in the future.

3.5.1 Game Platforms

Regarding platforms, mobile and PC were the systems chosen to be used as shown in figure 3.3. When comparing both platforms, mobile appears to have been the main platform chosen when the game being created specifically for older adults, with the exception of study [30] which used PC, probably due to the game used as the base benchmark also being on PC. This indicates that the familiarity of the player with the system as well as the accessibility of ownership of a mobile phone in current landscape is a very important factor in a serious game for older adults [26]. Mobile games also tend to have simpler interactions, such as touch input [26], while PC contained games with harder mechanics like World of Warcraft [31, 32], indicating that games created for mobile tend to be naturally simpler and more intuitive then games created for PC.

3.5.2 Interaction and Usability

Several interaction methods were able to be identified in these studies, but the prioritized interactions appear to be simple and familiar controls, such as tapping, clicking and keyboard inputs [27, 30]. This design choice reflects the need to reduce the technological barriers for older adults who tend to have less experience with this type of interfaces.

Multiple studies also mentioned and added accessibility features, such as large/adjustable fonts, high contrast interfaces, adjustable difficulty and simplified menus. As an example, [26] incorporated multiple of these aspects as well as other features such as theme selection in case of color blindness and game instructions for an easier understanding of the game. Some other accessibility features were mentioned were the importance of interface scaling as well as visual clarity in massive multiplayer games [31, 32].

Although user-centered design approaches were associated with better usability outcomes, small sample sizes and short interventions limit the analysis of long term effects of these features, which could end up hindering the usability, such as reluctance to engage in competitive features or changes in motivation [26, 35].

These findings align with the broader usability recommendations for older adults, where simplicity and readability are prioritized in order to keep engagement.

3.5.3 Engagement Strategies

From these studies multiple engagement mechanisms were identified, with these being:

- Self-improvement and progression systems [26, 31–33]
- Small competitive elements [26–28, 35]
- Social interaction with other players [27, 29, 31, 32, 35]
- Entertainment and casual gameplay [26–30, 34, 35]
- Emotional engagement [30]

Progression-based engagement is more common in large multiplayer games, such as in World of Warcraft [31, 32], which uses character progression, item collection and cooperative gameplay to motivate players for extended periods of time, proving to be a good way to maintain players on the game for the desired play session.

In contrast, mobile or casual serious games emphasise short sessions, entertainment and light competition, which may better fit daily routines of the older population, as well as trying to prevent addiction to these types of games [26, 27, 29].

Some studies also showed that multiplayer features did not always result in meaningful social interaction, mainly due to asynchronous game use and few simultaneous participation opportunities [27, 35]. This could possibly be improved if the player count increased but it is not reliable due to the target population being relatively small.

The findings relative to emotional engagement should also be interpreted cautiously, as the study [30] involved a younger segment of the older adults population, meaning the results could differ when compared to the results obtained using a older segmemt of the older adults population.

3.5.4 Wellness Activities

The studies reviewed promote well-being through different types of activities, such as socialization with other players, feelings of accomplishment, reminiscence through familiar activities and creative or knowledge-based challenges [26, 28].

The most reported well-being mechanism was social interaction, making use of either multiplayer or social media. For example, the exploration of the design [28] and creation [27] of serious games specifically meant to strengthen the social networks of older adults, showing that game-based communication features can support meaningful interaction.

Reminiscence was also applied in games that incorporate culturally familiar elements, such as traditional games. An example of such is present in study [26], which selected the traditional Chinese board game Gobang as the basis for their digital game, allowing participants to easily start playing as well as reconnect with a familiar activity from their past.

Progressive challenge and increasing difficulty were also identified as important factors in promoting feelings of competence and personal accomplishment, which may contribute positively to emotional well-being [30, 33].

3.5.5 Study Types and Evaluation Methods

There are multiple evaluation methodologies that were applied to the studies analysed, including:

- Usability Studies [26, 29, 30]
- Feasibility Studies [35]
- Qualitative Interview and Focus Groups [28, 34]
- Cross-Sectional Surveys [31, 32]
- Randomized Controlled Trials [27, 33]

Looking at the results highlighted by Table 3.4, many studies focused on usability or feasibility rather than clinical effectiveness [26–29, 34, 35]. Very few studies attempted to measure well-being outcomes using controlled experimental designs [33].

Several studies reported that social interaction features in digital games were associated with positive psychosocial outcomes among older adults, including reduced feelings of loneliness, greater perceived social support, and stronger social connectedness [26–28, 31, 32].

A limitation present in most studies is the absence of subsequent interventions, which limit the analysis of long term outcomes that would then translate into real-world benefits [28, 29, 34].

The results could also be influenced by participant characteristics, as several studies involved users which were already socially active, already with prior knowledge of technology or even games, which limits how general the findings are since it in part excludes the less experienced older adults [27, 31, 32, 35].

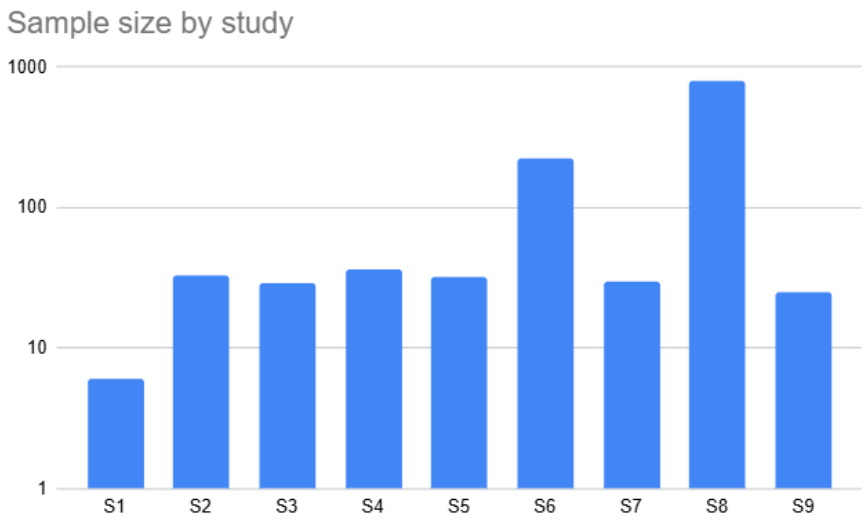


Figure 3.4: Graph with sample size per study

3.5.6 Clinical Effectiveness

While several studies suggest that digital games may positively influence well-being, the evidence presented is very lacking. Some studies do report qualitative improvements in social engagement or emotional well-being, such as increased enjoyment, greater motivation to participate in activities, enhanced social interaction, feelings of accomplishment, and reduced perceptions of loneliness or isolation [26–28, 32, 35], however many of these studies relied on participant interviews, focus groups, usability feedback, or self-reported satisfaction rather than standardized outcome measures [28–30, 34]. Only some studies used more structured quantitative assessments, such as measures of social connectedness, loneliness, usability, engagement, and perceived well-being [26, 27, 31, 32, 35], but even in these cases, the evaluations were often limited by small sample sizes (as shown in figure 3.4), short intervention periods or exploratory designs.

Overall, digital serious games do present some evidence that they could be beneficial for the well-being of older adults, but further research using robust experimental methodologies is required.

3.6 Results Discussion

This analysis highlights that, although serious games demonstrate some promising potential to support older adults well-being, there is still very few studies done that combine all the main design aspects considered beneficial in the literature. This became evident by looking at the results obtained in this systematic review, as most studies focused on isolated dimensions such as usability, socialization or emotional engagement, but few implemented all these elements into a single cohesive experience.

A pattern that emerges quickly is that positive outcomes are more consistent when the games are designed with the target population (older adults) in mind. Multiple techniques such as accessible interfaces, simple interaction methods, familiar mechanics and clear progression systems were frequently associated with better usability and higher satisfaction among participants [26, 28, 33, 34]. Additionally, studies that considered the users needs during development reported fewer issues in usability along with more positive engagement outcomes [26], which reinforces the importance of involving the target demographic in the design process of serious games, particularly through user feedback and evaluation activities, as these appear to align game mechanics better with the capabilities and expectations of the target demographic.

The importance of balancing challenges and difficulty was another relevant finding found in these studies. These suggest that a difficulty adjusted to the user along with progression systems can benefit the well-being of older adults by promoting feelings of accomplishment and competence [30, 33]. However, the challenge has to be adjusted to the capacity of each user and maybe even user-controlled, to accommodate the different cognitive, physical, and technological capabilities of the older adults, indicating that future interventions should have a method to control the difficulty to the capabilities of the user, either by automatically adjustable difficulty or user-controlled difficulty in order to avoid frustration or disengagement.

Another important factor showed by this analysis is that emotional and social dimensions are crucial to the effectiveness of serious games in this context. Several studies reported that recognizable scenarios, meaningful leisure activities and opportunities for reminiscence were associated with greater enjoyment and emotional engagement [26, 30, 34]. Similarly, socialization such as opportunities to communicate and relationship building were also consistently linked to reduced loneliness and a stronger feeling of connectedness [27, 31, 32, 35], but the studies also revealed that socialization features alone do not guarantee this, as poor multiplayer implementation and participation burden can lead to reduced engagement [27, 35]. This suggests that socialization mechanisms should be implemented in a way that feels natural, accessible and rewarding, as well as in a way that they are not required to be interacted with or proceed in the game.

Despite all of these promising findings, the state of the art remains limited in various ways. Many studies only made use of short-term interventions, small samples, qualitative feedback or participants who were already familiar with technology and socially active [26, 27, 31, 32, 35]. Some studies also presented valuable design recommendations but did not develop and test a game created with said recommendations [29, 34]. This results in limited evidence of how to effectively create a serious game that combines all of these areas into a single long-term serious game experience for older adults.

According to the patterns identified in this review, the most promising approach to the development of a serious game in this area is to develop the game alongside the target demographic combining strong usability support, short but engaging play sessions, meaningful and relatable activities, user-controlled progression and difficulty, and opportunities for social interaction. These aspects were consistently associated with better outcomes in the studies review and are identified as the main design principles that should guide the development of future serious games to

improve the well-being of older adults.

Some supplementary material with other information are also present in the annexes of chapter 3 (B.1).

Chapter 4

Technologies Used

4.1 Introduction to technologies

With the knowledge obtained in the systematic review, it becomes obvious that the technologies to be used to develop the serious game have to be chosen with the characteristics of the serious game in mind, such as game mechanics, user interfaces, accessibility features, deployment requirements and maintaining a manageable development scope.

The game was then decided to be made using the Unity game engine, with most of the assets used either being from the public domain or author-created, with some exceptions that require attribution. The choice of technologies was made taking into account the characteristics mentioned above as well as development efficiency, accessibility, platform support, cost and familiarity with the tools.

This chapter presents the technologies used during development and justifies their selection.

4.2 Unity Game Engine

Starting with the game engine, Unity was selected to be used in the development of the serious game. Unity is one of the most widely adopted game development platforms, supporting the creation of games for multiple platforms including computer, mobile devices, consoles and web environments.

Multiple factors led to the selection of Unity as the game engine for this project. First, Unity includes everything needed to create a serious game in itself, such as scene creation, user interface design, asset management, animation systems, audio management and scripting capabilities. This allows for a less complex development process as it completely removes the need to use multiple different software solutions for each step required.

Second, the programming language used in Unity is C#, which is a mature, object-oriented programming language, which in turn means that it has extensive documentation of how to use it as well as a large amount of community support. This allows for a easier development of the game itself, since any doubt is probably already answered somewhere on the internet. C# enabled the

implementation of game mechanics, user interactions and accessibility features while maintaining readable and maintainable code.

The third factor was familiarity with the engine. Previous experience with the game engine from other games developed in the past in Unity reduced the learning curve and allowed more time to be dedicated to the development of the game rather than the learning of the game engine. This is also considered beneficial as the main objective of this dissertation is to develop and evaluate a game rather than evaluate game engines.

Forth, Unity allows for quick prototyping due to its built in testing capabilities, which allow not only quick testing on the computer where the game is being created but on a mobile phone in real time, allowing easy spotting of errors and quick modification. This flexibility was valuable for refining game mechanics and interface elements designed for the target population.

Fifth and final, Since unity is one of the most used game engines, it is also one of the most used game engines for serious games. Due to this, learning resources, tutorials, community forums and technical documentation are readily available, which facilitates the development and problem solving in the creation of the serious game.

4.3 User Interface

The user interface was developed using a mixture of Unity's built-in UI systems and manually created click detection and assets. While the unity UI systems where used to create menus, texts, videos and buttons, manual click detection and assets where used in most interactions with the games themselves.

The Unity UI framework simplified the implementation of designs that are accessible to the target audience, which were identified during the systematic review. Examples include larger text sizes, high-contrast interface elements, and simplified navigation structures. The manually created assets allowed for some stylization of the games, but all of them keeping in mind the accessibility needs of the target audience, such as visual clarity and high-contrast.

Because the target population consisted of older adults, special attention was given to maintaining a clean interface with a limited number of simultaneous elements, as well as self-explanatory UI elements, in a way to reduce the amount of text each older adult needed to read. Unity's interface tools enabled the rapid adjustment of layouts, font sizes, spacing, and positioning throughout development.

4.4 Asset Integration

In order for the games to be more appealing, the project made use of graphical and audio assets obtained freely from online sources. These assets included user interface buttons (background and overlying image), background images, characters/environmental elements (trees, moles, flowers, boxes), images used in textures and in the games and music tracks.

The use of open access assets allowed more time to be spent on the development of the game itself rather than on the development of the assets. This approach was also chosen due to limited amount of resources.

The assets selected were chosen in part by how much they matched the visual style of the game. The choice of each asset was also affected by its clarity, readability and visual simplicity, as these are crucial if they are a main part of the game, since they can impact the accessibility for the older adults.

All assets are open source, except for one which requires mention. All of the assets used were integrated into Unity using the engine's asset management system.

4.5 Advantages and Limitations of the technology

The technologies chosen provide some advantages, such as:

- **Development Efficiency:** Using only one program reduced the complexity presented by this project. Unity provided all the needed development tools which allowed implementation, testing and refinement to occur efficiently
- **Cost Effectiveness:** All of the technologies used are free of use, which means that no financial investment was needed. This was crucial for this project to be able to be made.
- **Accessibility Support:** Unity's UI tools as well as scene manager allowed quick implementation of the games in a accessible way for the target demographic. It also allowed quick adjustments based on usability considerations and design recommendations obtained through the literature review.
- **Scalability:** With the technologies chosen being minimal, expansion with other technologies is easily implemented in Unity. Additional mini games, accessibility settings, deployment platforms and gameplay systems can also be easily added.
- **Documentation:** Due to the popularity of the Unity engine, extensive documentation, other games and tutorials have been made by the community and allows for a quicker development of the game as well as easier debugging of code.

However, the technologies chosen also provide some limitations, such as:

- **Engine Overhead:** Since Unity is a general-purpose game engine, it includes multiple features that were not needed for this project, mean it can be more complex that what is needed for the project, as well as possibly slightly making performance of the game worse.
- **Asset Limitations:** Due to the need to use external freely available assets, the visual style of the game may not be consistent, as they were created by different artists with different art styles. It also limits the control over their design and customization when compared to assets created specifically for the project.

Chapter 5

Game Design and Requirements

With the findings obtained in the systematic review, the serious game was designed in a way that prioritized accessibility, simplicity, familiar interactions and activities associated with positive emotional experiences.

The systematic review highlighted that activities which promote feelings of accomplishment, emotional engagement, reminiscence and leisure activities are associated with positive well-being outcomes in older adults. It also highlighted the need to simplify the interactions and navigational structures of the games, in order to minimize the technological barrier present in older adults.

Finally, the decision was made to make the game a collection of minigames designed and integrated into a virtual environment. Each of the minigames represents different activities associated with positive psychological well-being.

This chapter display the decision making that went into the definition of the game, along with its requirements, design decision, gameplay structure and accessibility considerations.

5.1 Design Goals

There were five main design goals, these being:

- Game must contain activities associated with well-being
- Minimize the technological barriers
- Game must encourages engagement through short gameplay sessions, with total being around 15 min a day
- Provide feelings of accomplishment and progression
- Make the games accessible for older adults

These goals were derived from the systematic review as well as the needs of the PhD dissertation this dissertation is framed on and serverd as the foundation for all other design decisions

5.2 Functional Requirements

Regarding functional requirements, the game should:

- Allow players to access a village environment
- Allow players to access the minigames through the village environment
- Associate each minigame with a well-being theme
- Allow players to start minigames at any time
- Give clear instructions before gameplay begins
- Give visual feedback for successful actions
- Support interactions using simple touch-based controls

5.3 Non-Functional Requirements

Regarding non-functional requirements, the game should:

- Be easy to learn without prior gaming experience
- Use large and readable interface elements
- Minimize the number of interactions to perform tasks
- Minimize the amount of text present in the game
- Maintain short play sessions suitable for casual use
- Keep a consistent visual style across the minigames
- Run smoothly on commonly available hardware
- Avoid complex as well as fast mechanics

5.4 Game Concept

The final game adopts a village-like environment that acts as a central hub for the selection of the different minigames related to different well-being activities.

Upon entering the game, the player is presented with a title screen. When the "Começar" button is pushed, a information screen appear that quickly explains the objective of the game as well as a tutorial on how the village works. Upon clicking the button present in this page, the player is then presented with a small village containing five houses. Each house contains a unique minigame. This structure was selected because it is a very simple and intuitive way to navigate

multiple minigames while giving the freedom to the players by allowing them to choose which activity they wish to engage with.

The use of the village instead of a menu with all of the minigames allows for a more engaging and coherent experience. This environment also encourages exploration while maintaining the simplicity desired.

The village serves as the central area from which all gameplay activities can be accessed. Before each of the activities a tutorial of the minigame as well as a small explanatory video is presented to the user.

5.5 Well-Being Framework

The design of the games well-being framework was inspired by Seligman's PERMA model of well-being [36], which proposes that human well-being can be described through five dimensions: Positive Emotion, Engagement, Relationships, Meaning and Accomplishment.

The PhD dissertation this dissertation is framed on seeks to investigate the application of the PERMA framework to the development of serious games for older adults. However, due to the scope and time constraints of a Master's dissertation, it was not feasible to develop game mechanics that are capable of addressing all of the five dimensions of the desired model.

The project was then focused on implementing activities that primarily target three of the dimensions, with these being Positive Emotion, Engagement and some opportunities for Accomplishment.

Positive Emotion is promoted through activities designed to be enjoyable, relaxing and familiar. Gardening and Music have been consistently associated with enhanced psychological well-being and positive emotional experiences among older adults. Gardening has been linked to increased self-esteem, social engagement, life satisfaction, and overall well-being [37], while music-based activities have been shown to support emotional well-being and quality of life [38]. Furthermore, in this case music could be used as a trigger for reminiscence, if the songs chosen are familiar to older adults, with reminiscence evoking memories and positive emotions valuable for older adults [39]. Reminiscence-based interventions have also demonstrated benefits for psychological well-being, happiness, and life satisfaction [38, 39]. Therefore, gardening and music were selected for this project. Thought regulation was also explored, as it aligns naturally with the Positive Emotion dimension through its focus on fostering positive affect.

Engagement is addressed through the active participation of the player in the minigames, which requires attention, concentration and interaction. These minigames all maintain a level of challenge that is appropriate for the target population, which encourages the players to challenge themselves to beat the minigames.

Accomplishment is indirectly addressed by the game mainly due to the satisfaction of successfully completing each of the minigames, as well as the scoring system in some of the minigames. The challenging nature of the minigames also naturally increases the sense of accomplishment on successful game completion.

While the implementation of the other two dimensions, Relationships and Meaning, would also be possible, it would increase the complexity of the project to unachievable levels, as it could require the implementation of multiplayer systems or even a full narrative-driven experience, which would take much of the time needed for this project.

The implementation of the other two dimensions of the PERMA model could be a worthwhile exploration for future work on this project.

5.6 Gardening Activities

Two gardening-themed minigames were chosen to be implemented.

5.6.1 Gardening Whack-a-Mole

This minigame implements the traditional whack-a-mole video game but adds a gardening as the context of the game. The player is interacting with moles in order to protect his garden from the small animal. The player is expected to select the moles as they appear and reach the desired score before time runs out.

This game was chosen because of multiple factors, namely the simplicity of the interactions, the immediate feedback, the short play sessions and the feelings of accomplishment.

The interaction required just consists of a simple touch action on top of a mole, which makes it accessible for users with limited gaming experience.

5.6.2 Plant Matching

The second minigame in this theme requires players to match equal plants in order to get improved plants for their garden. This encourages observation and pattern recognition while maintaining the complexity of the game low.

The objective of this one is to provide a simple relaxing game that still challenges the player slightly, due to the necessity of beating it under the time constraint, while maintaining the gardening them.The interaction requires consists of a touch on each of the equal plants to join them.

Together, the two gardening minigames promote engagement through familiar and positive leisure activities.

5.7 Music Activities

Two music-themed minigames were chosen to be implemented.

5.7.1 Rhythm Matching

This minigame is inspired by rhythm games where players must interact with notes in the correct timing, such as Osu!.

The activity encourages concentration, timing and engagement with music while using a simple interaction model.

Visual cues guide players as to when they must touch the note and provide feedback after each touch.

5.7.2 Piano Playing

The second music minigame is inspired by rhythm games where players must interact with descending notes, such as Piano Tiles.

This activity promotes similar aspects to the Rhythm Matching activity, such as concentration, timing and engagement, while still using a simple interaction model.

The descending tiles along with the UI guide the player as to when and where to touch and hold on the screen, with the UI providing feedback when the player is executing the action correctly.

5.8 Thought Regulation Activities

5.8.1 Thought Sorting

The final activity focuses on organization of common thoughts. Players are presented with images representing common occurrences of daily situations of older adults, such as a call from the grandson. The player must then classify each thought as a thought to keep or to discard and sort them into the correct box.

The objective of this minigame is to encourage reflection on common situations and improve emotion regulation for the emotions originated from said situations.

Unlike the other activities which focus primarily on leisure and engagement, this activity directly targets emotional awareness and self-regulation.

The interactions consist one again of two touches one to chose the image and another to chose the box desired. There is also visual feedback when a choice deemed correct is chosen.

5.9 Accessibility Considerations

Accessibility was one of the main considerations while working on the design of the game.

From the systematic review multiple design principles were adopted to be applied in the serious game:

- Large interface elements
- Clear visual hierarchy
- Simple navigation
- Consistent interaction patterns

- Immediate feedback
- Minimize text when possible
- Short activity duration
- Simple and intuitive gameplay mechanics

These principles aim to reduce frustration and improve usability for older adults whether they have prior experience with digital games or not.

Chapter 6

Development and Implementation

This chapter will go over the implementation of the serious game presented in Chapter 5. The game was developed using the Unity game engine as mentioned and presents a village as the environment, in which each house contains a minigame designed to promote different aspects of older adults well-being.

The implementation focused on accessibility, simplicity and ease of navigation, all while integrating activities inspired by PERMA framework. This chapter presents the development environment, software architecture, implementation of the village hub, implementation of each minigame and the respective second variant, and accessibility features incorporated into the final prototype.

6.1 Development Environment

6.1.1 Unity Game Engine

The game was developed using Unity 6.3. Unity was selected due to its flexibility, extensive documentation, rapid prototyping capabilities, and previous experience with the platform, as mentioned in the last chapter.

Using a familiar development environment reduced the learning curve associated with the implementation of the serious game, which allowed focus to be directed to the gameplay design as well as usability considerations. Unity's component-based architecture also allowed the implementation of reusable gameplay systems and user interface elements.

The project was implemented using C# scripts integrated within Unity's development environment.

6.1.2 Asset Integration

All the assets used in the game where either created specifically for this game or obtained freely from online repositories and imported into Unity through the Asset Management system.

The assets created included:

- User interface icons;

- Environment decorations;
- Functional environment elements;
- Visual feedback effects.

While assets obtained included:

- User interface icons;
- Environment decorations;
- Functional environment elements;
- Images for materials/backgrounds;
- Minigame music.

Even though the elements originated from different sources, an effort was made to ensure some visual consistency throughout the game.

6.2 System and Application Architecture

The implementation follows a component-Based architecture with layered responsibilities and event-Driven communication designed around player interactions. Rather than handling user input directly within each minigame script, the interaction process is divided into multiple stages responsible for detecting, interpreting, and processing player actions.

represents the overall software architecture of the developed game. It is divided into three primary layers, these being the interaction layer, the gameplay layer and the support systems layer. The interaction layer is responsible for detecting and interpreting player actions, the gameplay layer is responsible for implementing the logic in each game and the support systems layer provides reusable functionality shares between activities.

This allows code reuse between minigames which allows for quicker development, which was crucial for the limited time frame. It also allows for improved maintainability due to reducing coupling between gameplay logic and common systems, facilitating future expansions.

6.2.1 Interaction Layer

The first layer is responsible for detecting player interactions within the game environment and processing them.

The first stage uses raycast collisions to identify which element in the scene player wants to interact with and, if it is a functional element, sends the information to the next processing stage.

The next processing stage of this layer receives the information obtained from the raycast system and calls the correct function in the game script.

After an object is detected, this stage determines the information required from said object and passes it to the correct function within the next layer. Different types of clicks may lead to different functions being called depending on the current minigame.

The purpose of this layer is to provide a mechanism for identifying user interactions and verifying if it is important to the game in question. This separates the technical detection of interactions from the gameplay logic itself.

6.2.2 Gameplay Layer

The second layer contains the gameplay logic associated to each scene.

Each minigame as well as the central hub is implemented through a dedicated script, which is responsible for managing the various aspects of the game, such as game rules, progress tracking, score calculation, win and loss conditions as management of player feedback.

Some scenes such as the tutorials and the initial menu only contain UI elements, where the interaction detection is made by Unity already, so these scenes only contain the gameplay layer, responsible for performing actions based on the button clicks of the users.

By separating gameplay logic from interaction handling, modifications to one minigame can be performed without affecting the interaction systems.

6.2.3 Support Systems Layer

In addition to the layers mentioned above, some other support systems were developed to provide reusable functionality across multiple scenes and minigames, representing the final layer. These systems encapsulate some behaviors that would otherwise be duplicated throughout the project, persistent code designed to track progression of the user and data structures.

An example of one of these would be the beat controller. Rhythm based games make use of this component in order to synchronize gameplay with the song. This system generates a event based on the beat of the song on the desired frequency. These events are then used to either spawn a note or a tile depending on the minigame being played.

This event-driven approach improves modularity and allows rhythm logic to be centralized in a single component.

6.2.4 Application Architecture

The game follows a hub-based architecture centered around a village which represents as the game environment.

Upon start of the game, the player begins in the village, which acts as the central navigation area. From this location, players can choose one of the five houses to enter a minigame, with each house containing a different minigame.

The overall structure of the game is shown in figure 6.1

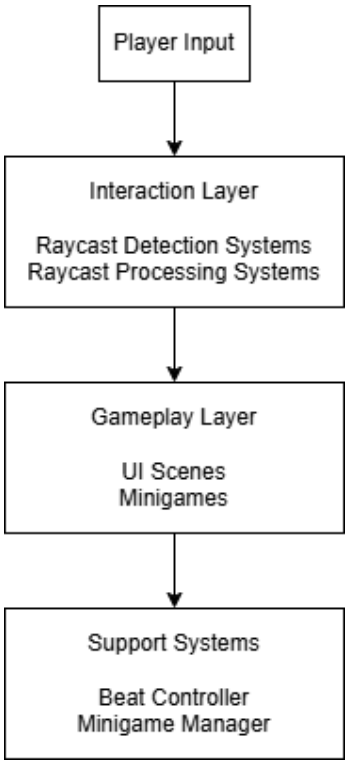


Figure 6.1: Architecture diagram of the serious game

This structure was chosen to allow the players to freely choose which minigame they want to take part in while maintaining a simple navigation model.

6.2.5 Scene Management

Each area of the game was implemented as an independent Unity scene.

The project contains the following scenes:

Table 6.1: Scenes with the respective purpose

Scene	**Purpose**
MainMenu	Initial game screen
Intro	Small explanation of the games objective and village tutorial
Village	Central navigation hub
Whack & Whack2	Gardening activity and respective variation
Plant	Gardening activity
Rhythm	Music activity
Piano	Music activity
Thought & Thought2	Thought regulation activity and respective variation
Tutorial	Tutorial screen for each minigame

The transition between scenes varies by scene. For UI only scenes it occurs when the player clicks the button to start or the back button, for the central hub it occurs when the player click one of the houses or the back button and for the game scenes it occurs when the game ends.

6.3 Game Implementation and Navigation

6.3.1 UI Scenes Implementation

The UI scenes function as connections to the village hub and to the minigames and can have multiple purposes.

The first UI scene presented is the main menu of the game, which allows the player to quit the game or start it. Once the player starts the game from the main menu, a second UI scene is presented to the player, this one explaining the objective of the game along with some instructions on how to interact with the village hub, which is the destination once the player click the "Começar" button.

Figure 6.2: Main menu of the game

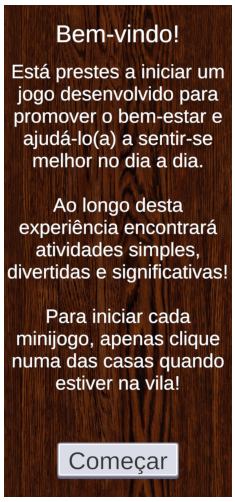


Figure 6.3: Introduction of the game

The final UI scenes are the tutorial screens. These appear before every minigame and contain the title of the minigame with a small explanation of the minigame. A small video is also presented to the player, indicating how to play the game, with the clicks made being visible within the video. Once the player clicks the "Começar" button the minigame starts.

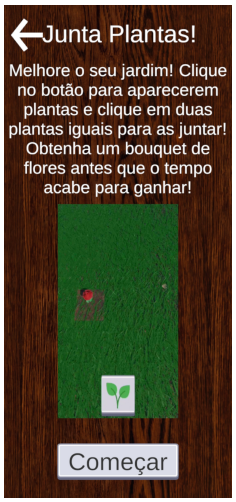


Figure 6.4: Tutorial of Plant Matching minigame

6.3.2 Village Hub Implementation

The village acts as the central element of the game, connecting all possible minigames in the game.

Players are presented with a depiction of a village with five houses. Each of the houses contains different a minigame that represents a different activity. Players can freely chose which minigame they want to play next by choosing the respective house, this being done by a simple tap on the desired house.

The village environment was chosen due to possibility for real world associations for the older adults. It also allows for an intuitive and easy to navigate structure which is was also a priority in order to reduce cognitive load as well as encouraging exploration of all the minigames.

The village layout is presented in figure 6.5

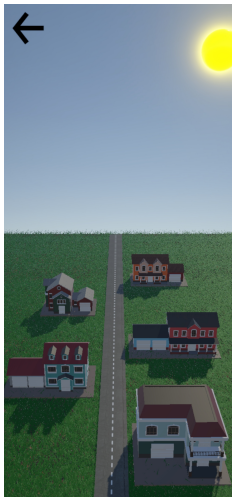


Figure 6.5: Village layout

6.3.3 Minigame Implementation

6.3.3.1 Whack-a-mole

The whack-a-mole minigame is the traditional whack-a-mole gameplay with a gardening background, as the player must eliminate the moles from their garden.

A mole appear at a random position in one of 5 holes present on the screen at random intervals that get shorter every time the mole appears. The player must select the moles by tapping them, with is done making use of raycast collisions.

However, the moles do not disappear, like in the traditional game, instead they stay on the board and the player must hit them for another one to be able to appear in that location. The player must hit 10 before the time runs out. This change was done in order to simplify the game to make it more accessible to older adults.

The implementation consists of multiple aspects. The first aspect is the spawn of the moles, that tracks which holes are currently occupied via a variable and selects a random hole from the remaining holes. It also tracks the time it takes for each mole to appear next time, as the initial time for each mole is a random number between two and five seconds, which is halved every time the mole goes down, with a minimum of 0.5 seconds.

Another aspect is the mole retreat. When a mole is hit by the player, it retreats with an animation of the mole going down, freeing the variable associated with that hole. When a mole retreats, a point is added to the player score.

The final aspect would be the win/lose detection. Time is tracked and presented in the player UI and in case the desired score is reached or the time runs out it displays the final screen to the player with the result of the game. The message on the lose screen varies with the amount of moles that where hit, encouraging the player to try again if he lost.

This minigame also contains a variation, where instead of moles, the player must click on foxes instead. The variations continuously switch between themselves when the player wins the minigame. The aim of this feature is to increase replayability

Figure 6.6: Whack-a-mole minigame

6.3.3.2 Plant Matching

The plant matching minigame requires players to connect identical plants in order to improve their garden.

By clicking the button on the bottom of the screen, the player spawns a new plant of tier 1 on the scene. The player must then spawn enough plants and join plants by selecting the plant they want to join of the same tier in order to progress. The join interaction selection is done by taping the desired plant and then the other desired plant, with the tap detection being done with raycast collisions, as taping and dragging could be considered a harder interaction system for the older adults. Joining a plant of the same tier generates a plant of the tier above of the plants joined.

The game ends when the player gets a plant to the third tier.

The plant spawns are determined by a list of available positions in a three by five grid and the plant is spawned in a random space from the list. Once spawned, the position is stored in a list of used positions and removed from the available positions.

Joining plants requires verification as to if the plants selected match in tier (in case they don't a reminder is presented to the player) and the joins are presented via an animation that moves one plant to the other, ending in removing both from the scene and spawning a new plant from the tier above in the place of the plants joined. The indication that a plant is selected is transmitted to the player by the plant gaining a yellow hue.

For win/lose detection the countdown presented to the player is used. If the countdown timer reaches zero the lose screen is presented and if the third tier is reached the win screen is presented. The message presented on the lose screen varies depending on the highest tier of plant achieved, encouraging the player to try again if he lost.

Another feature worth mentioning is the initial blinking of the spawn plants button. Before the player clicks the button to spawn a plant, the button blinks with a yellow color trying to attract the attention of the player to click it, in order to make the game more intuitive.

This minigame also contains a variation with a different type of plant. The variations continuously switch between themselves when the player wins the minigame. The aim of this feature is to increase replayability

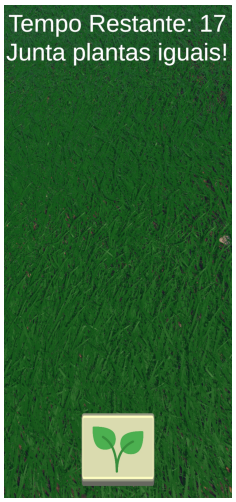


Figure 6.7: Plant Matching minigame

6.3.3.3 Play Piano

The play piano minigame is a rhythm based minigame inspired by commercial rhythm minigames such as piano tiles.

A tile spawns at the top of the screen in one of three lanes and move down toward three different buttons. The player must hold the corresponding button at the bottom of the screen once the tile passes through the button, gaining points.

To win the player must reach the score of 1800 points before the end of the song.

The minigame starts with a small countdown to give players a chance to get ready for the rhythm game, as these require an increased amount of concentration.

The first tile spawns in a random lane of the three possible lanes and the following tiles spawn in one of the two lanes that where not used by the previous tile. This is done by keeping track of the last lane used in a variable. Every tile spawns at every two beats of the song playing and the tiles are stretched to fit the two beat gap of the song making use of the song bpm, making it so that once on tile ends, the next one starts. To do this, a beat controller is used which calculates the time that the desired number of beats would take to be reproduced in the specific song knowing the bpm, separating the song into intervals that are used to then then call an event that spawns the next tile.

The player holding is detected via raycast collisions. If the raycast collision detects both the button and the tile, then it starts tracking the time both are being held. Once the player lets go of the button or the tile ends, the time is then compared to the size of the tile, which converted to time represents two beats as already mentioned. The maximum score of 100 points is obtained if the player hold the tile for 80% or more of the time the tile took to pass the button, and then reduces linearly down for any percentage lower than the 80%.

Whenever the button is being pressed while a tile is behind it, a glow around the button is present indicating that the player is doing the correct action.

The win/lose detection is simpler in this minigame compared to the previous ones, as the verification is simply done at the end of the song. If the score achieved by the player is above 1800 the win screen is shown, otherwise the lose screen is shown. The message on the lose screen varies depending on how close the player was to the goal, encouraging the player to try again if he lost.

The minigame also has a variant with a different song. The variations continuously switch between themselves when the player wins the minigame. The aim of this feature is to increase replayability.

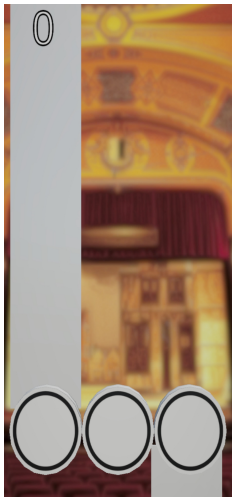


Figure 6.8: Play Piano minigame

6.3.3.4 Rhythmic Notes

The rhythmic notes minigame is a rhythm based minigame inspired another commercial rhythm minigame, OSU!.

A note spawns in a random location in a grid of five by nine. Each note has a circle around it and when the circle reduces to the size of the note the player must click the note, gaining points for doing so, with the touch being detected using raycast collisions.

To win the player must reach the score of 1800 points before the end of the song.

The minigame starts with a small countdown to give players a chance to get ready for the rhythm game, as these require an increased amount of concentration.

Each note spawns at every two beats of the song, making use of the same beat controller mentioned in the play piano minigame. The circle surrounding the note reduces and reaches the note after one beats time and continues to reduce for another beat until his scale reaches zero. The score is calculated when the player click the note by comparing the size of the note with the size of the circle. If the circle is within a 20% margin of the size of the note, either from being bigger or smaller, maximum points are awarded, these being 100. Any bigger or smaller the points scale linearly down. The notes disappear if not clicked within the two beat window, resulting in no points gained by the player.

The win/lose detection as simple as in the play piano minigame, as the verification is the same. If the score achieved by the player is above 1800 the win screen is shown, otherwise the lose screen is shown. The message on the lose screen varies depending on how close the player was to the goal, encouraging the player to try again if he lost.

Similar to the play piano minigame, this minigame also has a variant with a different song. The variations once again continuously switch between themselves when the player wins the minigame. The aim of this feature is to increase replayability.

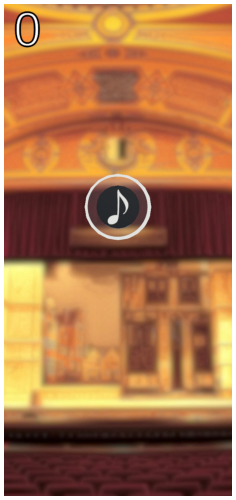


Figure 6.9: Rhythmic Notes minigame

6.3.3.5 Thought Sorting

The thought sorting minigame focuses on thought organization in order to deal with the emotions related with the thoughts presented.

The player is presented with six different thoughts represented by images and the player must insert the thought in either the "Guardar" (keep) or "Deixar ir" (let go) box. To insert a thought in a box the player must select the thought and then the box they want to insert it in. In case the player doesn't select the thoughts/box in the correct order, a hint is presented to the player. The selection is made by a touch that is detected using raycast collisions and indicated to the user by the thought gaining a yellow hue. A animation is played taking the thought to the box when both are selected.

If the selection made by the player is correct, the box lights up from the inside indicating a good choice. At the end the thoughts from each box are presented to the player showing them their choices, with an animation bringing the thoughts from out of the boxes.

This minigame does not have a win/lose screen nor a countdown as the objective of this minigame is to try to help the players deal with emotions and therefore allow the players to deal with them at their own pace and with no clear winning or losing conditions.

This game also contains a different variation, where instead of images the thoughts are presented by a small amount of text. The variations continuously switch between themselves when the player completes the minigame. The aim of this feature is to increase replayability.

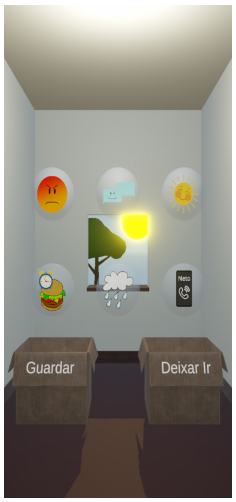


Figure 6.10: Thought Sorting minigame

6.3.4 Accessibility Features

Accessibility considerations were integrated throughout the development process, with multiple of them based on findings identified in the systematic review:

- **Large Interface Elements:** All buttons and interface elements were designed to be of large dimensions for readability and easier selection;
- **Clear Typography:** The fonts are kept as large as possible and with high-contrast color even with a different color outline when it improves readability;
- **Consistent Navigation:** All activities have the same navigation and menu structures;
- **Immediate Visual Feedback:** All correct user actions result in feedback, whether it being highlighting of object or an action happening to reinforce player actions;
- **Simplified Instructions:** Every minigame contains a short explanation describing the objective and controls, all minimizing the amount of text needed to read.

These measures aim to reduce technological barriers and improve usability for older adults.

6.3.5 Challenges Found

During the development of the game, several challenges emerged.

The first challenge found was related to visual consistency, as the assets where obtained from online archives, which resulted in some loss of visual consistency.

The second challenge was also related with assets, as some of the minigames required specific assets, such as the thought sorting minigame, which required a simple asset that could be easily readable at a distance and still convey the thought it is meant to represent, which resulted in the need to manually create some assets.

Another challenge present was the need to maintain the controls as simple as possible. While a user that regularly uses a mobile device can easily do most controls, a older adults with limited experience might struggle with more advanced controls, so an effort was made to keep the games with the simplest possible controls, the touch.

Finally, implementing the minigames so that they aligned with well-being principles while remaining engaging was also a challenge that actively guided the design of every one of the minigames present in this game.

Chapter 7

Evaluation Methodology

An evaluation to assess the usability and motivational qualities of the serious game was the following step. Given that the application was designed for older adults and aimed to promote well-being through multiple activities, it was important to evaluate both the user experience and the perceived enjoyment of the game.

To do so, the evaluation was conducted with members of the target demographic. This evaluation was mostly focused on evaluating usability and intrinsic motivation after direct interaction with the game.

7.1 Evaluation Design

A mixed-methods evaluation approach was used, collecting both quantitative and qualitative data.

Quantitative data was collected using standardized questionnaires while qualitative data, such as participants' behaviours, difficulties, and interactions with the game, was collected from observations recorded during the gameplay sessions.

The evaluation focused in usability, user satisfaction, intrinsic motivation and engagement. Usability was assessed using the System Usability Scale (SUS) adapted to Portuguese by Martins et al. [40], user experience was assessed using the User Satisfaction Evaluation Questionnaire (USEQ) adapted to Portuguese by Domingos et al. [41], and intrinsic motivation was assessed using the Intrinsic Motivation Inventory (IMI) adapted to Portuguese by Fonseca and Brito [42].

The evaluation process consisted of:

1: Sociodemographic questionnaire;

2: Gameplay session;

3: Post-test questionnaires (SUS, IMI and USEQ);

This design allowed the collection of measurable usability indicators as well as opinions regarding the developed application.

7.2 Participants

Prior to participation, all individuals received information regarding the objectives of the study, the evaluation procedure and the handling of collected data. Participation was voluntary and informed consent was signed by all participants before the beginning of the evaluation.

The study was approved by the Ethics Committee of the Faculty of Engineering of the University of Porto (FEUP), making sure it complied with institutional and ethical standards for research involving human participants.

The evaluation was conducted with older adults that represent the target audience of the serious game.

Participants were recruited through a senior center that agreed to collaborate with the study. Recruitment was conducted in accordance with ethical procedures approved for this dissertation.

The objective of conducting tests with the older adults was to assess the usability and motivational aspects of the game from the perspective of the intended users.

A total of six older adults participated in this study.

7.3 Evaluation Instruments

7.3.1 Sociodemographic Questionnaire

Before interacting with the game, each participant completed a short questionnaire that collected sociodemographic data.

This questionnaire included questions about gender, age, nationality, civil status, education level, level of technological ability and previous game experience.

This information was collected to characterize the participant sample and allow better interpretation of the results.

7.3.2 System Usability Scale

The System Usability Scale (SUS) was used to assess the perceived usability of the serious game.

SUS is a widely used questionnaire with ten items that evaluates the usability of interactive systems through a five-point Likert scale.

The instrument generates a score ranging from 0 to 100, with higher scores indicating better perceived usability. The result allowed identification of possible usability problems that could be of concern due to lack of technological knowledge.

SUS was selected due to its simplicity reliability and extensive use in the evaluation of software applications and serious games. The Portuguese translation of this instrument created by Martins et al. [40] was used.

7.3.3 Intrinsic Motivation Inventory

The Intrinsic Motivation Inventory (IMI) was used to assess the subjective experience of the participants while interacting with the serious game.

IMI evaluates multiple aspects of the user experience, such as interest, enjoyment, perceived competence, effort, importance, value, usefulness, pressure and tension.

The responses are provided through a five-point Likert scale and allows for an estimate of the motivational engagement of the participants with the activity.

IMI was selected because motivation and engagement are particularly relevant when evaluating serious games aimed at promoting well-being, as well as allowing a evaluation of the game's potential to foster voluntary and repeated interaction. The Portuguese translation of this instrument created by Fonseca and Brito [42] was used.

7.3.4 User Satisfaction Questionnaire

The User Satisfaction Evaluation Questionnaire (USEQ) was used to assess the satisfaction of the participants with the serious game.

USEQ is a short questionnaire designed to evaluate the subjective satisfaction of the participants when interacting with a digital system. It uses a five-point Likert scale that allows to capture the perception of the users regarding the quality of the interaction, ease of use and overall satisfaction.

USEQ was selected because user satisfaction is an important factor in the acceptance and continued use of serious games. Furthermore, measuring satisfaction complements the usability assessment provided by SUS and the motivational assessment provided by IMI, allowing for a broader understanding of the perception of the application from the participants.

The Portuguese translation of this instrument created by Domingos et al. [41] was used.

7.4 Evaluation Procedure

The evaluation of the game was conducted physically and individually for the older adults.

At the beginning of each session, participants received a brief explanation of the study objectives and were informed about the evaluation process.

Participants then fill out the sociodemographic questionnaire.

Afterwards, participants were asked to interact with the game. To ensure exposure to all implemented mechanics, participants were required to play each of the minigames contained in the serious game. No time limit was imposed during the gameplay. Participants were encouraged to explore the game at their pace and even explore the variations of the minigames if wanted.

Once the gameplay session was completed, participants were then asked to fill the SUS, IMI and USEQ questionnaires.

7.5 Data Analysis

The questionnaire responses were analyzed using descriptive statistical methods.

For the SUS questionnaire, individual scores were calculated according to the standard scoring procedure and converted into scores ranging from 0 to 100.

For the IMI questionnaire, the mean scores were calculated for each evaluated aspect.

For the USEQ, individual item scores were averaged to assess overall satisfaction.

Sociodemographic information was summarized using descriptive statistics.

Qualitative data obtained consisted of observational notes recorded during the evaluation sessions, including participants' difficulties, requests for clarification, spontaneous comments, and notable interaction behaviors while playing the game. These observations were subsequently reviewed to identify recurring patterns and usability issues that complemented the quantitative results obtained from the questionnaires.

The combination of quantitative and qualitative data provides a broader understanding of the usability and motivational characteristics of the developed serious game.

Chapter 8

Evaluation Results

This chapter presents the results obtained during the evaluation of the developed serious game. This evaluation was conducted with older adults that fit the criteria of this project, namely being aged over 65 years or older, capable of providing informed consent, and able to interact independently with the evaluation device. The participants played the game, completing each of the implemented minigames at least once, and answered a set of standardized questionnaires after completion of the game(see Chapter 7)

The participants played the game making use of a mobile phone provided to them by the research team. This way, the experience was equal to all users as the device used was the same for all participants.

The results presented in this chapter will follow the evaluation dimensions presented in Chapter 7, which are usability, user satisfaction, intrinsic motivation, and qualitative feedback.

8.1 Participant characterization

A total of 6 older adults participated in the evaluation of the serious game.

The participants age range was between 67 and 93 years, with a mean age 80.83 years with a standard deviation of 8.49 years. The participants were evenly split between female and male and all were Portuguese nationals. Four of the participants had completed education up to the first cycle of basic education, while the remaining two participants had completed education up to the second cycle of basic education.

Most participants reported interaction with technology, mostly mobile phones, but mostly only as a mean to make calls, with only two of the participants reporting they used the mobile phones for other purposes as well, mostly social media. Of those, only one reported having some mobile gaming experience.

8.2 System Usability Scale Results

The SUS questionnaire was used to evaluate the perceived usability of the developed game. The formula used to calculate the user scores was the following:

$$\text{SUS Score} = 2.5 \times \left[\sum_{i=1,3,5,7,9} (X_i - 1) + \sum_{j=2,4,6,8,10} (5 - Y_j) \right] \tag{8.1}$$

where:

- i and j correspond to the questionnaire item (question) numbers.
- X_i is the user's score for the odd-numbered question i.
- Y_j is the user's score for the even-numbered question j.

Table 8.1 shows the results obtained from the SUS questionnaire:

Participant	**SUS Score (0-100)**
P1	65
P2	60
P3	60
P4	45
P5	52.5
P6	85
Average	**61.25**
Standard Deviation (SD)	**12.40**

Table 8.1: SUS scores per participant, average and standard deviation

The reported mean SUS score of the participants was 61.25 with a standard deviation of 12.40. According to the standard SUS interpretation benchmark, this score indicates that the game falls within the marginal usability range, which means the system is usable but presents several usability challenges that may hinder optimal interaction.

The relatively high standard deviation suggests variability in the user experience, which is consistent with observational findings, indication differences in prior digital experiences.

These results suggest that while participants were able to complete the required tasks, improvements are necessary to increase clarity of interaction and reduce confusion during gameplay sessions.

8.3 Intrinsic Motivation Inventory Results

The IMI was used to evaluate participants' motivation regarding interacting with the game.

The questionnaire was analyzed according to its individual subscales, these being Interest/Enjoyment, Effort/Importance, Perceived Competence and Pressure/Tension, with each of the negatively worded items being reverse-scored before calculating the average value for each dimension. Since a five-point Likert scale was used, results are between 0-5.

Table 8.2 shows the results obtained from the IMI questionnaire:

Participant	Interest/ Enjoyment	Effort/ Importance	Perceived Competence	Pressure/ Tension
P1	3.8	2.75	3	2
P2	3.8	3.5	3.8	2
P3	4.4	3.5	3.8	1.75
P4	4	2.5	3.6	1.5
P5	4.6	2.75	3.6	1.5
P6	4	3.5	3.6	1.25
Average	**4.1**	**3.08**	**3.57**	**1.67**
SD	**0.3**	**0.42**	**0.27**	**0.28**

Table 8.2: IMI subscale scores per participant, subscale average and standard deviation

For Interest/Enjoyment, the mean of all participants was 4.1 with a standard deviation of 0.3, which corresponds to a high score, which suggests that the participants generally enjoyed the game and found it engaging. This finding aligns with the comments made by the participants during the evaluation sessions, some of which expressed appreciation for the game's music as well as theme.

Regarding Effort/Importance, the mean of all participants was 3.08 with a standard deviation of 0.42, which corresponds to a moderate score. This indicates that the participants did not perceive the activities as particularly demanding, although some difficulty was observed due the difficulty in some minigames played in the evaluation sessions, mainly due to lack of time, and could indicate some uncertainty about the objectives of some minigames.

The Perceived Competence scale reported the mean of all participants to be 3.57 with a standard deviation of 0.27, which corresponds to a moderate score once again. This is consistent with what was observed in the evaluation sessions, where in some minigames even the participants with prior mobile phone experience had some difficulties understanding certain mechanics before successfully interacting with them.

Finally, for Pressure/Tension, the mean of all participants was 1.7 with a standard deviation of 0.28, which is the lowest score obtained. Seeing as this dimension measures feelings of stress and pressure during interaction, the low value suggests that participants generally felt relaxed while playing the game, despite encountering some difficulties during gameplay.

Overall, the IMI results suggest that the participants enjoyed the game and found it to be non-stressful, although improvements in gameplay clarity and interaction mechanics may increase confidence and perceived competence among participants.

8.4 User Satisfaction Evaluation Questionnaire Results

The USEQ was used to assess the overall satisfaction of the participants with the game.

Participant number six did not answer the last question, stating that they did not feel able to provide an informed response to that question. Consequently, the participants' overall USEQ score was calculated using the remaining answered items only, with all other participants completing the questionnaire in full.

The value of question five was altered due to the question being reverse-coded, with the new value obtained by subtracting the original value from 6. Every other question is scored directly

Table 8.3 shows the results obtained from the USEQ:

Participant	**Average Score**
P1	3.67
P2	3.5
P3	4.3
P4	3.67
P5	3.8
P6	4.83
Global Average	**3.97**
SD	**0.47**

Table 8.3: Average USEQ scores per participant, global average and standard deviation

Participants obtained a mean USEQ score of 3.97 with a standard deviation of 0.47 (with the scores being between 0-5). This results corresponds to a overall positive level of satisfaction with the application. Although participants encountered difficulties while interacting with certain game mechanics, particularly in the Play Piano and Plant Matching minigames, they generally reported enjoying the experience.

The relatively small standard deviation indicates that the satisfaction levels were reasonably consistent across participants, which indicates that the game was positively received despite the usability limitations identified through the SUS questionnaire.

8.5 Qualitative Results

The qualitative feedback was obtained via observations recorded during the evaluation sessions and revealed several recurring themes.

8.5.1 Positive Aspects

Participants reported liking the themes chosen for the activities, mainly the gardening theme.

The village structured appeared to be very accessible, as most participants quickly understood how to make use of the mechanism for navigating between activities.

The music chosen for the rhythm minigames was also mentioned as calm and enjoyable.

From the presented minigames, Whack-a-Mole gardening minigame appeared to be the easiest to understand, use and enjoy, as most participants were able to beat the game and some making some statements that showed high engagement.

8.5.2 Difficulties Understanding Mechanics

A recurring theme involved difficulties understanding the objectives and mechanics of certain minigames.

In the Plant Matching minigame, participants showed some difficulty understanding the join mechanic as well as how to generate new plants.

The Thought Sorting minigame appeared to not have a clear objective for the participants, with multiple of them reporting not understanding what to do in the minigame.

In the Play Piano minigame participants where uncertain as what to do, with one of the participants clicking the buttons at random, some others clicking the buttons and not holding them and some remained inactive while observing the screen.

Finally, the difficulty appeared to be to high mainly in the rhythm based minigames, with the point target being too high for most participants.

8.5.3 Timing Related difficulties

Another recurring theme involved the time constraints in the various minigames.

The Plant Matching minigame countdown timer was too short, which limited the time available to understand the mechanics of the game before the game concluded.

In the Rhythmic Notes minigame, the notes that appeared on the screen disappeared slightly too fast for the reaction of the participants, with multiple notes not being clicked due to time.

Similarly, in the Play Piano minigame the choice to start a note right after the one before, similar to the current commercial games, appeared to actively hinder the participants as they were not able to quickly change from one button to the other, resulting in skipping tiles all together, meaning some time between notes would be best for the target population.

8.5.4 Visual Attention and Cognitive Load

The observational data also revealed that many participants focused their attention on a single area of the screen rather than monitoring the entire play area.

Examples of this observations range from, just focusing on one of the holes in the Whack-a-Mole minigame while other moles were already on screen, monitoring only one specific region of the screen in the Rhythmic Notes minigame and ignoring the notes outside that region, concentrating in a single lane and button in the Play Piano minigame ignoring the others and inserting most thoughts in the same box in the Thought Sorting minigame.

Additionally, some participants showed some confusion in Thought Sorting minigame, interpreting the decorative sun in the background scene as a interactive gameplay component and being unable to understand if a thought is selected or not.

Another observation made is that some participants hesitated before initiating activities, even when the required interaction consisted solely of selecting a clearly labeled "Começar" (start) button, appearing uncertain about whether they were expected to interact with the interface or wait for further instructions.

This behavior indicates that some game elements require stronger visual guidance or a reduction in the number of simultaneously active areas.

8.5.5 Influence of Technological Experience

Participants with prior experience using smartphones and digital applications generally demonstrated better performance across the multiple minigames.

Even though some age differences between participants also appeared to influence the performance, technological familiarity appeared to influence performance more strongly than age.

This observation is consistent with previous research suggesting that prior exposure to technologies can facilitate interaction with serious games.

8.6 Summary of Findings

The evaluation results indicate that the developed game achieved positive usability, satisfaction, and motivation scores overall. The participants were generally satisfied with the application as reflected by the USEQ scores and found the game moderately enjoyable according to the Interest/Enjoyment dimension of the IMI questionnaire. Additionally, the low Pressure/Tension score suggests that participants did not find the activities stressful, despite experiencing some interaction difficulties.

The SUS score generated indicated that although participants were able to complete the activities, improvements are required to make the interaction more intuitive and accessible.

According to the qualitative observations, the Whack-a-mole minigame was the most successful, with the Rhythmic Notes being the second most successful, even despite the difficulties mentioned in section 8.5, mainly due to both of these making use of simple interaction mechanics (a single tap to do the intended mechanic), along with clear visuals, such as the appearance of the moles and notes on screen and consecutive disappearance after user interaction.

Frequently participants experienced difficulties understanding game mechanics, particularly during their first interaction with a new activity, and some times focusing their attention on only one region of the screen, making them unable to respond to the multiple simultaneous stimuli.

The observations collected during the sessions indicate that simplifying the mechanics, increasing interaction time windows, improving instructions, and reducing visual complexity may further improve accessibility and overall user experience.

Additionally, the hesitation of initiation of activities indicated that, for some older adults, even simple interaction patterns that are familiar to experienced technology users may not be immediately intuitive. This indicates that clear visual cues, explicit instructions and immediate feedback are crucial when designing a serious game for older adults.

Observations also suggested that previous experience with digital technologies influenced gameplay performance, with the participants most familiar with technologies adapting quicker to the interaction mechanics than those with limited technological experience.

Despite these limitations, both the questionnaire results and the observations during evaluation sessions suggest that the proposed approach has potential as a well-being-oriented serious game for older adults. At the same time, it highlights several opportunities for improving accessibility, interaction design, and difficulty before wider deployment.

8.7 Limitations

The results in this chapter should be interpreted cautiously due to multiple limitations.

Firstly, in order to verify the possible well-being improvements the game should have also been evaluated with healthcare professionals, however due to the time constraints of a masters dissertation that evaluation was not possible to be made.

Secondly, the participant sample was small, with only 6 participants, and obtained through convenience sampling. Even though this approach is common, it limits the generalizability of the findings to the broader older adults population.

Another limitation is that the evaluation was conducted during a single gameplay session. This implies that the data collected reflects the participants' first thoughts while playing the game for the first time, rather then thought out comments about a long-term interaction with the game. With one of the objectives of the game being promotion of well-being through long-term repeated use, a longitudinal study would provide a comprehensive assessment of its potential impact, however due to the time constraints of a master dissertation, that study was not possible to be conducted.

Additionally there are some concerns about the characteristics of the target population. During the evaluation, some participants presented age-related difficulties, with some mentioning difficulty in sight and others appearing to have some hearing impairments, which occasionally affected communication and interaction with the application. Furthermore, some participants appeared uncertain regarding the interpretation of certain questionnaire items, despite the questionnaires being administered with researcher support. As a result, some responses may not fully reflect the participants' intended opinions.

Finally, the observational data was recorded by the researcher during the evaluation sessions and therefore represent qualitative observations rather than formally coded qualitative data. Although these observations provided valuable context for interpreting the questionnaire results, they remain inherently subjective.

8.8 Future work

This evaluation also clearly highlighted some areas that could be explored in future iterations of the game.

One of the primary improvements that could be done is the redesign of some minigame mechanics. The Rhythmic Notes minigame should be simplified by reducing note disappearance speed, possibly by making the notes take four beats to disappear instead of the current two beats. For the Play Piano minigame, the frequency of tiles should be reduced, allowing for participants

to hit the tiles more consistently, possibly exploring the possibility of changing to tap instead of hold and providing clearer visual guidance. For both of these the target score in order to win the game should also be lowered to better accommodate mistakes.

As for the Plant Matching minigame, an improved tutorial with a better explanation of the interaction mechanics along with a longer gameplay duration would benefit the game.

Finally, the Thought Sorting minigame would benefit from a simplified background and clearer visual guidance, which should be supported by a better explanation of the interaction mechanics and objectives in the tutorial.

Future versions could also make use of onboarding procedures. Seeing as some participants hesitated before interacting with simple interface element, additional guidance such as animations to attract the attention of the user, more informative videos, voice instructions, text to speech in the tutorials and step-by-step guides could facilitate the learning process for the users.

Another possible improvement involves the addition of either player controlled difficulty or adaptive difficulty. Changing the difficulty level based on player skill would allow for the various minigames to remain engaging while accommodating different cognitive and motor abilities.

Finally, future evaluations should involve a larger and more diverse participant population, involving healthcare professionals and more older adults from multiple backgrounds. A longitudinal study would also be valuable to investigate whether regular use of the game produces measurable improvements in older adults' well-being over extended periods of time.

Chapter 9

Conclusions

The aging of the global population is becoming an increasingly worrying concern. Knowing this, a strategy must be developed to ensure the well-being of older adults. Serious games represent a promising approach by combining entertainment with activities that may support cognitive stimulation, emotional well-being, and continued engagement.

This dissertation presented the design, development and evaluation of a serious game aimed at promoting the well-being of older adults. In order to develop the possible game for the target population, a systematic review was carried out with focus on serious games, usability and accessibility for older adults. The game was developed using Unity game engine and consists of a village environment containing five minigames inspired in activities associated with improved well-being, with these being gardening, music and thought regulation.

Regarding well-being, the PERMA model by Seligman was chosen to be the framework this project was guided by. The game focused on three dimensions of the PERMA framework, these being Positive Emotion, Engagement and some Accomplishment. Future developments could address the remaining two dimensions, Relationships and Meaning, and expand the Accomplishment dimension, providing a more comprehensive implementation of the framework, but for this project, even though the full PERMA model was not implemented, the framework provided a valuable conceptual foundation for structuring the overall experience.

The evaluation involved members of the target population, where the older adults participated in gameplay sessions in which they completed all implemented minigames before evaluating the application using questionnaires such as System Usability Scale (SUS), Intrinsic Motivation Inventory (IMI) and User Satisfaction Evaluation Questionnaire (USEQ), complemented by qualitative observational notes regarding participants' interaction with the application, collected during gameplay.

The results obtained in the evaluation indicate that participants perceived the game positively and reported satisfactory levels of enjoyment and satisfaction. Participants also experienced low levels of pressure while interacting with the game, suggesting that the activities were generally relaxing rather than stressful. One minigame in particular, Whack-a-Mole, proved to be the most intuitive, with the participants quickly understanding the mechanics of the game, due to the simple

controls, clear visual feedback and clarity.

The evaluation also identified multiple issues, mostly regarding usability, with the main problems being difficulty in understanding game mechanics and lack of time either for interactions or the minigames themselves, with Play Piano and Thought Sorting being the minigames that most older adults appeared to struggle with. These findings further reinforce the importance of testing applications with the target population when developing serious games for older adults, as without the evaluation these usability problems would not have been identified.

Overall, the evaluation demonstrated the potential of serious games as a tool for promoting the well-being of older adults. Although several aspects of the game require refinement, the findings indicate that serious games can provide an enjoyable experience for older adults while highlighting important design considerations for future developments aimed at this population.

9.1 Contributions

The main contributions of this dissertation are the following:

- Design and implementation of a serious game specifically developed to promote the well-being of older adults;
- The integration of activities inspired by gardening, music and thought regulation within a unified game environment;
- The application of the PERMA well-being framework as a conceptual guide for game design, focusing primarily on the dimensions of Positive Emotion and Engagement, with some aspects of Accomplishment;
- The evaluation of the developed game with older adults, providing quantitative and qualitative evidence regarding usability, satisfaction, motivation, and interaction challenges.

These contributions provide practical insights into designing accessible serious games for older adults and may support future research addressing digital interventions for healthy aging.

Additionally, this project was also presented in **IJUP 2026 - 19º Encontro de Investigação Jovem da U.Porto**, which is an annual event where University of Porto students can present and discuss projects in which they have participated. The event took place from the 6th to the 8th of may 2026 at the Abel Salazar Building, Porto, where this project was presented in the form of a scientific poster.

References

[1] Instituto Nacional de Estatística (INE). *Índice de Envelhecimento — INE*. https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&contecto=pi&indOcorrCod=0012909&selTab=tab0. Accessed: 2025-10-08. 2025.

[2] United Nations Population Fund. *Ageing*. https://www.unfpa.org/ageing. Accessed: 2025-10-08. June 2024.

[3] Yu Zhonggen. "A Meta-Analysis of Use of Serious Games in Education over a Decade". In: *International Journal of Computer Games Technology* 2019.1 (2019), p. 4797032. DOI: https://doi.org/10.1155/2019/4797032.

[4] Clark C. Abt. *Serious Games*. New York: Viking Press, 1970.

[5] Bárbara-Mariana Gutiérrez-Pérez et al. "Use of serious games with older adults: systematic literature review". In: *Humanities and Social Sciences Communications* 10.1 (2023), p. 939. DOI: 10.1057/s41599-023-02432-0.

[6] Joaquin A. Anguera, Faith M. Gunning, and Patricia A. Areán. "Improving late life depression and cognitive control through the use of therapeutic video game technology: A proof-of-concept randomized trial". In: *Depression and Anxiety* 34.6 (2017), pp. 508–517. DOI: https://doi.org/10.1002/da.22588.

[7] Yesol Kim, Soomin Hong, and Mona Choi. "Effects of Serious Games on Depression in Older Adults: Systematic Review and Meta-analysis of Randomized Controlled Trials". In: *Journal of Medical Internet Research* 24.9 (2022), e37753. DOI: 10.2196/37753.

[8] Valeria Manera et al. "'Kitchen and cooking,' a serious game for mild cognitive impairment and Alzheimer's disease: a pilot study". In: *Frontiers in Aging Neuroscience* Volume 7 - 2015 (2015). DOI: 10.3389/fnagi.2015.00024.

[9] Theresa M. Fleming et al. "Juegos serios para el tratamiento o la prevención de la depresión: una revisión sistemática". In: *Revista de Psicopatología y Psicología Clínica* 19.3 (ene. 2015), pp. 227–242. DOI: 10.5944/rppc.vol.19.num.3.2014.13904.

[10] John T. Cacioppo and Stephanie Cacioppo. "Chapter Three - Loneliness in the Modern Age: An Evolutionary Theory of Loneliness (ETL)". In: ed. by James M. Olson. Vol. 58. Advances in Experimental Social Psychology. Academic Press, 2018, pp. 127–197. DOI: https://doi.org/10.1016/bs.aesp.2018.03.003.

[11] Steve Nebel, Sascha Schneider, and Günter Daniel Rey. "Mining Learning and Crafting Scientific Experiments: A Literature Review on the Use of Minecraft in Education and Research". In: *Educational Technology & Society* 19 (Jan. 2016), pp. 355–366.

[12] Wendy S. Beckman. "The Effectiveness of Microsoft Flight Simulator as a Training Aid for Private Pilot Training and Proficiency". In: 2013. URL: https://api.semanticscholar.org/CorpusID:69844749.

[13] David C. Mohr et al. “Behavioral Intervention Technologies: Evidence review and recommendations for future research in mental health”. In: *General Hospital Psychiatry* 35.4 (2013), pp. 332–338. ISSN: 0163-8343. DOI: https://doi.org/10.1016/j.genhosppsych.2013.03.008.

[14] Theresa M. Fleming et al. “Serious Games and Gamification for Mental Health: Current Status and Promising Directions”. In: *Frontiers in Psychiatry* Volume 7 - 2016 (2017). ISSN: 1664-0640. DOI: 10.3389/fpsyt.2016.00215.

[15] Pamela Kato et al. “A Video Game Improves Behavioral Outcomes in Adolescents and Young Adults With Cancer: A Randomized Trial”. In: *Pediatrics* 122 (Sept. 2008), e305–17. DOI: 10.1542/peds.2007-3134.

[16] U.S. Food and Drug Administration. *De Novo Classification Request for EndeavorRx (DEN200026)*. Tech. rep. DEN200026. Accessed: 2026-04-27. Center for Devices and Radiological Health (CDRH), FDA, 2020. URL: https://www.accessdata.fda.gov/cdrh_docs/reviews/DEN200026.pdf.

[17] Scott H Kollins et al. “A novel digital intervention for actively reducing severity of paediatric ADHD (STARS-ADHD): a randomised controlled trial”. In: *The Lancet Digital Health* 2.4 (2020), e168–e178. ISSN: 2589-7500. DOI: https://doi.org/10.1016/S2589-7500(20)30017-0.

[18] Alaa Abd-alrazaq et al. “The Effectiveness of Serious Games in Alleviating Anxiety: Systematic Review and Meta-analysis”. In: *JMIR Serious Games* 10.1 (Feb. 2022), e29137. ISSN: 2291-9279. DOI: 10.2196/29137.

[19] Ann DeSmet et al. “A meta-analysis of serious digital games for healthy lifestyle promotion”. In: *Preventive Medicine* 69 (2014), pp. 95–107. ISSN: 0091-7435. DOI: https://doi.org/10.1016/j.ypmed.2014.08.026.

[20] World Health Organization. *Decade of Healthy Ageing: Baseline Report*. Tech. rep. Geneva: World Health Organization, 2020. URL: https://www.who.int/publications/i/item/9789240017900.

[21] Neil Charness and Walter R. Boot. “Aging and Information Technology Use: Potential and Barriers”. In: *Current Directions in Psychological Science* 18.5 (2009), pp. 253–258. DOI: 10.1111/j.1467-8721.2009.01647.x.

[22] Rhys Mantell et al. “Evaluating the User Experience and Usability of Game-Based Cognitive Assessments for Older People: Systematic Review”. In: *JMIR Aging* 8 (June 2025), e65252. ISSN: 2561-7605. DOI: 10.2196/65252.

[23] Milan N. A. van der Kuil et al. “A Usability Study of a Serious Game in Cognitive Rehabilitation: A Compensatory Navigation Training in Acquired Brain Injury Patients”. In: *Frontiers in Psychology* Volume 9 - 2018 (2018). DOI: 10.3389/fpsyg.2018.00846.

[24] Freya Probst et al. “A scoping review on human-centered design approaches and considerations in the design of technologies for loneliness and social isolation in older adults”. In: *Design Science* 10 (2024), e39. DOI: 10.1017/dsj.2024.22.

[25] Amy Cole et al. “Codesign approaches involving older adults in the development of electronic healthcare tools: a systematic review”. In: *BMJ Open* 12 (July 2022), e058390. DOI: 10.1136/bmjopen-2021-058390.

[26] N. Li and W. Chen. “A Mobile Game for the Social and Cognitive Well-Being of Elderly People in China”. In: vol. 242. 2017, pp. 614–621. DOI: 10.3233/978-1-61499-798-6-614.

[27] Jeroen Janssen et al. “A Digital Gaming Intervention to Strengthen the Social Networks of Older Dutch Adults: Mixed Methods Process Evaluation of a Digitally Conducted Randomized Controlled Trial”. eng. In: *JMIR formative research* 7 (Oct. 2023), e45173. ISSN: 2561-326X. DOI: 10.2196/45173.

[28] Jeroen H. M. Janssen et al. “Older Adults’ Views on Social Interactions and Online Socializing Games - A Qualitative Study”. eng. In: *Journal of Gerontological Social Work* 66.2 (2023), pp. 274–290. ISSN: 1540-4048. DOI: 10.1080/01634372.2022.2100548.

[29] Tom Kolthoff, Ton AM Spil, and Hai Nguyen. “The adoption of a serious game to foster interaction between the elderly and the youth”. In: *2019 IEEE 7th International Conference on Serious Games and Applications for Health (SeGAH)*. Aug. 2019, pp. 1–8. DOI: 10.1109/SeGAH.2019.8882443. (Visited on 11/05/2025).

[30] Min Zhou et al. “Emotionally Challenging Games Can Satisfy Older Adults’ Psychological Needs: From Empirical Study to Design Guidelines”. In: *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. CHI ’25. New York, NY, USA: Association for Computing Machinery, Apr. 2025, pp. 1–19. ISBN: 979-8-4007-1394-1. DOI: 10.1145/3706598.3713899. URL: https://dl.acm.org/doi/10.1145/3706598.3713899 (visited on 11/05/2025).

[31] D. Kaufman and F. Zhang. “Can playing massive multiplayer online role playing games (MMORPGs) help older adults?” In: vol. 1. 2015, pp. 527–535. DOI: 10.5220/0005551405270535.

[32] F. Zhang and D. Kaufman. “Can playing massive multiplayer online role playing games (MMORPGs) improve older adults’ socio-psychological wellbeing?” In: vol. 583. 2016, pp. 504–522. DOI: 10.1007/978-3-319-29585-5_29.

[33] S. Ballesteros et al. “Brain training with non-action video games enhances aspects of cognition in older adults: A randomized controlled trial”. In: *Frontiers in Aging Neuroscience* 6.OCT (2014). DOI: 10.3389/fnagi.2014.00277.

[34] Ramón R. Palacio et al. “Towards videogame design guidelines to promote significant leisure activities in Mexican older adults”. In: *Proceedings of the 4th Mexican Conference on Human-Computer Interaction*. MexIHC ’12. New York, NY, USA: Association for Computing Machinery, Oct. 2012, pp. 43–46. ISBN: 978-1-4503-1659-0. DOI: 10.1145/2382176.2382186. URL: https://dl.acm.org/doi/10.1145/2382176.2382186 (visited on 11/05/2025).

[35] Bas D L Châtel et al. “Social Gaming to Decrease Loneliness in Older Adults: Recruitment Challenges and Attrition Analysis in a Digital Mixed Methods Feasibility Study”. In: *JMIR Serious Games* 12 (Jan. 2024). ISSN: 2291-9279. DOI: 10.2196/52640.

[36] Martin Seligman. “PERMA and the building blocks of well-being”. In: *The Journal of Positive Psychology* 13.4 (2018), pp. 333–335. DOI: 10.1080/17439760.2018.1437466. eprint: https://doi.org/10.1080/17439760.2018.1437466.

[37] Theresa L Scott, Barbara M Masser, and Nancy A Pachana. “Positive aging benefits of home and community gardening activities: Older adults report enhanced self-esteem, productive endeavours, social engagement and exercise”. In: *Sage Open Medicine* 8 (2020). PMID: 32030127, p. 2050312120901732. DOI: 10.1177/2050312120901732.

[38] Lauren Istvandity. “Combining music and reminiscence therapy interventions for wellbeing in elderly populations: A systematic review”. In: *Complementary Therapies in Clinical Practice* 28 (2017), pp. 18–25. ISSN: 1744-3881. DOI: https://doi.org/10.1016/j.ctcp.2017.03.003.

[39] Wilson Tam et al. “The effectiveness of reminiscence-based intervention on improving psychological well-being in cognitively intact older adults: A systematic review and meta-analysis”. In: *International Journal of Nursing Studies* 114 (2021), p. 103847. ISSN: 0020-7489. DOI: https://doi.org/10.1016/j.ijnurstu.2020.103847.

[40] Ana Martins et al. “European Portuguese Validation of the System Usability Scale (SUS)”. In: vol. 67. June 2015. DOI: 10.1016/j.procs.2015.09.273.

[41] Célia Domingos et al. “European Portuguese Version of the User Satisfaction Evaluation Questionnaire (USEQ): Transcultural Adaptation and Validation Study”. In: *JMIR Mhealth Uhealth* 9.6 (June 2021), e19245. ISSN: 2291-5222. DOI: 10.2196/19245.

[42] Antonio Fonseca and António Brito. “Propriedades psicométricas da versão portuguesa do Intrinsic Motivation Inventory (IMIp) em contextos de actividade física e desportiva”. In: *Análise Psicológica* 19 (Dec. 2012), pp. 59–76. DOI: 10.14417/ap.344.

Appendix A

Third-Party Assets

Table A.1: Third-party assets that required attribution used in the developed game.

Asset	Author	Source	License	Purpose
Open Box	Nata Gabbiano	https://sketchfab.com/3d-models/open-box-2e85b6d923fc425889c91ec67c1dc243	CC BY 4.0	Used as interactable asset, representing the keep and let go boxes, in the Thought Sorting minigame.

Appendix B

supplementary Material

B.1 Chapter 3

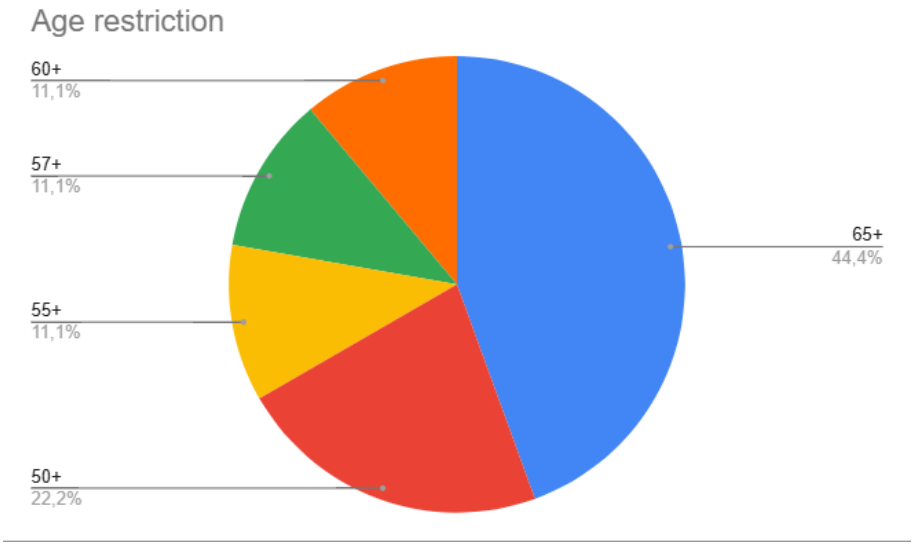


Figure B.1: Graph with the ages that the studies consider older adults

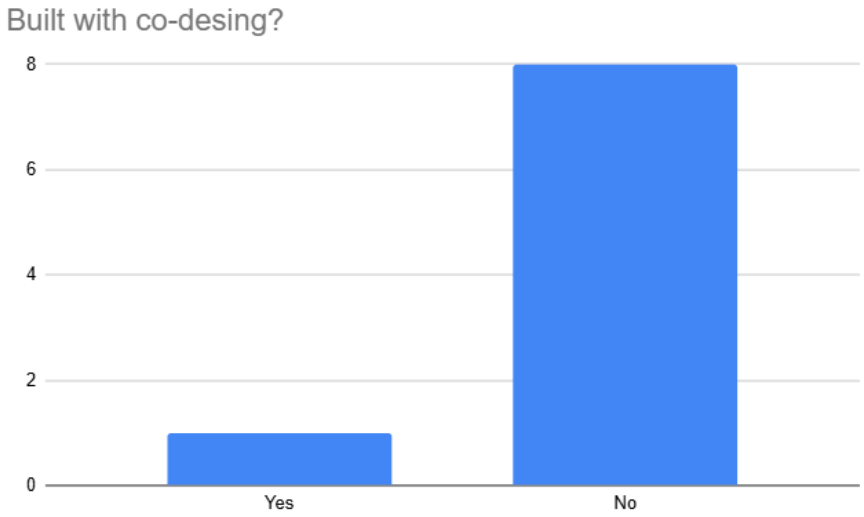


Figure B.2: Graph with the amount of studies that use co-design

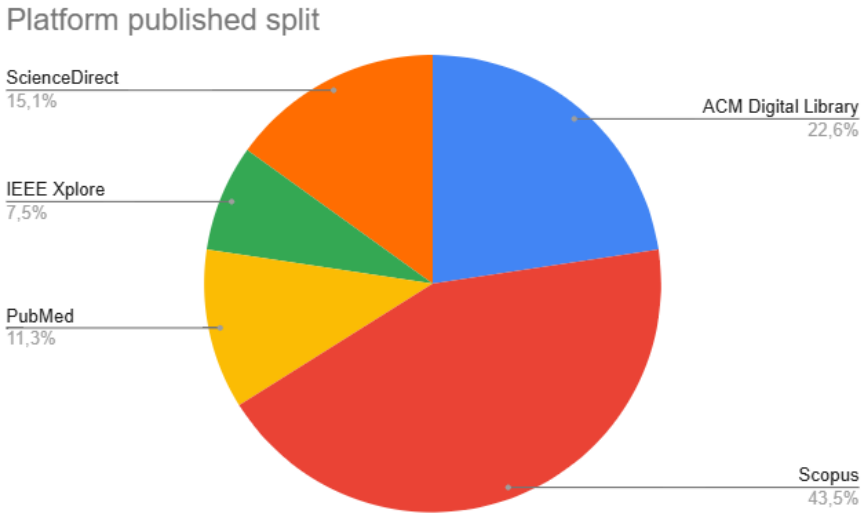


Figure B.3: Graph with the split of studies per Database