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GAMIFICATION MECHANISMS TO IMPROVE PATIENT ADHERENCE IN WEB-BASED HEMIANOPIA THERAPY

TESIS PARA OPTAR AL GRADO DE
MAGÍSTER EN CIENCIAS, MENCIÓN COMPUTACIÓN

MEMORIA PARA OPTAR AL TITULO DE
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RESUMEN

TESIS PARA OPTAR AL GRADO DE MAGÍSTER EN CIENCIAS MENCIÓN COMPUTACIÓN

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MECANISMOS DE *GAMIFICATION* PARA EL MEJORAMIENTO DE LA ADHERENCIA DE PACIENTES EN TERAPIAS DE HEMIANOPIA BASADAS EN LA WEB

Eye-Search es una aplicación desarrollada por el University College of London, que proporciona una Intervención Terapéutica Autoguiada online y gratuita para el tratamiento compensatorio de la hemianopía, siendo esta condición, una donde los pacientes sufren de daños a su campo visual. Esta aplicación tiene como objetivo mejorar las funciones visuales del paciente, en términos de velocidad y precisión, demostrando resultados exitosos en la mejora de la agudeza visual de los pacientes. Sin embargo, se identificó una falta de experiencias atractivas debido a la naturaleza repetitiva de las actividades terapéuticas proporcionadas por la aplicación, lo que hace que se perciban como tediosas y exhaustiva, comprometiendo asi la adherencia del paciente a la terapia.

Gamification es definida como el uso de elementos de diseño de juegos en otros contextos para hacerlos más atractivos e interesantes. A pesar de que se esta área ha sido aplicada con éxito en múltiples contextos, en la literatura hay una falta de estudios que proporcionen pautas de diseño para la aplicación de *Gamification* a Intervenciones Basadas en la Web, y menos aún para las que proporcionan un tratamiento para la hemianopía.

Ante este vacío en la literatura, en el presente trabajo se propuso estudiar cómo se pueden diseñar y evaluar mecánicas de *Gamification* para la mejora del *engagement* y la adherencia al contexto de una Intervención Terapéutica Web de corto plazo para el tratamiento compensatorio de la hemianopia, sin degradar su componente terapéutico. Para realizar este estudio, se desarrolló una versión rediseñada de la aplicación Eye-Search. Este consta de tres mecánicas principales de *Gamification*: (1) Un sistema de tareas diarias con recompensas extrínsecas diseñado utilizando el marco Hook, para la mejora del compromiso a corto plazo y la adherencia a la aplicación; (2) Un personaje no jugable, para actuar como una fuente de relación social y apoyo; y, (3) Un sistema de práctica espaciada para promover el desarrollo de habilidades motoras y cognitivas. La aplicación desarrollada consistió de una aplicación web desarrollada en Unity WebGL, una API Restful Node.js y una base de datos MySQL.

Para evaluar el diseño de la aplicación desarrollada, así como para verificar la no degradación del componente terapéutico de la misma, se realizó una prueba de concepto, donde se estudiaron estadísticamente los datos registrados sobre el rendimiento de los usuarios y se compararon con los resultados de la version anterior. Además se realizó un análisis temático sobre entrevistas semiestructuradas realizadas con los usuarios. A partir de los resultados, se elaboraron unas pautas de diseño reutilizables para la aplicación de estrategias y mecánicas de *Gamification*, para la mejora del compromiso y la adherencia a corto plazo para el diseño de una aplicación web del área de la salud para el tratamiento de la hemianopía.

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GAMIFICATION MECHANISMS TO IMPROVE PATIENT ADHERENCE IN WEB-BASED HEMIANOPIA THERAPY

Eye-Search is an application developed by the University College of London, which provides a free open online Self-Guided Web-Based Therapeutic Intervention for the compensatory treatment of hemianopia, being this condition, one where patients suffer from damage to one half of their visual field. This application has the objective of improving a patient's visual functions, in terms of speed and accuracy, in daily visual search tasks, demonstrating successful results in improving patients' visual acuity. However, a lack of engaging experiences was identified due to the repetitive nature of the therapeutic activities provided by the application, causing them to be perceived as tedious and tiring, and compromising patient adherence to the therapy.

Gamification is defined as the use of game design elements in other contexts in order to make those contexts more engaging and interesting. Despite it being successfully applied in many contexts, there is a gap in the literature for design guidelines or empirical support for the application of Gamification to Web-Based Interventions, and even less for ones that provide compensatory treatment of hemianopia. In light of this gap, in the present work, it was proposed to study how Gamification tools and mechanics can be designed and evaluated for the improvement of short term engagement and adherence to the context of therapy for users in a Self-Guided Web-Based Therapeutic Intervention for the treatment of hemianopia, without compromising its healthcare component. To perform this study, a redesigned version of the Eye-Search application was developed. This redesign consisted of three principal Gamification mechanics: (1) A daily task extrinsic reward system designed using the Hook framework, for the improvement of short-term engagement and adherence to the application; (2) A Non Playable Character Companion, to act as a source of social relatedness and support; and, (3) A spaced break system to promote the development of motor and cognitive skills on users. The developed application consisted of a front-end web application developed in Unity WebGL, a Node.js Restful API and a MySQL database.

To evaluate the design of the developed application, and verify the non degradation of the therapeutic component of it, a proof of concept in the form of a mixed method study was carried out. Data logged by the application about users performance was statistically studied and compared to the results of the previous application. Also, a thematic analysis was carried out over semi-structured interviews held with users. From the results of these studies, reusable design guidelines for the application of Gamification strategies and mechanics, for the improvement of short-term engagement and adherence of users, to the design of an Web-Therapy hemianopia healthcare application were crafted.

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En primer lugar, quiero agradecer a mi familia, la cual en todo momento ha sido una fuente de apoyo incondicional, especialmente en los momentos más difíciles, dándome ánimos y motivación para salir adelante. Quiero agradecer a mi Mamá por siempre estar para mí, preocupándose de mi bienestar, y siendo una fuente incondicional e infinita de amor y apoyo, sin la cual, este proceso universitario hubiera sido imposible. A mi Papá por siempre estar orgulloso de mis logros por pequeños que sean y apoyarme en todo momento, a mi hermano Mando por ayudarme en los años que estuvimos juntos y siempre buscando darme buenos y divertidos momentos, como también su apoyo, y a Tete por haberme ayudado en el semestre más difícil de mi vida, mi primer año universitario en una ciudad que no conocía, y por siempre estar ayudándome a formar un buen futuro, además de ser una fuente de muchos momentos de diversión. Gracias a ustedes pude llegar hasta acá

En segundo lugar, quiero agradecer a la gente que hizo esta tesis posible. Agradezco mucho al profesor Alex por haberme dado la oportunidad de participar en este extraordinario proyecto, y haber confiado en mí al darme una responsabilidad de esta índole. A mi profesor guía Francisco quien con sus conocimientos y apoyo me guió a través de cada una de las etapas de esta tesis, y en especial a mi hermano Pedro, quien me introdujo a esta área donde se desarrollan proyectos que cambian la vida de las personas y me ayudó a encontrar un tema de tesis cuando más perdido estaba, motivando a realizar un proyecto de esta magnitud.

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Chapter 1

Introduction

The digital world is constantly advancing and with it, new opportunities of communication and interaction have arisen. In particular, in the area of healthcare, the use of technology and interactive computing applications is an integral part of medical treatments. In that respect, new technologies introduce great opportunities for professionals of the area, who can offer their assistance from a distance with significant flexibility in terms of time and methods, and even provide treatment to anonymous people [5]. Web-based therapies and treatments are encompassed by the term *Web-Based Intervention*, which is defined as *"a primarily self-guided intervention programs that is executed by means of a prescriptive online program operated through a website and used by consumers seeking health- and mental-health related assistance"* (Barak, p. 5) [5]

There are three main subtypes of Web-Based Interventions, which are split by their program purpose. The first category consists of the *Web-Based Education Interventions*, which are self-guided intervention program for the purpose of creating positive changes and improvement of awareness about medical health related topics to its users. The second category, consisting of programs with the purpose of creating positive cognitive, behavioural, and emotional change. This group is composed of *Human-Supported Web-Based Therapeutic Interventions*, which incorporate a human, usually a health professional, to provide support, guidance, and feedback to the user; and *Self-Guided Web-Based Therapeutic Interventions*, the latter not needing a health professional's supervision, and being characterised by a number of multimedia formats, interactive online activities, and feedback support. These interventions are frequently being modelled on effective face-to-face treatment, prevention programs, which let users easily access to health therapies, as well as allowing for the massification of these.

In this context, researchers from the University College of London developed Eye-Search [53], a free open online Self-Guided Web-Based Therapeutic Intervention, with the goal of treating patients that suffer from hemianopia. This condition stems from the damage to a part of the field of view [52]. Hemianopia often occurs as a consequence of a stroke, traumatic brain injuries, or tumours due to the way vision is processed in the brain. Furthermore, this condition can be accompanied by other disorders, such as Visual Neglect, where patients can see a decreased response to stimuli on the path of their visual field [11]. A patient that

suffers from hemianopia has his/her independence severely affected, as he/she suffers from fear of tripping, falling, or encountering people or objects that for him/her may appear out of nowhere. Affected individuals are left impaired on a range of key activities of their daily living [54].

Eye-Search has the objective of improving a patient's visual functions, in terms of speed and accuracy, in real world or daily visual search tasks. This treatment does not improve or recover lost visual field, but improves the patient's available vision. This therapy strategy is known as Compensatory Strategy. Eye-search has proven to be successful in a study held with 78 hemianopic patients who took part in the web therapy for 11 days, after which, their vision improved by 24% [54].

This thesis work is part of a research collaboration between the Department of Computer Science at the University of Chile and the University College London (UCL) Institute of Neurology, being Alex Leff[1], Professor of Cognitive Neurology, the direct contact with UCL and collaborator of this research. The research of Gamification mechanics and development of the application was performed by the student under the supervision of his thesis advisor at the University of Chile. The on-site clinical trials were conducted in London under the supervision of Dr. Leff, following clinical regulations for testing and implementation. As Eye-Search is an application available online and currently in use, the project has a particular advantage of already consisting of a group of patients (suffering from hemianopia) who served as user testers and offered valuable feedback into the development process in a short lapse of time.

1.1 Problem Statement

Eye-Search consists of a Web-Based application where users can register for free and take part of the online therapy it offers. The application has two main components: (1) assessment tests for diagnosing and measuring the type of hemianopia of the patient; and (2) a game that acts as the training therapy. The assessment component, depicted on (Fig. 1.1) consists of the following four activities: (A) The Visual Neglect test, where users must click on specific targets before time runs out, in order to detect visual neglect on the user; (B) The daily living activities questionnaire test, where they must rate the difficulty of performing 6 specific daily living activities; (C) Visual field test, where users must pinpoint in which area a flashing light appeared in order to measure the users visual field; and (D) Crowded desk test, which measures the user average reaction speed. The second component, the training therapy, consists of a visual search game, where the user must search for a moving object on the screen. Both of these services were implemented in Adobe Flash Player.

There are currently three main approaches to rehabilitation of visual field defects and they all have one therapeutic principle in common: mass practice of a specific visual task, with the expectation that improvement on this task will generalise to a range of ecologically useful visual functions. The available treatments aim to: (1) replace part of the intact visual field with part of the damaged field, (2) partially restore the lost visual field region, (3) compensate by reorganising the process of making exploratory eye movements in the

[1]Alex Leff Website at UCL.

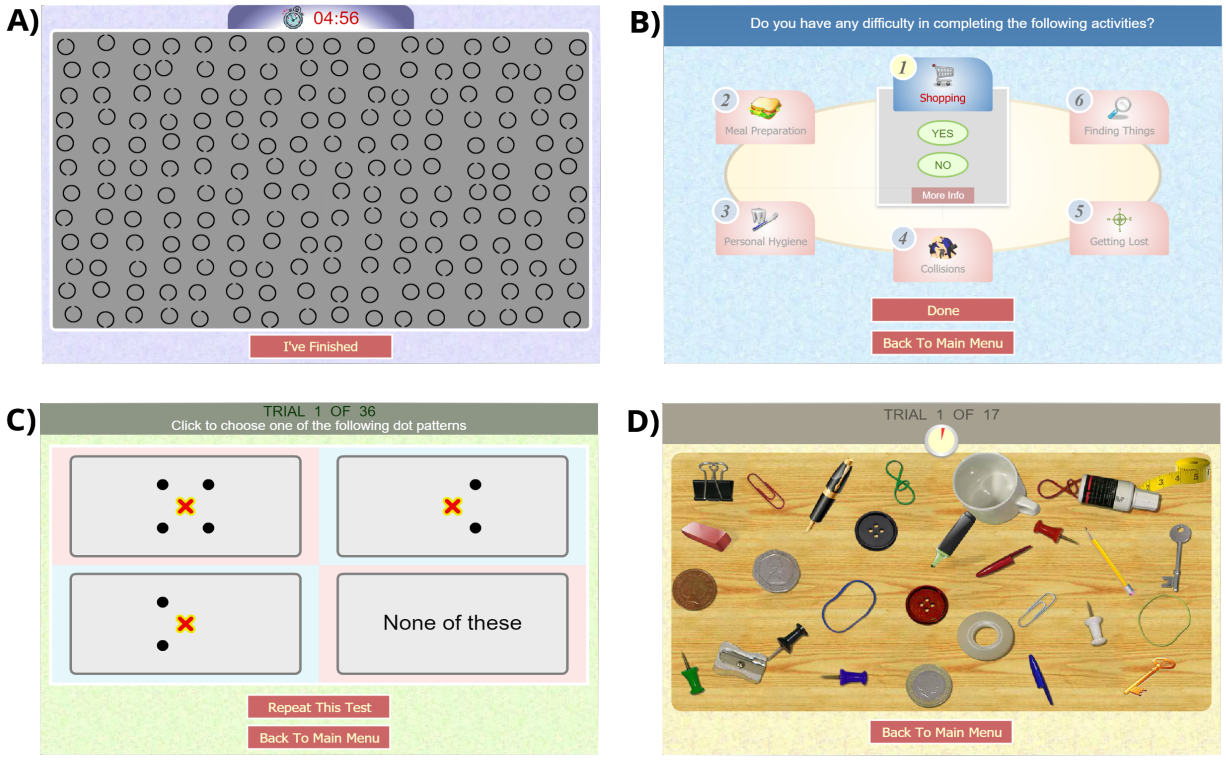


Figure 1.1
Screenshots from the four Eye-Search assessment tests.

blind field (compensatory therapies). This last approach is the one used by the Eye-Search application.

For the compensatory therapy the application offers, it is recommended that the usual therapy session on the application last for 20 to 40 minutes, and should be performed on a daily basis over the period of one month. As mentioned, Web-Based Therapy has proven to be successful in improving patient's visual functions for daily activities [37]. Based on previous trials conducted over the approximately five years Eye-search has provided Web-Based Therapy, a lack of engaging experiences has been identified in the application, which can be explained by the following two identified concerns: (1) in its current form, the application only consists of a single multiple-level game and four assessment tests; and (2) these tests, in the context of the proposed therapy, are perceived as being quite repetitive. Therefore, for a patient that uses the Web-Based Therapy every day, it can rapidly become a tedious and exhausting activity, which puts in danger the patients' adherence and commitment to fulfilling the therapy [55].

Adherence to any kind of treatment is something that the patient must commit to, if he/she is expecting to succeed, as adherence is considered an important modifier of health system effectiveness. Consequently, providing an engaging user experience turns out to be a significant design concern to be addressed in the context of Web-Based Therapies.

The improvement of UX (user experience), in terms of usability, cognitive load, and affective experiences, is an area widely studied by the field of HCI (Human-Computer Interaction).

There has been a growing interest in studying and understanding what motivates users to use, or not, a product, system, or service. Regarding this last concern, experiments through the years have taught us that it is not enough to have a functional or working system, as effective and acceptable software solutions should also motivate and engage users in their interaction. In that respect, enjoyment, alongside usability and aesthetics, are among the main areas of improvement of UX [45].

There are different HCI approaches to deal with the problem of a lack of user engagement. One of these is grounded in a field of research and practice called *Gamification*, an area which originated from the understanding of the factors that make games fun and what motivates people to play them voluntarily with so much engagement. More concretely, in HCI, Gamification is defined as "The use of game design elements in non-game contexts"(Deterding, p. 10) [17]. Gamified mechanisms are not intended to operate as a full game experience, but rather contain mechanics that make the context more appealing and, most importantly, engaging, hence making it enjoyable for the users. In this context, engagement can be described as the desire for continuing to play and complete the game levels or achievements it may have. Currently, Eye-Search presents a small level of Gamification, in terms of having activities with visual cues and a degree of randomness in them. However, there is still room for improvement in this area, as Gamification implies much more than the current functionality offered in the application. More in particular, gamifying a system implies leveraging cross-disciplinary research and practice, including game design, behavioural economics, motivational psychology, and user experience [65].

Gamification is still an emergent field and much remains to be done. It has been successfully applied in many contexts, for example ranging from physical exercise applications (like Nike+)[2] to teaching applications (like Duolingo[3]). However, despite the many positive empirical results proving its applicability and effectiveness, there are still many open research questions in the field. Mainly, there is a need for theoretical and applied research regarding *gameful* design methods. For instance, while many methods have been proposed in the literature, they often lack empirical support regarding the definition of design guidelines and software architectures to be used for implementation [16], as they usually focus more on motivational design techniques and how to personalise Gamification mechanics to individual users.

The use of Gamification as a solution to the presented issue of low engagement in Eye-Search presents a challenge. In that respect, current literature falls short regarding design guidelines for the application of Gamification on healthcare systems, and even more regarding its application to the case of hemianopia rehabilitation therapies.

All things considered, in this thesis work, **Gamification tools and mechanics for the improvement of patient engagement in a healthcare Web-Therapy application were studied, designed, and evaluated**. This problem is relevant to HCI, as it aims to identify novel tools and mechanics for improving short-term user engagement and retention in a healthcare context. As a particular application domain, this work considers the case of hemianopia treatment with Eye-Search. Therefore, the expected reusable knowledge to be

[2]Nike+ official Website.
[3]Duolingo official Website.

acquired by this thesis work will be presented in the form of design guidelines, as well as conceptual models covering various interaction schemas.

1.2 Theoretical Background

In order to describe the proposed solution and the hypotheses of the thesis work, some concepts and frameworks that were used and applied will be briefly described in this section.

While designing a gamified experience, many aspects from game design are borrowed. One of these, is the Mechanics, Dynamics, and Aesthetics (MDA) framework [71], used as a formal and iterative approach to game design, along its tuning. This framework splits game design intro three components:

- Mechanics: Rules or functioning components of the game, for which the designer and programmers have direct control.
- Dynamics: Player interaction with the mechanics, which determine what each player is doing in response to the mechanics of the system, both individually and with other players.
- Aesthetics: Feelings evoked on the player during his interaction with the game. They can also be viewed as the composite outcome of the mechanics and dynamics as they interact with and create emotions.

By splitting game design in these three layers, it allows game designers to consider both themselves and the players perspectives, allowing them to observe how a small change in a mechanic can cascade and affect the user experience. From the designers' perspective, the mechanics give rise to dynamic system behaviour, which in turn leads to particular aesthetic experiences. From the players' perspective, aesthetics set the tone, which is borne out of observable dynamics and eventually, operable mechanics [34]. This three layer design as well as how each of these components is perceived by the designer and player, is depicted on (Fig. 1.2).

A Non-playable character (NPC) is defined as a game mechanic in which a character in a game is not controlled by a player [47]. The term carries a connotation that the character is not hostile towards players and that is an entity whose behaviour is usually scripted and automatic. Non-playable characters serve a number of purposes in games, being the following three the most common [66]:

1. As plot device: NPCs can be used to advance the storyline.
2. For assistance: Acting as partners to the player.
3. Game functions: NPCs often serve as save points, item stores, health regeneration points, and so on.

In the area of Gamification Mechanics, a reward system supplies users with intrinsic and extrinsic motivators while they interact with the system [69]. Reward systems differ based on type of play and have different effects on players according to their preferences and motivations. Despite this, eight main reward systems can be found in the area of Gamification and game design:

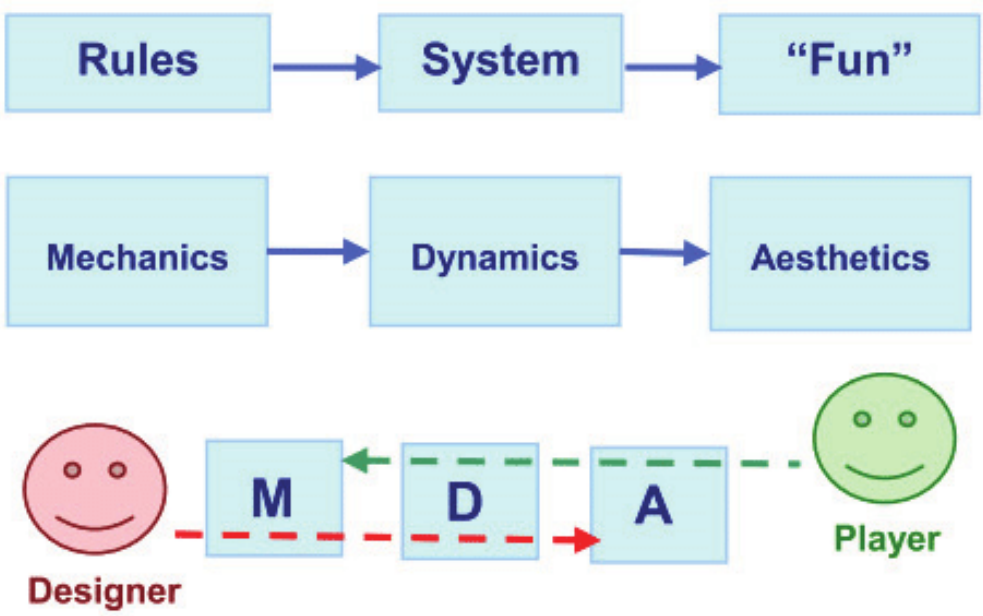


Figure 1.2
MDA Framework three main components with its equivalents. Taken from (Leblanc, 2004) [34]

1. Score Systems, which mark player performance.
2. Experience Points Systems, where users' avatars or accounts "level up", quantifying their progress in the game, when specified goals or actions are achieved.
3. Goods Granting System Rewards, which consist of virtual items that can be used by players or their avatars.
4. Feedback system, which consists of messages from the system to inform or congratulate the user.
5. Redeemable Points System, which comprises points that can be earned, cashed in, and used inside the system for transactions.
6. Unlocking mechanisms, where players get access to more game content once certain requirements are met.
7. Achievements and Badges System, which consists of titles that are bound to players accounts, rewarding them for completing specific and sometimes challenging tasks.
8. Visual multimedia Systems, which aim to reward players with visual and audible attractive stimuli following successful plays or completion of tasks.

These reward systems can be combined and structured in order to motivate users to be on board and keep using an application. In that respect Eyal et al. [22] developed a reward system which they called *The Hook Reward Framework*. In this framework, the authors state that, in order to create high-frequency engagement, the reward systems must be structured in four-phases: (1) A Trigger to make the users start using the application; (2) An Action, which is a behaviour executed by users in anticipation of a reward; (3) A Variable Reward, which can be of any kind if the systems stated previously; and (4) Investment, in order to

improve the users experience or engagement of using the application by the rewards obtained in the process.

1.3 Hypotheses

Based on the concepts described on the Theoretical Background section and definition of the research problem to address in this thesis work, we hypothesise that:

H1 The application of Gamification strategies and mechanics to the design of an Web-Therapy hemianopia healthcare application does not degrade patients' adherence.

H2 The application of Gamification strategies and mechanics to the design of an Web-Therapy hemianopia healthcare application does not degrade its treatment component.

1.4 Research Questions

In order to assess the validity of the hypotheses stated above, this thesis work aims to provide an answer to the following research questions:

RQ1 How are Gamification tools and mechanics considered for improving the design of short-term engagement in a hemianopia Web-Therapy treatment application?

RQ2 How does a Gamified hemianopia Web-Therapy treatment application need to be designed, in terms of mechanics and interactions, in order to maintain its core treatment functionality?

1.5 Objectives

To answer the stated research questions, the work reported in this thesis aims to achieve the following objectives.

1.5.1 General objective

Design and evaluate Gamification tools and mechanics to increase short-term[4] user engagement in a web-therapy application, for increasing patient adherence and improving on the recovery treatment.

1.5.2 Specific objectives

The specific objectives derived from the general research objective are the following:

SO1 Study and identify what Gamification tools and mechanics can improve short-term engagement and patient adherence when applied to a healthcare Web-Therapy context, without harming the healthcare rehabilitation component.

[4]The thesis focuses on a short-term scope because of time constraint reasons, and a long-term study is proposed as future work

SO2 Redesign the Eye-search application in terms of users' interaction and system architecture, to allow the successful implementation of the studied and chosen Gamification tools and mechanisms.

SO3 Develop the redesigned Eye-search application and implement Gamification tools and mechanisms, which will allow the study of their effectiveness.

SO4 Reinforce the effectiveness of the applied Gamification mechanisms, in terms of adherence and engagement, without degrading the therapy component of the application.

1.6 Developed Solution

The developed solution for this thesis work consisted of a Gamification centred redesign of the Eye-Search application, and its corresponding validation, in terms of User Experience, without compromising its therapy component. This redesign focused mainly on the addition of Gamification mechanics as a way to increase the application engagement. This redesign was done using the MDA (Mechanics, Dynamics and Aesthetics) [34] framework. The redesign of the application is explained in depth in chapter 4. In summary, the following three main Gamification mechanics were used in the design:

1. Non-playable Character Companion: NPC was added into the application, to act as a guide and tutor to the user. This NPC accompanies the user as they use the application, acting as a guide, as the tutorials are given by this character. The NPC also functions as a source of intrinsic motivation to the user, as it gives the user positive and reinforcement feedback while they are doing each activity. All in all, this NPC gives the users a feeling of social relatedness [24] and support during the therapy process, as well as a source of help to enhance the application navigation and use.
2. Reward System: This system was implemented using the Hooks [22] methodology. Users are given daily and weekly goals, which consist of activities inside the application they are tasked to do. Each time the users complete these goals, a reward in the form of a cosmetic for the NPC companion is given to them. This system aimed to: First motivate users to interact daily with the application, and second as to interact with its recommended amount of 20-40 minutes. This last point was achieved by designing the tasks of the goals to take this amount of play time.
3. Unlockable Content and Customisation: Each reward consists of a cosmetic element that can be considered as a reward of the virtual good type, that can be equipped to the NPC companion. These rewards act as an extrinsic motivator and as a way to increase user commitment and engagement [71].

For the validation of the developed solution, as well as its gamified design, a proof of concept in the form of a mixed method study was carried out. The users selected for the study were the ones that had completed the therapy on the application, that is, users that had completed the daily goals for 28 days. With this user population, the following two analysis were conducted:

This study analysed data from two sources. The first corresponds to quantitative data logged by the application about users' performance and their use statistics of the application, in the time span of three months. And the second source, came from a user study in the form of a semi-structured personal interview held with users that had finished the therapy

provided by the application.

- For validating the perceived usefulness of the redesigned application, as well as validating user perception towards goals, rewards and the NPC companion, a thematic analysis was carried out over qualitative user study obtained from semi-structured interviews with a sample of the selected population of users.
- For validating that the redesigned application does not degrade its therapy component, a statistical data analysis was conducted. In this analysis, user performance of the redesigned version of the application was compared, in terms of users average reaction speed throughout the course of the therapy , with the user performance registered on the previous version of the application [54].

1.7 Methodology

For the software development, the *user centred design* was adopted for the design and programming of the solution. This development consisted of three iterations with the following steps: (1) Understanding of the context of use, (2) Specification of the user requirements, (3) Solution design and development; and (4) Revision, evaluation, and testing of the design against the requirements. This process is depicted in figure 1.3. This methodology was chosen as it allows the fast construction of systems focused on users, while at the same time, reducing the risk and uncertainty during development, as the target users of the product are involved through the whole process. Ensuring a highly accessible and usable product for them.

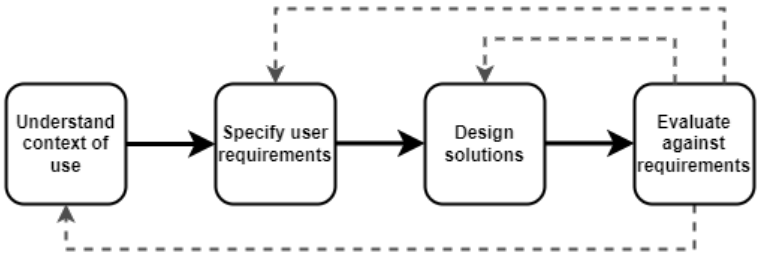


Figure 1.3
Schema depicting the user centred design methodology.

The research methodology used for studying the validity of the proposed hypotheses of this thesis work is an exploratory case study, based on the classic formulation proposed by Robert Yin [70]. This methodology was chosen mainly because it is quite effective for the investigation of empirical topics, situated in a real-life contemporary context, where there is no control over behaviours and events. Also, the "case" for this study is well defined, as the main target of the study are patients with hemianopia that use Web-Based Therapies for rehabilitation. And the exploratory counterpart of this investigation is chosen upon the fact that, as stated in section 2, to the best of our knowledge there is no information on past research relevant to the topic to be addressed in this thesis. Therefore, a considerable amount of work to be conducted in this research is expected to be spent exploring and studying different sources in detail, hence being a more flexible approach well suited for the case.

Regarding the methodology itself, it is composed of five main components that are defined as follows.

1.7.1 Study Questions

The research questions that prompted this thesis work are the ones stated in section 1.4, which mainly aim to address how Gamification must be used to increase patient engagement in a hemianopia healthcare Web-Therapy application, without degrading its treatment component.

1.7.2 Theoretical Framework and Study Propositions

The theoretical framework in which this thesis work is grounded is established in sections 1.1 and 2. The main components of this framework are: Gamification, therapy Apps, User experience, Human-Computer Interaction, and Healthcare applications.

It is necessary to establish the theoretical framework, as it encapsulates and defines this thesis work scope, as well as establishing the context in which the following study propositions are relevant:

- Implications and consequences of a healthcare hemianopia therapy when Gamification tools and mechanisms are applied.
- Gamification mechanisms and tools that are useful for the improvement of short-term engagement.
- The underlying relation between the implementation of Gamification tools and mechanics and patient adherence.

These propositions help lead the research focus, regarding the data that is necessary to obtain results and answering the stated questions in this thesis proposal. This development and study methodologies consists of the following steps followed to develop this thesis:

1. A first functional prototype was developed, which featured the core main therapy activities of the Eye-Search application: these are the four assessment tests and the visual search therapy game. For this prototype, the therapeutic background behind Eye-Search had to be studied, in order to maintain its core component. For the development of the prototype, it was done using the Unity game engine [64] with its WebGL [29] build. For this task, the engine was studied and familiarised with, in order to understand its features and limits.
2. The gamified version of the application was designed using the MDA Design Framework [34]. For this design, the state-of-the-art had to be researched, in order to choose what mechanics could be included in the new design for the fulfilment of this thesis work. Also, we studied how these mechanics affected the interaction between the user and the application. A validation of this design was conducted with the product owner.
3. Using MDA design, a wireframe prototype was developed, which featured all the new mechanics that were to be added to the redesign of Eye-Search.
4. A user study was conducted using the wireframe prototype. The study consisted of a qualitative validation with users, who were individually interviewed and who presented the prototype. This validation aimed to evaluate user perception towards the perceived

usefulness of the prototype, as well as the new Gamification mechanics added.

5. A second functional working prototype of the application was developed, where all the Gamification mechanics validated by the previous user study were implemented. This prototype was developed and implemented using a three-layer architecture, and was uploaded to a UCL server to be used during the next user validation.
6. With the second iteration of the prototype, a second validation was conducted with experienced users of Eye-Search and with the product owner. The user study used to validate this prototype consisted of a *Thinking Aloud* [33] study where users were delivered a means to interact with the latest prototype of the application and were asked to complete a series of tasks on the application, while spelling out their thoughts. During this validation, quantitative data was gathered regarding the user interaction with the application. The type of data gathered were the number of critical and non-critical errors made, time taken to complete tasks and if the user could successfully complete each task. This data logged was used for studying the usability of the prototype.
7. A third and last iteration of the application was developed, featuring all the feedback gathered on the second user study, as well as the product owner feedback. After applying the changes, this final iteration of the application was published and launched to the public on a UCL website.
8. A final study in the form of a proof of concept mixed method study was performed. This study analysed data from two sources:
   (a) The quantitative data logged by the system about users' performance and their application use data, were statistically analysed, in order to measure the application adherence and verify the non-degradation of the application's therapeutic component, in the time span of three months. The application's therapeutic component was measured in terms of users average reaction speed improvement throughout the course of the therapy and comparing it with the results obtained by the previous application, and the application adherence was measured in terms of average use time of the application by users, per therapy day, and by comparing the amount of users in the different stages of the application with the statistics of the original application.
   (b) Qualitative data from semi-structured personal interviews held with users that had finished the therapy provided by the application was analysed through a thematic analysis, which aimed to obtain insight about users perceived usefulness of the redesigned application, as well as validating user perception towards Gamification mechanics introduced.

1.8 Overview of the Thesis Document

The reminder of this thesis is structured as follows: In Chapter 2 the Related Work is presented and discussed, identifying the theoretical framework in which this work is developed, analysing the state of the art on user experience improvement, gamification applications and mechanics, and its use on healthcare contexts. In Chapters 3, 4, and 5, the three iterations of this thesis prototype are presented respectively. Each of these iterations consists of the identification of requirements for the building of the prototype, its design and development, its validation, and the results of the iteration process. In chapter 6, we present a validation study is presented, describing in detail the process and the two sources of data studied:

qualitative data from semi-structured personal interviews, and quantitative data about users performance, from the application logs. In addition, we discuss the obtained results and proposing reusable guidelines for the implementation of Gamification in a Web-Based Interventions for the treatment of hemianopia context. Lastly, in chapter 7, the conclusions of this thesis are stated and perspectives regarding future work are presented.

Chapter 2

Related Work

Prior research reports three main design currents to deal with the improvement of user experience and engagement in interactive systems. These are: *Persuasive Technology*, *Positive Technology*, and *Gamification*.

2.1 Persuasive Technology

Persuasive Technology, defined as interactive computing systems designed to change people's attitudes and behaviours, concentrates on experiences that are more beneficial from the user's perspective [1]. This approach has its basis in the psychological field of influence and persuasion. In particular, this design approach has been widely used in the field of mobile healthcare, which is the use of mobile applications for the assessment and improvement of lifestyle among users [46].

Despite its wide usage, this area is more developed in its psychological component than in design. In that respect, most of the research and empirical evidence on its effectiveness have not strictly followed a systematic process and failed to offer proper guidelines in designing software architectures [61]. Persuasive technology has shown to be more suitable for promoting activities for the improvement of lifestyles rather than increasing the enjoyment of existing ones, unlike Gamification. Even though, games and by consequence, gamified applications are rich in microsuasion elements, which are defined as smaller persuasive elements added seemingly to persuade and motivate users to keep using the application.

As stated by Fogg [1] the overall goal of most games is to provide entertainment, not to persuade. But during the entertainment experience, players are bombarded with microsuasion elements, sometimes continuously, designed to persuade them to keep playing. Among them, the most featured microsuasion elements on games are, as mentioned by the author, short-term engagement mechanics, like reward systems or enjoyable visual feedback like sound and animations. All in all, this makes *Persuasive Technology* a tool that, despite not being the best suited for the improvement of engagement, can greatly improve a gamified experience with microsuasion elements.

2.2 Positive Technology

Positive Technology is defined by Calvo et al. [12] as the application of *Positive Technology* on interactive computational systems. Positive psychology is the study of the "good life", or the positive aspects of the human experience that make life worth living on both individual and societal well-being. More concretely, Calvo et al. [12] argue that this design approach is part of a larger public concern about how our digital experience affects our emotions and our quality of life, thus reflecting an emerging focus on humanistic values in many different disciplines.

Based on Positive Psychology assumptions, *Positive Technology* can be used to manipulate the quality of human experience through its structuring, augmentation and/or replacement in order to generate well-being at these three key levels [9]:

1. **Hedonic** or the enjoying of self, which refers to using the technology to induce positive and pleasant experiences.
2. **Eudaimonic** or using technology to support individuals in reaching engaging and self-actualising experience.
3. **Social and Interpersonal level** or using the technology to support and improve social integration and connectedness.

Following this three level approach, Positive Psychology, and therefore *Positive Technology*, mainly focus on delivering three characteristics of personal experience, one for each key level: affective quality, engagement, and connectedness. In this way, if a technology is able to deliver this personal experience, following in the process the three key level approach of Positive Psychology, it is considered to be a *Positive Technology*.

One kind of technology capable of this in particular, are video games. As stated by Argenton et al. [3], video games are able to address these three key level approaches. In the **Hedonic** approach, video games can elicit several emotional states [44], being these in general associated to positive emotions, and to a wide variety of pleasant situational responses, and, in other cases, acting as cathartic pleasure as they represent a relief valve for emotional tensions, anger and aggressiveness. Regarding the **Eudaimonic** approach, video games can be identified as "flow activities", that is to say that video games are able to make the player enter a flow state, a state in which the player is fully immersed in a feeling of energised focus, full involvement, and enjoyment in the activity process [15]. The ability to make the player enter a flow state, makes the video game intrinsically able to provide enjoyable experiences creating rules that require the learning of skills, defining goals, giving feedback, making control possible, and fostering a sense of curiosity and discovery [3]. Lastly, games are able to explore the **Social** level, either by direct social interaction with other players through online components of games, or by making the player interact in various ways with Non-playable characters (NPCs).

On the whole, *Positive Technology* aims to understand how technology can be designed for people to experience positive affect but does not necessarily imply the design of a fun or pleasant-to-use product. As with the case with *Persuasive Technology*, the application of *Positive Technology* is not exclusive with other technologies, and other technologies can greatly benefit if they consider the principles and guidelines presented by *Positive Technology*

when designing their systems. *Positive Technology* acts as a valuable asset for the development and improvement of user experience and user-centred design models in technological design, being technologies like video games, and consequently serious games and gamified application, able to take full advantage and apply the principles and frameworks of *Positive Technology* when designing their applications.

2.3 Gamification

Gamification is defined as: *"The process of game-thinking and game mechanics to engage users and solve problems."* (Zichermann, p. 16) [71]. Gamification focuses on the application game mechanics in non-game contexts, in order to enhance systems by creating similar experiences to those experienced when playing games, motivating and engaging users in the process. [31] There are two main ways to promote user engagement concerning the state of the art in Gamification research and practice. First, Reward-Based Gamification focuses on creating an immediate spike in engagement as users strive to explore this new system [51]. As long as these rewards continue to be supplied to the user, their behaviours continue to be motivated as a way to earn the proposed rewards. As this approach largely depends on extrinsic reward mechanisms, it is more appropriate for fostering immediate to short-term engagement.

The second approach —Meaningful Gamification— as proposed by Nicholson [51], aims to motivate engagement through the generation of personal connections as a way to induce long-term change in users. In its core, it is grounded in a humanistic belief that there are some activities in which people engage in because they have intrinsic or internalised motivations for doing so. Nicholson describes an innovative gameful design that moves away from the usual reward-based design, which consists of six concepts:

- Play: Facilitating the freedom to explore and fail within boundaries.
- Exposition: Creating stories for participants that are integrated with the real world setting.
- Choice: Develop a system that allows the participants to have power in their hands.
- Information: Using game design and game display concepts to allow participants to learn more about the real-world context.
- Engagement: Encouraging participants to discover and learn from others interested.
- Reflection: Assisting participants in finding other interests.

Despite making the distinction between both approaches, it is worth pointing out that, as stated by Nicholson [51], they can both be used as a complement to each other. If the goal is long-term change, rewards must be used sparingly. If the player sets his or her own goal, then rewards can be useful to help a player know when he or she has done something to move toward that goal.

In the area of design methodologies for Gamification and game design, one which stands out is the MDA Framework [34], which breaks game design into three main components:

1. Mechanics: Coded subsystems and functioning components of the game, which guide the player actions.

2. Dynamics: Run-time behaviour of the mechanics acting on player input
3. Aesthetics: Emotional responses evoked in the player.

This framework formalises games and gamified applications, as artefacts that build behaviour via interaction. It supports clearer design choices and analysis at all levels of study and development. This framework allows the consideration of both designer and player perspectives, as the designer can only modify the game mechanics, which generate dynamics that are perceived as aesthetics by the player.

As the framework establishes, designers must consider which interacting with user inputs, generates emotional responses on users. Regarding useful game mechanics applied in Gamification context, Zichermann and Cunningham [71] describe the following main game mechanics:

- Points, distinguishing experience, redeemable, skill, karma and reputation points.
- Levels, in terms of complexity transition, as well as progress proof.
- Leaderboards, as social incentives.
- Badges, an indicator of social promotion.
- Onboarding of new players.
- Challenges and quests system.
- Social engagement loops.
- Customization.
- Feedback and Reinforcement.

In order to choose which game mechanic's should be included in a given context, these must be intrinsically related to the type of user the Gamification application is aiming for. Individuals respond and perceive Gamification differently according to individual attributes. Thus, a gamified application that motivates one individual might not have the same effect on another individual, and a "one-size-fits-all" approach towards *Gamification* tends to present mixed results on its effectiveness [32]. Following the same line of reasoning, the users of the Eye-Search application feature two main defying characteristics that must be considered: (1) They suffer the hemianopia condition in different degrees; (2) Their median age is 60 years [53].

To the best of our knowledge, there is no previous work that has connected Gamification with users of these two characteristics, and there are even fewer works that focus on applications for people with the hemianopia condition. The closest work that features this connection would be the work done by Waddington et al. [68], who developed a game-based therapy for the treatment of neurological vision impairment in young people. This application aimed to deliver a visual scanning of on-screen stimuli, with increased engagement and adherence of users. The game itself consists of a full-blown game experience, where the player is presented with an avatar character, who must progress through a series of levels in order to escape an island before a volcanic eruption. Each level consists of a visual scanning activity where a user must search for a specific stimulus in an array of coloured shapes. Despite the activity being successful, by fully engaging their young patients for the duration of the related therapy, this work does not provide useful guidelines to this thesis. First, applications designed for young people of median age 15 [68], greatly differ from the target user age of Eye-Search. And second, a game-based therapy greatly differs in design to the process of

gamifying and application, as the first acts as a full-blown game experience, which greatly focuses on featuring a coherent narrative, characters with roles and purposes; dialogues and diverse gameplay elements, which mainly focus on entertaining the user while delivering a therapy.

As stated, there is a gap in literature regarding guidelines or frameworks for the application of Gamification to the specific target users of the Eye-Search application. But, there are guidelines related to Gamification on older adults that can be useful in this context. One of these design guidelines is the one proposed by Gerling et al. [28], who addressed the knowledge gap in this area and conducted a literature review about game design for senior citizens experiencing age-related changes, especially cognitive and physical limitations. Of this study, the following guidelines can be extracted:

- Carefully explore the abilities of your target audience to provide accessible gameplay, recommending a participatory and iterative design approach closely involves the elderly persons.
- Create meaningful metaphors and relate to real-world actions to facilitate the entry into play, as elderly persons frequently lack gaming experience.
- Provide games which adapt to a broad range of players and gaming situations, for example, providing different player roles and levels of game complexity.

On the subject of applied and empirical studies of Gamification in the field of healthcare, there are works that review the current state of its application in the areas of physical improvement and weight loss [14], as well as the improvement of mental health and well-being [13]. For instance, Gamification has been successfully used for the treatment of cognitive behavioural therapy in children with anxiety disorders [60]. In this latter work, the researchers implemented Gamification mechanisms in a clinical portal geared towards children, known as SmartCAT (Smartphone-enhanced Child Anxiety Treatment). Before gamifying the portal, it only offered a two-way communication between the patient and the therapist. The designed Gamification mechanisms were based on a reward strategy so as to drive children engagement in completing their weekly skill-builder modules. The application proved to be successful, and showed that the application of Gamification over an already existing system can yield good results with the use of the reward strategy.

In the case of the application of Gamification in healthcare contexts, it has shown success in making mundane tasks interesting to patients. As stated by Lerouge et al. [42], in their literature review of application of user-centred design on diabetes studies, patients of this condition must adopt changes in their personal behaviours and habits in order to combat the condition. In this context, it was shown how the application of the reward Gamification mechanic as a form of award to users for routine behaviours and actions yielded high satisfaction among participants, making the process easier for them. Gamification has also been successful in the case of improving patient states of mind in complex healthcare scenarios. Moreno et al. [49] studied how Gamification mechanics can be successfully implemented in a support system for cancer patients. This support system was mainly implemented in order to improve their satisfaction, self-use, and self-esteem for coping with the cancer condition, as self-determination and fighting spirit is considered key in the treatment of cancer [48].

Overall, the area of Gamification application in healthcare has shown positive results on

different healthcare contexts in the recent years. Despite this, Gary et al. [27] made a review of healthcare applications and evaluated the negative effects that Gamification can bring into the healthcare context, in terms of acting as a distraction of the medical protocol. They concluded that these negative effects can occur when the Gamification applied is not liked or correct for the target users, and when application fatigue occurs, a phenomenon that is explained as the users difficulty to adapt to a different application than the ones they are used to using.

Gary et al. [27] also point out that the following challenges are still present in the area of Gamification applied to healthcare contexts:

1. A validated framework shown to improve health outcomes for all medical areas does not exist.
2. Gamification does not hold user interest for long periods of time.
3. A lack of user-centred design principles in building Gamification elements.
4. Clinicians are not included in Gamification design.

2.4 Web-Based Interventions

In the area of Web-Based Interventions, which is the case of Eye-Search, Barak et al. [5] conducted a literature review in order to propose guidelines as well as some clarity and consistency in this area. The authors propose that, in order to classify an application as a Web-Based Intervention, it must feature the following four key components to encapsulate the essential ingredient:

- **Program Content**: Considered by the authors as the most basic and necessary component of these kinds of applications, it consists of the disseminated information within the application, which is delivered to the users. This content can have two purposes: educate or create a therapeutic change.
- **Multimedia choices**: This refers to the multimedia option chosen by the application to disseminate its content, as many applications often use only large portions of texts for this purpose. Barak et al. [5] propose that including a greater variety of multimedia formats is advantageous and most probably makes the Web-Based Intervention more engaging and dynamic.
- **Provision of Interactive Online Activities**: This component indicates if the Web-Based Intervention offers patients the opportunity to participate within the program in a more interactive way, for example, in viewing their progress in self-monitoring tools or interactive activities. By including this component, patient interest and engagement with the program increases, while also enhancing patients' understanding of the program content. On the whole, these features evoke feelings of ownership with the Web-Based Intervention, making the user experience a more personalised one.
- **Guidance and Supportive Feedback**: It relates to a mechanism whereby patients can obtain information about themselves and their progress. As users of this kind of application usually need to act by themselves, guiding and supporting them can really benefit their performance.

Web-Based Interventions, as they are part of healthcare, must consider the target user

of the application, as, depending on the users, they might not have access if they feature some degree of disability, which is not considered in the design of the software. In the case of this thesis work, the Eye-Search application targets a user group which mainly features a disability of the kind of visual impairment of different degrees. In order to design an application which is usable by its audience, accessibility guidelines must be considered on its design. Despite there not being any direct guidelines for the design of applications related to users with the hemianopia condition, there are guidelines for the design of applications for users with visual impairments.

One closely related to the Web-Based Intervention nature of the application, are the Web Content Accessibility Guidelines (WCAG) [36], published by the World Wide Web Consortium (W3C). These guidelines can be separated in four main principles:

1. **Perceivable**: Information and user interface components must be presentable to users in ways they can perceive. Making the application flexible and adaptable in the way it displays information, as well as, distinguishable in any case.
2. **Operable**: User interface components and navigation must be operable, and flexible in the way it is operated.
3. **Understandable**: Information and the operation of the user interface must be understandable, predictable, and consistent on the whole application.
4. **Robustness**: Content must be robust enough that it can be interpreted by a wide variety of user agents, including technologies.

Other useful guidelines developed in the area of inclusive applications, are the ones presented by the International Game Developer Association (IGDA). The IGDA defines accessibility as: "The ability to play a game even when functioning under limiting conditions. Limiting conditions can be functional limitations, or disabilities — such as blindness, deafness, or mobility limitations" (IGDA, p. 5) [7]. Among the main categories of disabilities recognised by this organisation are: Visual, Auditory, Mobility and Cognitive disabilities.

For the context of this work, this literature review focuses on visual disabilities, as hemianopia belongs to this category. As described by IGDA, Visual disabilities come in three major types: blindness, which is the loss of vision not correctable with lenses; low vision, where light and motion detection is limited; and colour blindness, which is the inability to detect certain colours. In the case of the hemianopia condition, this can be categorised as a low vision visual impairment, as, this disability is defined as "A visual acuity of 20/70 or worse in the better eye using a best-corrected spectacle correction, or visual fields of 20°(twenty degrees) or less." (IGDA 5). For this kind of disability, the guidelines provided by the IGDA advise that strong emphasis must be put in the audio design of the game, and that many examples of inclusive audio design can be found on *audio games*. These are games in which the user interface and game events use primarily sounds instead of graphics to convey information to the player [25]. Those games can provide an accessible gaming experience to visually impaired players, usually handicapped by conventional games. Based on the literature research done by Garcia et al. [25], the following approaches can be taken when developing these kinds of games:

- Create and characterise game entities.
- Create and characterise the environment.

- Teach the player how to play or how to give instructions.
- Always provide input feedback.
- Create responsive game menus and teach the user how to navigate on them.

As stated by the IGDA, these guidelines and features of audio games can be used to improve the accessibility of any kind of game, even allowing that a game can be played regardless of the disability. In the case of Eye-Search, despite not being a game necessarily, it does feature many activities and interactions, which are closely related to them, especially on its therapy activities, which are based on a game. With this in mind, these guidelines are considered while developing the application.

2.5 Rehabilitation Therapies

In the domain of rehabilitation therapies, there have been works that study how the implementation of some game or Gamification mechanics can enhance or affect the therapeutic process. An instance of these studies is the one conducted by Gabele et al. [24] who, in the context of a Software-based training used in cognitive rehabilitation as a successful therapy for brain damage, proposed the inclusion of an NPC (Non-playable Character) Companion to support the patient therapy and analysed which characteristics it should have. The authors considered the use of an NPC in their rehabilitation program in order to promote the feeling of social relatedness during the therapy process. This sentiment is of utmost importance in these kinds of therapies, as, for the nature of the condition patients have, existing social contacts can be reduced considerably. With the inclusion of an NPC that assists the user, the software tries to provide a similar relationship to the one between therapist and patient that a clinical therapy features. After an explorative feasibility study based on a structured interview, the following guidelines were obtained:

- To support the patient's motivation, the companion can guide him/her starting from the initial training, show the patient progress on a map in rehabilitation, remind him/her of good experiences, note frequent mistakes made during training and set a reminder for the next training session.
- The desired companion is predominantly described as an empathetic friend and competent at the same time.
- The companion has to take the leading role and be motivating, but also strict if necessary. Being the NPC a combination of companion and mentor.
- The patient shows the desire for trust and guidance in a situation that cannot be assessed by the individual.
- The focus is therefore not on appearance, but rather on the attributes and characteristics of the NPC.
- The NPC age appearance preferred by users is defined by two factors: (1) The NPC must not be too old, as in the long-term, the NPC should remain strong and healthy; and (2) The users prefer characters which are closer to their own age.

On another note, the Eye-Search application induces results on the motor skills of users by repetitive practice, categorising it as a Practice-Based rehabilitation therapy. In this area, Johanson et al. [38] conducted a study about factors that influence skill development in a gaming context. These skills can be of two types: (1) Cognitive skills, which include

problem solving, memory, language, and emotional skills; and (2) Motor skills, which consist of anything that requires body or limb movements in order to make a physical response. In this context, the authors explored the effects of spaced practice on both types of skills development while playing games. Their research consisted of an experiment where users were asked to play for 25 minutes a "minimal action game", i.e., a game which features clear goals and requires minimal learning. The players were divided into two groups: one group would play continuously, while the other would have breaks of 10 minutes every 5 minutes of play. Both groups would have a break of 1 day before the last 5 minutes of play. Among the obtained results, the continuous play group performed poorly compared to the other group. The authors concluded that the difference in performance between groups is due to, in continuous practice, there being little no time for the brain to generalise and process the feedback and performance information gathered during play. In this way, the introduction of spaced practice can help the improvement of motor skills, which is applicable to the compensatory eye movement training featured in Eye-Search.

A factor strictly related to the effectiveness of rehabilitation treatment the is patient's adherence to them. As stated in the introduction, adherence to any kind of healthcare procedure is something that the patient must commit to, if he/she is expecting to succeed. Adherence is considered a modifier of utmost importance on health systems effectiveness, making user adherence a key factor on the effectiveness of an application like Eye-Search. In this context, studies have been made regarding patients' habit formation, for therapies and treatments that require perseverance and commitment from them.

Many health professionals often shy away from giving advice on modifying behaviour because they find traditional behaviour change strategies time-consuming to explain and difficult for the patient to implement [40]. And, even when patients successfully initiate the recommended changes to their routines, the gains are often transient [41] because few of the traditional behaviour change strategies have built-in mechanisms for maintenance. Despite this, once the habit is successfully formed, these are likely to persist even after conscious motivation or interest dissipate [26].

There have been studies on the influence of Gamification mechanics on habit formation. One of these is known as the Hook Model [22], which is defined as a model usable for the building of habit-forming products. This model establishes that, in order to "hook" the user or player with a product, they must pass through four phases: a trigger to begin using the product, an action to satisfy the trigger, a variable reward for the action, and some type of investment that, ultimately, makes the product more valuable to the user. As the user goes through these phases, he builds habits in the process. The application of a habit-formation framework, like the one established by the Hook-Model, to a healthcare context, would be able to ensure users adherence through the process, increasing in the process the probability of a successful treatment. This makes the Hook-Model a useful tool to apply on the redesign of Eye-Search.

2.6 Summary of Related Work

In HCI Gamification has a well-developed theoretical counterpart, with several studies reporting on tools and mechanics that proved to successfully increase engagement and general

user experience. However, there is a lack of reusable design knowledge, for instance in the form of guidelines or system architectures, as a way to assist software designers in the implementation of Gamification mechanics, especially in healthcare contexts. As stated by Gary et al. [27], there are no validated Gamification frameworks in the healthcare area that have shown to improve health outcomes. And in this same context, Gamification has in some cases, adopted negative connotations, being considered a distraction to healthcare interventions. This variable effectiveness of Gamification frameworks in healthcare is strictly correlated to the "one-size-fits-all" approach to the Gamification of systems, often used due to the lack of reusable guidelines. With this generic approach, the characteristics of the target users of the system are not considered, making Gamification not well received and sometimes incorrect for the target audience.

In light of these gaps, this thesis presents a case study that explores the effects of the application of Gamification on the engagement and adherence of users in a Web-Based Intervention for the treatment of the hemianopia condition. Aiming to contribute with verified and reusable frameworks and guidelines for the design of a healthcare Gamification application for users of old age who suffer from the hemianopia condition.

Chapter 3

Solution Design Iteration I: Therapy Prototyping

The first iteration of the application consisted of a simple web application, which featured the core activities of Eye-Search. This iteration aimed to study the software the project was going to be developed on and to analyse the insights of the therapy component of Eye-Search. This build also aimed to validate the base therapy components of the application, in order to ensure that the core mechanics were correctly implemented before studying Gamification mechanics and later adding new components to it.

3.1 Prototype Design

To develop this first iteration and choose which engine or software to use for its development, we first analysed which key features of the previous version of Eye-Search were required to be present on the new version. The old Eye-Search application was developed on Adobe Flash software [35] and was hosted on a web-page, allowing users to connect and access the therapy without needing to install further software. The application offered users an account system where they could register to the application using their email. The application offered its users 4 assessment activities: ***Visual Neglect Test***, ***Visual Field Test***, ***Crowded Desk Search Test*** and ***Activities of Daily Living Questionnaire***; and one therapy activity: The ***Visual Search Game***. Lastly, for each of these activities, user performance was logged and stored on a SQL database. Given this analysis, we identified key features that a new version of the application would need to have:

1. Be developed in an extensible and maintainable software, as its previous engine, Adobe Flash Player was no longer supported by browsers after December 31, 2020.
2. Be a web application with free access to its users.
3. Feature an account system for the users, in order to save their progress.
4. Feature the 5 key core interactable activities of Eye-Search.
5. Feature database connectivity to save user statistics and performance on the different activities.

On the basis of the five points raised, the engine chosen for the development of the application was Unity with its WebGL platform. The reason behind why Unity was chosen was because the Eye-Search application core component, the 5 therapy activities, have a high focus on interaction with a user interface, to generate visual feedback as well as allow the therapy to take place, making them be gamified in nature, and acting as kind of mini-games. In this way, the reason a Game Engine was chosen for developing the application was to optimise and focus the development on the user experience of the 5 core activities of the application. In this way, the activities performance, input delays, and responsive controls could be optimised, improving the user experience in the process. In addition, the Unity WebGl build integration is highly compatible with modern browsers, allowing the application to be more accessible, and maintainable over time.

3.2 Therapy Component Analysis

Before implementing each activity of the application for this prototype, we carried out a study of the core therapy features of the application. In this study, the previous version of the application, as well as the healthcare background of it was studied. Associated software requisites were extracted to be used for the implementation and validation of this same prototype.

3.2.1 Therapy Flow

The therapy provided by Eye-Search is based on a training procedure for a compensatory eye movement training therapy, designed to improve visual search performance in patients with visual field defects. To provide this therapy, the Eye-Search application consists of four assessment activities: ***Visual Neglect Test***, ***Visual Field Test***, ***Crowded Desk Search Test*** and ***Activities of Daily Living Questionnaire***; and one therapy activity: The ***Visual Search Game***. The user, upon registration is asked to do the four assessment activities and then he/she is allowed to interact with the visual search therapy game. The four assessment tests are used to analyse the user's condition, as well as measure the performance; while the visual search activity acts as the therapeutic training provided by the application. The therapy provided by the application has a recommended playtime of approximately one month in which the user is asked to do as many visual searches as possible. Each time the user reaches 400 visual searches, he/she is then asked to repeat the four assessment tests. In this way, the application can be separated in four stages:

- BL: Baseline, When the user has just started using the application.
- T1: after 400 visual searches of the therapy game.
- T2: after 800 visual searches of the therapy game.
- T3: after 1200 visual searches of the therapy game.

We explain each of the five main components of the application along the role each one plays in the therapy of the application:

3.2.2 Visual Neglect Test

The visual neglect test consists of an interactive timed activity in which users are presented with a frame which contains 192 black rings, arranged on 16 columns of 12 rings each. These rings are split into three types: (1) Rings with a small gap on top; (2) Rings with a small gap on their bottom; and (3) Fully complete rings. These three types are depicted on (Fig. 3.1).

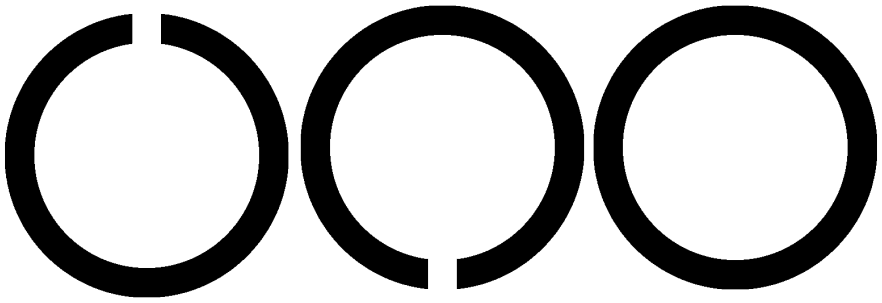


Figure 3.1
The three types of ring featured on the Visual Neglect Test.

As stated, 129 of these rings are present on a frame on screen, on 16 columns of 12 rings each, and each of these columns features 4 of each type of ring positioned randomly on the column. Having each ring a random offset of up to $\pm 0.7°$[1]on the x and y axis. In this way each ring category is presented 64 times, giving an equal distribution of ring types. The task presented to the user is to click on all the rings of type 1, with a gap on top, that he/she can find. Each time the user clicks on a ring, it flashes with a green colour for a brief time, in order to inform them that the correct type of ring was clicked. The user has 5 minutes to interact with this activity, but can end it at any time by clicking a finish button on the screen. This is depicted on (Fig. 3.2).

This assessment test is used to establish if the user features the Visual Neglect condition. This condition, also known as *visual inattention*, is a disorder of attention in which patients exhibit a horizontal gradation of attention across their visual field such that, when there are many competing stimuli present, they differentially respond to those on one side of the visual field. Patients with this condition often have normal visual fields, but it can also co-occur in patients with hemianopia [43]. The medical approach used by Eye-Search to diagnose the user with this condition is of the study of the user re-exploration, that is, by measuring the amount of revisits, or clicks twice on the rings on the screen. An analysis of his/her search behaviour can be made and can be successfully diagnosed [56].

Considering this medical approach, the Visual Neglect Assessment test logs the following data of the user performance:

- Number of targets or rings of type 1 found on the first 8 columns.
- Number of targets or rings of type 1 found on the last 8 columns.
- Number of times targets or rings type 1 found are clicked on the first 8 columns.
- Number of times targets or rings type 1 found are clicked on the last 8 columns.

[1]These degrees are calculated from a user who is fixed 57 cm away from the screen.

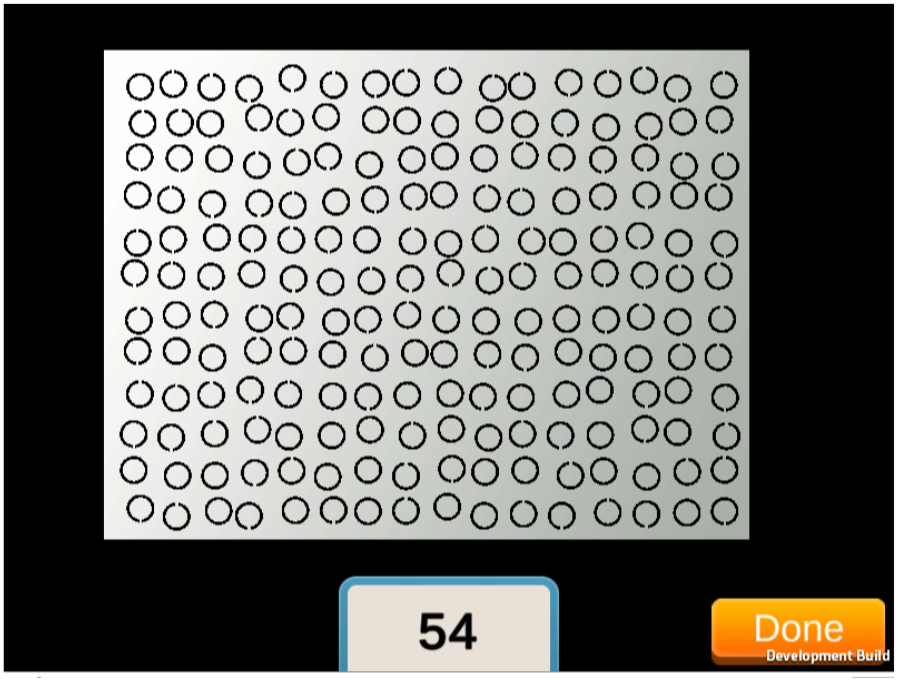


Figure 3.2
Display of the interactive phase of first prototype of the Visual Neglect Assessment Test.

As it can be seen on the data logged by the application, the user performance measured is split on the left and right side, in order to perform diagnoses for each half of their visual field. With this data logged by the test, Eye-Search diagnoses the user with Visual Neglect on either half of their visual field if *the user must miss twice as many targets on one side compared with the other, and he must revisit twice as many targets on one side compared with the other*. If this observed behaviour happens in at least two stages of the therapy he is categorised with visual neglect. Taking all this into account, the software requirements extracted from this assessment test are depicted on table (Table. 3.1).

Table 3.1
Software Requirements of the Visual Neglect Assessment Test.

Healthcare Requirements	Usability Requirements	Database Requirement
1. The gap on the rings must be of 0.3°. 2. There must be 129 targets distributed pseudo-randomly over 16 columns of 12 rings, each having 4 of each type of ring. 3. The rings must have a jitter ±0.7°in the x and y axis.	4. The user has 5 minutes to complete each round. 5. The user can end the test at any time.	6. Number of targets clicked on the left side, the first 8 columns, and the right side, last 8 columns. 7. Number of revisits (distractors clicked more than once) on the left and right side. 8. Time spent on the test.

3.2.3 Visual Field Test

The Visual Field Test consists of 36 multiple choice trials, where the user is briefly presented with a visual stimulus and then is asked to select between four alternatives which were the stimuli he/she saw. The test visual stimuli consist of a centre red cross with a yellow outline and a combination of 16 different points of diameter 0.5°distributed over a grey canvas. These points are positioned on the canvas by displaying 8 of these on the left side, and other 8 at the right side, on 4 different degrees from the user point of view, which can be 1, 2.5, 5 and 10°accordingly, in both x and y axis. This is depicted on (Fig. 3.3). Lastly, the closer the point to the centre cross, the less contrast it has.

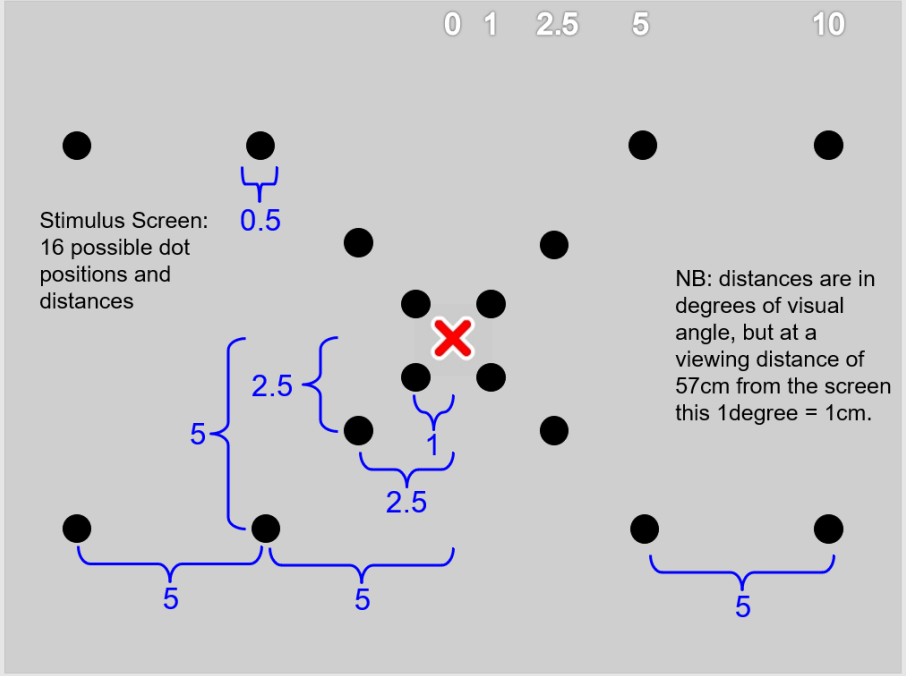


Figure 3.3
Visual Field Test visual stimuli distribution.

Regarding the test itself, before beginning the activity, the user is asked to do the test in an ideally dark atmosphere and to position oneself at a fixed distance of 57 cm from the screen. These instructions are depicted in (Fig. 3.4), where a red line is shown to the user in order to provide him with a tool to estimate these 57 cm, as three of these lines are approximately the right distance to the screen.

When the trail begins, the user is given four seconds to concentrate and pay attention to the stimuli that will be shown. In each of these four seconds a red square is shown at the centre of the screen, surrounding the central cross. For each second, this red square gets smaller, and at the fourth second the stimulus is shown for half a second. After the stimuli is shown, four alternatives are displayed on screen and a *one use* retry button to watch the stimuli again, as shown on (Fig. 3.5).

The points selected for the stimuli on each trial are chosen so each point is at least shown four times over the 36 trials. In this way, the test measures the user's field of view by

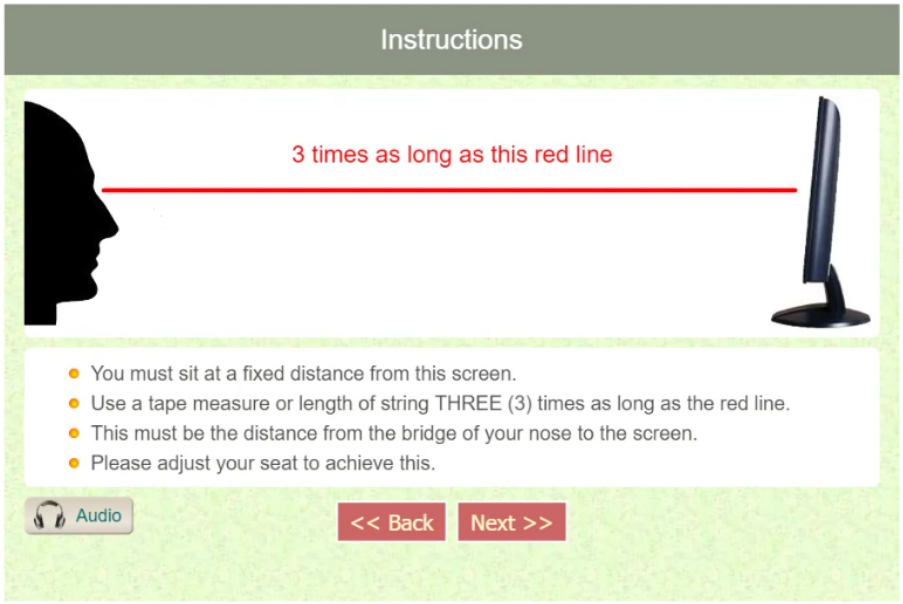


Figure 3.4
Instructions of the Visual Field Test featured on the original version of Eye-Search.

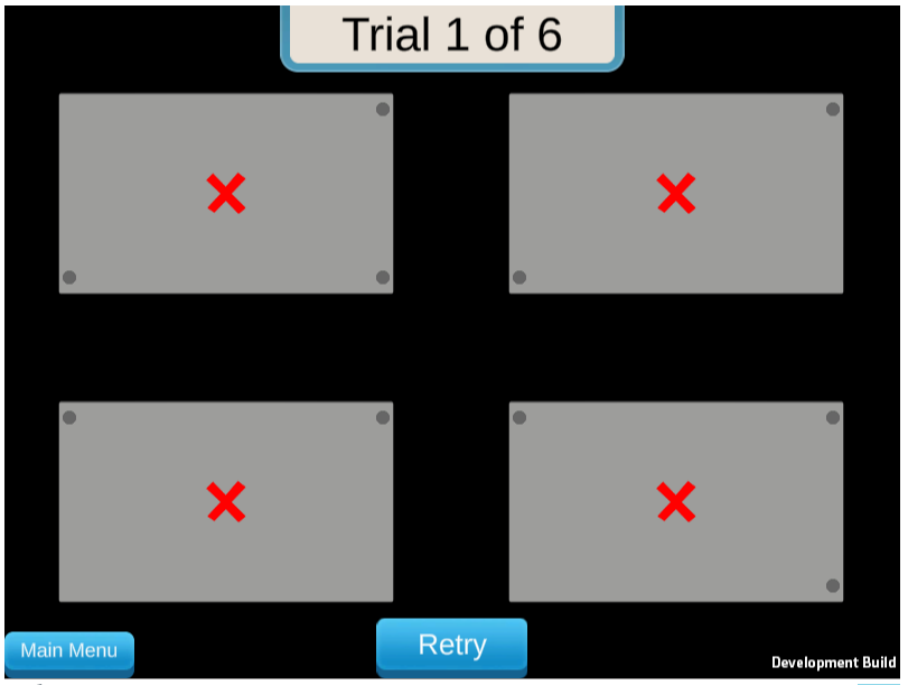


Figure 3.5
Visual Field Test alternative phase on the first prototype of the application.

assigning individual scores in a scale from 1 to 4 to each point, increasing the score by 1 each time the user successfully detects one of these points. It is important to outline that the multiple-choice answers for each trial do not have a binary correct/incorrect answer, rather, it is checked if in the option provided by the user, there were points that correctly belonged to the stimuli shown, so they can be counted as seen. An example of these alternatives is

depicted on (Fig. 3.6), where all the stimuli combinations for the visual distance of 2.5°are shown.

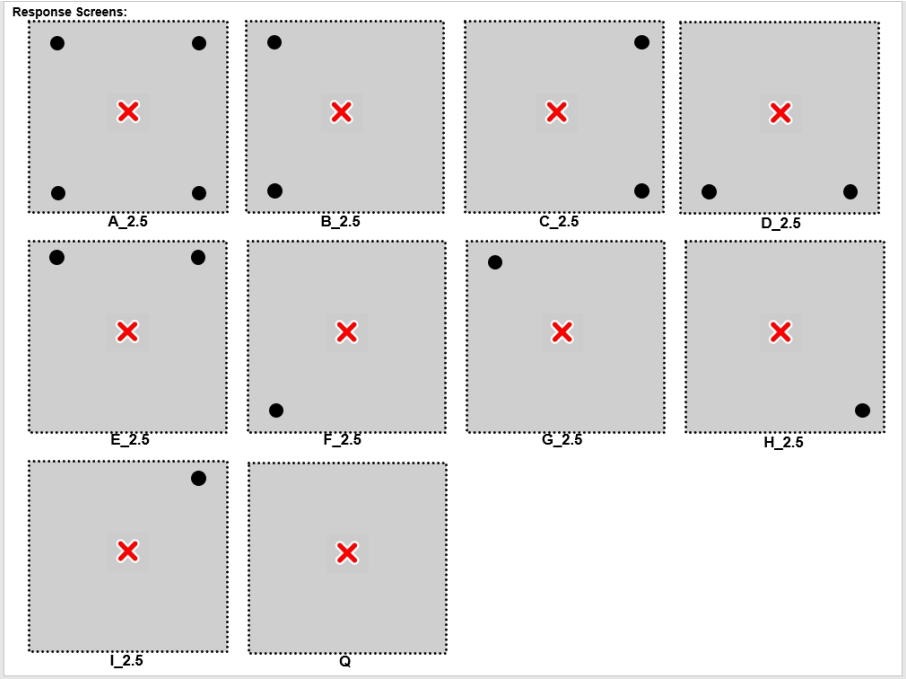


Figure 3.6
Visual Field Test possible distributions by degree of vision.

Table 3.2
Software Requirements of the Visual Field Assessment Test.

Healthcare Requirements	Usability Requirements	Database Requirement
1. 4 rows (top right, top left, down right and down left) of 4 points with visual distance 1, 2.5, 5, and 10°from the center of the screen must be set up. 2. Each point must have a set contrast with the background depending of their visual distance to the center of the screen. These values for the 4 points of each row are: 72, 70, 66 and 55 respectively. 3. Each point must appear 4 times over the 36 trials. 4. Each of the 36 trials are predefined, in terms of points to appear and alternatives to show. These trials must be arranged pseudo-randomly in the test.	5. The user must complete the 36 trials to finish the activity.	6. The times each of the 16 points was seen by the user, i.e., an alternative which contained a point from the stimuli shown was chosen. The minimum value is 0 and the maximum 4.

Using this score system, this test purpose on the therapy flow is to measure the user's field of view and categorise her/him with hemianopia on their left or right side accordingly. For this diagnosis, an analysis of the user performance is made over the points, splitting it over the 8 points positioned on the left, and the 8 points positioned on the right. In this way, the approach taken for this diagnosis is the following: *If the user misses 3 or more points on one side, i.e., and obtains a score less than 2 on that individual point, on over 50% of the therapy stages, it is considered that the user has a consistent field loss on that side, categorising him with hemianopia on that side.* The software requirements that correspond to this activity are depicted on (Table. 3.2).

3.2.4 Crowded Desk Test

The Crowded Desk Test is the third of the assessment test offered by the application. This test consists of an interactable search game activity where the user is tasked with searching a specific mundane desk object, like pencils, erasers, etc; in a desk-like environment full of other desk objects. An example of this is depicted on (Fig. 3.7). which consists of a screen-shot of a search round on the Crowded Desk Test on the first prototype of the application. Over a background multiple desk objects are positioned with a fixed timer to search for them.

Figure 3.7
Search round of the Crowded Desk Test on the first prototype of the solution.

This process of search has to be done 17 times, and each trial goes as follows: First a desk object is shown to the user for 5 seconds. After the 5 seconds the user is presented with a desk environment, where multiple desk objects are present in a random manner. The user has 60 seconds to find the object by clicking on it, if he clicks on an incorrect object a feedback is given to the user and the test continues until time runs out or the correct object is found. Regarding the object, this is chosen from a list in a random manner and for 8 of the trials it is positioned on the left side of the screen, and 8 times on the right side. The remaining round, which acts as the first one, positions the object in any of the sides and acts

as a tutorial trial, so the user can get used to the test before the application starts measuring the performance.

This test is used to measure the user's reaction speed, in both the left and right side. This outcome of this test is one of the two metrics used by the application to analyse and track user progress, as, Eye-Search, as a compensatory training therapy, aims to reduce this mean reaction speed as the user progresses through each stage of the therapy. The data logged by the test and used as a metric is the mean reaction speed in milliseconds for both their left and right side, as the object is positioned 8 times randomly on each side. The requirements extracted from this activity are depicted on (Table. 3.3).

Table 3.3
Software Requirements of the Crowded Desk Search Assessment Test.

Healthcare Requirements	Usability Requirements	Database Requirement
1. Over the 17 rounds, the first one is a "trial" round and user performance is not measured on it, and the and the remaining 16, in eight of them the item to search for must be positioned on the left side, and 8 on the right side.	2. The user has 60 seconds to complete each trial. 3. If time during a trial runs out, user performance in not logged. 4. The user must complete the 17 trials to finish the activity.	5. User reaction speed for the left and right side.

3.2.5 Activities of Daily Living Questionnaire

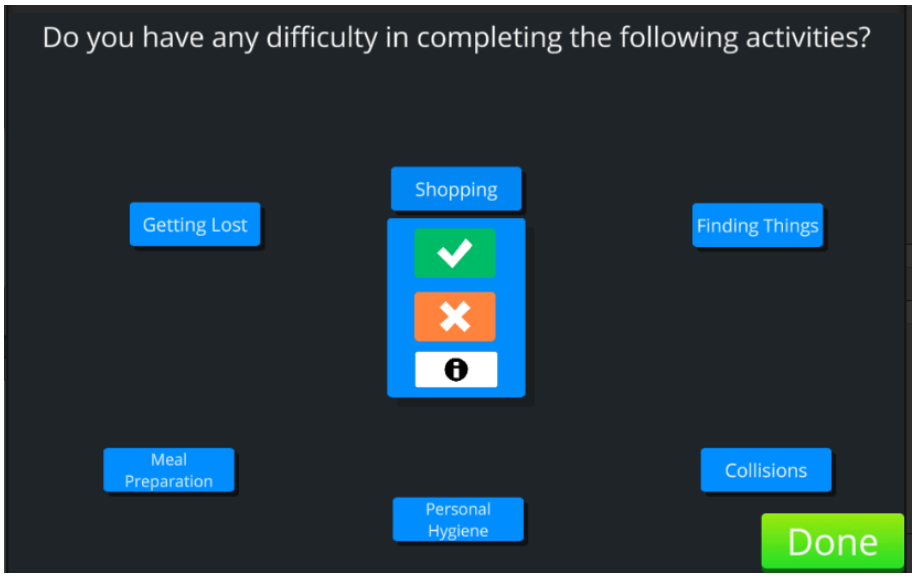


Figure 3.8
Activities of Daily Living Questionnaire on the first prototype of the application.

The last assessment activity consists of an interactive questionnaire of 6 items. In this questionnaire, users are asked to rate on a scale of 5 steps, from no problem to impossible,

6 activities related to their daily living: Shopping, Meal Preparation, Personal Hygiene, Collisions, Getting Lost and Finding Things. Once all 6 items are answered the test ends. The six items, as well as the version of this test on the first prototype of the solution is depicted in (Fig. 3.8). Here the 6 activities are featured on the screen as buttons, which the user can press to rate their difficulty on that item.

This test provides the second metric used in Eye-Search to measure the user performance. The average self-reported difficulty ratings for the 6 activities of daily living is used to track how the user has evolved over time and if the effects of the compensatory therapy have helped with this daily life. The associated software requirements are shown on (Table. 3.4).

Table 3.4
Software Requirements of the Crowded Desk Search Assessment Test.

Healthcare Requirements	Usability Requirements	Database Requirement
1. The user must rate their perceived difficulty, from impossible to no problem, on the six activities of daily living: (1) Shopping, (2) Meal preparation, (3) Personal hygiene, (4) Collisions, (5) Getting lost, and, (6) Finding things.	2. The user must answer each of the six questionnaires, one at a time. 3. The user must answer all questionnaires before finishing the test.	5. User perceived difficulty for each of the activities of daily living.

3.2.6 Visual Search Therapy Game

The last interactive activity on the Eye-Search application consists of a game aimed to provide a computer-based training task for the compensatory eye movement training therapy. This game consists of rounds where a stimulus, which is a white disc with a black letter C within, is positioned at the centre left or right side on the screen, at a horizontal angular distance of 57.5°, awaiting for the user to click on it. After the stimuli detects user input on itself, it starts moving towards the centre of the screen with a random trajectory between ±20°on vertical angular distance. After reaching the centre of the screen, this disc jumps 15°along the same trajectory, ending up with its inner black C pointing up or down. In this game users are tasked with, initially searching the disk on the screen and clicking it to begin the round, and after the round starts and the disk starts moving, they follow with their sight the disk as it travels through the screen until it stops after it jumps. Then finally, report as soon as possible at the bottom of the screen if the ending position of the disk was facing top or down. A depiction of the implementation of this activity on this iteration of the prototype is shown on (Fig. 3.9). This game features 16 stages with different difficulty settings, between them there is increased speed, lower contrast on the target disk and the presence of distractor disks which lack the *black c* within them. The application logs the amount of trials users have done so far, as well as their playtime on each session, considering also how many trials they perform. The associated requirements to this activity are depicted on: (Table. 3.5).

Figure 3.9
Visual Search Therapy Activity on the first prototype of the application.

Table 3.5
Software Requirements of the Visual Search Activity.

Healthcare Requirements	Usability Requirements	Database Requirement
1. The target is initially positioned at 17.5° if visual angle from the center of the screen, in either the left or right side. 2. The target randomly moves at fixed speed towards a location between -20° and +20° on the horizontal. 3. After crossing the center of the screen, the target jumps 15° along the same trajectory. 4. The target must either end pointing up or down, equally distributed among the trials.	5. The user can do as many trials as desired.	6. User reaction speed per trial.

3.3 Prototype development

We first studied and familiarised ourselves with the Unity Game engine for the development of the prototype. Unity Game engine was studied and familiarised with. Unity can be summarised as a component-based engine, where a hierarchy of these components is assembled and used to construct applications. In general, a Unity project or application is composed of multiple *Scenes*, which act as the root of this hierarchy. These *Scenes* are assets that contain all or part of a game or application, and any number of these scenes can be used on a project. From this *Scene*, any object positioned on it is a *GameObject*, which is the fundamental object in Unity and can be defined as a container of components, being that these components are the ones that define and implement the *GameObject* behaviour and functionalities. A graph depicting the described Unity hierarchy is shown on (Fig. 3.10).

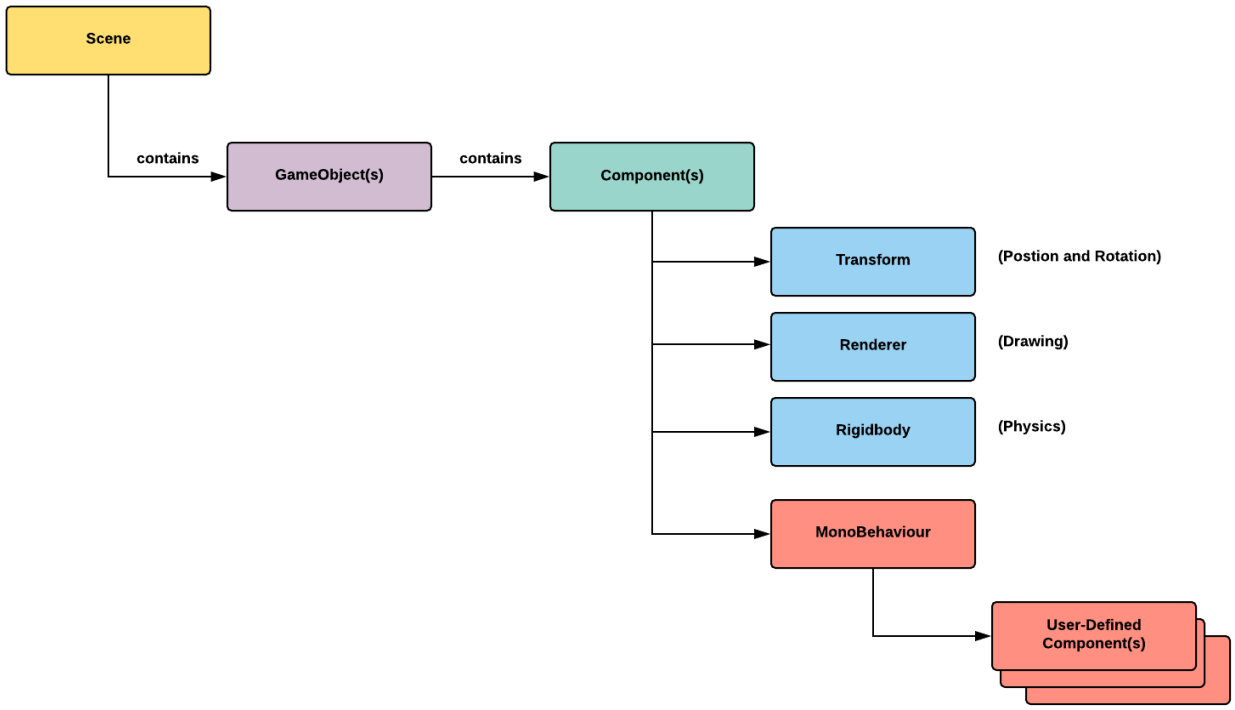


Figure 3.10
Schema of Unity component-driven engine with a combination of components that build games. Taken from (Baron, 2019) [6]

Regarding scripting in the engine, Unity engine is written in C++ language, but it offers a primary scripting api in C#, being the last the main language used for programming in Unity. Regarding web development, since 2014 on the version Unity 5.0, Unity started supporting the WebGl Platform as an option to build and run Unity applications. WebGL, which is short for Web Graphics Library, is a JavaScript API for rendering interactive 2D and 3D graphics within any compatible web browser without the use of plug-ins, making it fully integrated with web standards. WebGL allows Unity to publish content as JavaScript programs, which use HTML5 technologies and the WebGL rendering API to run Unity content in a web browser.

Once familiarised with the tools to use, the second step taken was the redaction of a

software requirement document. The requirements for this iteration of the product were identified from the therapy component analysis previously displayed, where requirements were divided into three types: (1) Healthcare requirements, which acknowledge the specific variables each activity must fulfil in order to correctly provide the expected assessment or therapy; (2) Usability requirements, stating the minimal user interaction needed for each activity to be fulfilled; and (3) Database requirement, which state what info regarding user performance must be logged from each activity. Lastly, before proceeding to implement each requirement, the document was approved by the client, allowing the implementation of the described requisites, ensuring that the prototype indeed implemented correct and necessary features.

Once the requirements were validated, the next step taken was the design application. For this, the software design methodology adopted was a modular programming approach. This design approach allows for a loose coupling between modules, as well as a high cohesion between each one, greatly improving the readability and extensibility of the project. Also, the Unity Engine greatly benefits form this approach, as multiple optimisations, which will be described in this section, can be incorporated

Six independent modules were created, one for each of the 5 core activities of Eye-Search, and a 6th module was created in order to act as a main menu of the prototype. Each module consisted of a Unity *Scene*, Assets used by that scene, and an *Assembly definition*. This last one consists of an Unity Asset, which can organise a group of scripts into *assemblies*, which are C# code libraries that contain all the compiled classes and structs that are defined by the scripts and which also define references to other assemblies.

By splitting the application into different Scenes, the Unity Engine performance is greatly optimised, as, with the load of each scene, only the assets and resources used by that scene are loaded into memory. On the other hand, the use of *Assembly Definitions* allows to organise and hierarchise the project code in a way that promotes modularity and reusability, as, in order to access to code from another assembly file, a link between assemblies must be made, which can only be unidirectional, as cyclical references between assemblies are not allowed. Lastly, the use of assemblies allows for optimizations in building time of the project, as, each time a script is changed, Unity only has to recompile the assembly to which that script belongs to, lowering overall compilation time for iterative code changes. With this in mind, the project code was structured as depicted in figure 3.11. A main assembly with all the code in common between activities, as well as code related to the application main menu was grouped on the System assembly, with all the assemblies from each activity referencing it.

Using this modular approach, each activity was implemented into an independent module, having in mind the functional and healthcare related requisites, in order to replicate the therapeutic effect of Eye-Search as faithful as possible. Lastly, each activity implemented a data structure, which represented the data each activity would need to log, and this structure could be inspected to verify if the data logging was correct.

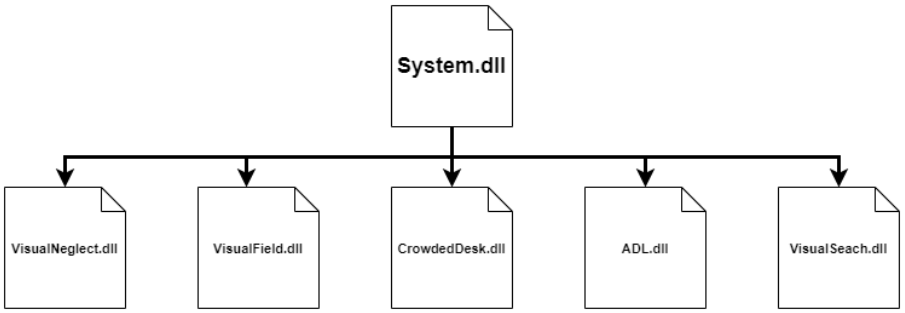


Figure 3.11
Assembly hierarchy on solution first iteration.

3.4 Iteration Evaluation

The evaluation of the prototype was carried out through two processes: A system testing and an Acceptance Testing. We explain each of these processes in detail in this section.

3.4.1 System Testing

The system testing consisted of the functional testing in the form of unit tests of each of the functional requirements specified on the Software Requirement Specification of this iteration of the solution. This unit testing was done using the Unity Test Framework package, which is a tool that allows testing code in a static environment or at run time in a custom-made scene, while also testing the code on specific target platforms. Using this framework, tests were structured on the following way:

- A test suite was created for each assembly definition.
- Each healthcare requirement was tested in a static environment, through a unit test.
- Each usability requirement was tested on run time in a test *Scene*, where user inputs were simulated, verifying the complying of the requirement and the stability of the code.
- Each database requirement was tested on run time on a test *Scene*, after simulating a play session, and verifying the correctness of the logged data of it.

This validation allowed us to verify the correctness and successful implementation of the agreed requirements on the developed solution of this iteration, ascertaining that the application was being built correctly and was a solid foundation for the next iteration of development.

3.4.2 Acceptance Test

For this version of the prototype, an acceptance test was held. This validation consisted in the use of the application executed against test scenarios (that represent a "player" or "user" journey), undertaken by a subject-matter expert (SME). In this kind of validation, the focus is on the journey and not on technical or system-specific details, staying away from "click-by-click" test steps to allow for a variance in users' behaviour

For the acceptance test of this iteration of the solution, the SME chosen to be in charge of the execution was the client, Professor. Alex Leff. The test scenarios chosen for the validation were designed by the SME, and consisted of typical user case scenarios of each of the five activities featured on the prototype. The acceptance criteria for each of these scenarios consisted in the correctness of:

- The healthcare variables and rules that operate over each test.
- The correct operation of activities conditions for fulfilment, and interactivity.
- The correctness of the generated user performance logs, checking the statistics were correctly generated and measured.

In order to deliver the prototype to the product owner for this acceptance test, a simple WebGL build was made. This prototype featured the four assessment activities, the Visual Search Activity and a menu where these activities could be accessed from. This acceptance test ended with successful results, as the prototype met the acceptance criteria, complying with both the functional and non-functional requirements established for this iteration of the solution. Summarising, given the three criteria established, the developed prototype was successfully implemented, and the healthcare background which dictates over implementation activities was validated, putting emphasis in that the application complies with the medical requirements needed for the therapy to be carried out.

In this iteration, the development focused on the correct implementation of the core component of the Eye-Search application, which are the four assessment activities, and the Visual Search Therapeutic activity. To ensure the correct implementation of the therapeutic component, this prototype was validated through a system testing, which covered each of software requirements specified for each activity, ensuring that each of the precise healthcare criteria needed for the therapy to be effective is met. In addition, an acceptance test with the SME was carried out, where the prototype developed was put in test through multiple case scenarios where the correctness of the activities was successfully evaluated. This first prototype effectively replicated the healthcare components that dictate over the Eye-Search compensatory hemianopia treatment provided, and acts as a verified foundation for the further development and integration of Gamification mechanics on this thesis work, as the core therapy component of the application has been correctly implemented and can be built upon, with the certainty that the therapy has been correctly implemented.

Chapter 4

Solution Design Iteration II: Gamification Prototyping and Design

Once the core therapy component of the application was validated, the next step was to design a gamified version of the solution. This iteration developed a conceptual design of the gamified version of the application using the MDA framework, and to validate it through a qualitative formative user study, where an intermediate design of the solution was built in the form of a wireframe prototype. With this in mind, the design made for the proposed solution consists of a group of chosen mechanics that, after interacting with the user, aim to evoke specific feelings in them. This design, as well as the chosen mechanics, dynamics and aesthetics selected for the design are depicted in: (Fig. 4.1), and each of them will be explained in detail in this chapter.

4.1 Mechanics

The base component of an application designed with the MDA framework are mechanics'. These are defined as: *"Constructs of rules and feedback loops intended to produce enjoyable gameplay. They are the building blocks that can be applied and combined to gamify any non-game context."* (Kumar, p. 69) [39] Mechanics are directly influenced by designers, and in order to choose which to add, they must be selected based on a thorough understanding of the type of user the application for to, as well as the mission of the application. With this in mind, the following mechanics were chosen for the gamified version of the application:

4.1.1 Non-playable Character

A Non-playable character is defined as a character in a game which is not controlled by a player [47]. The term carries a connotation that the character is not hostile towards players, and that they are entities whose behaviour is usually scripted and automatic. Non player characters serve a number of purposes in games, being the following three being the most common, non exclusive, usages [66]:

1. As plot device: NPCs can be used to advance the storyline.

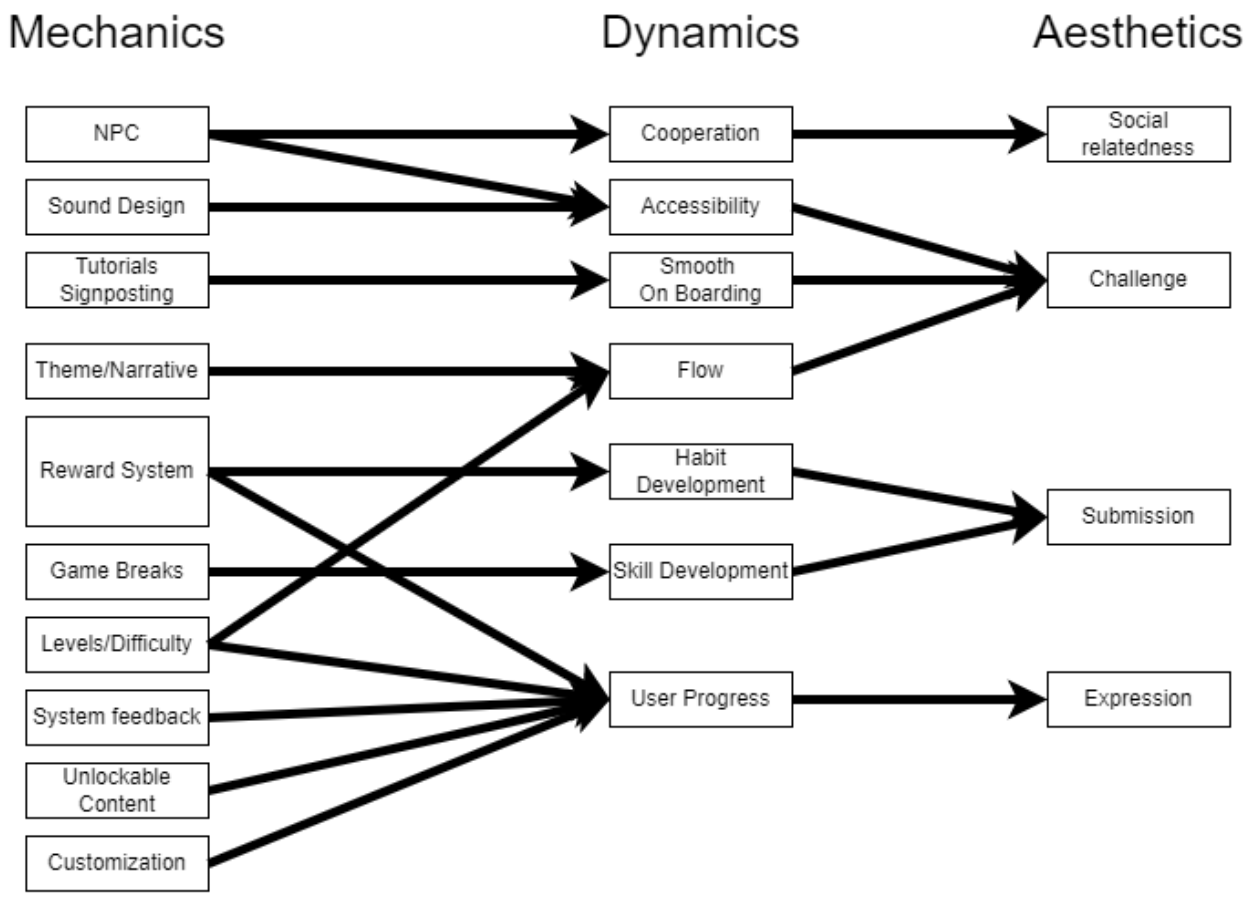


Figure 4.1
MDA design of the gamified version of Eye-Search.

2. For assistance: Acting as partners to the gamer.
3. Game functions: NPCs often serve as *save points*, *item stores*, *health regeneration points* and so on.

As can be seen, NPCs have a very versatile usage, being able to fulfil multiple roles. One of these roles, the companion one, in practice, can cover the three main purposes stated before. As a companion, an NPC can act as an assistant and partner to the player during their playtime and be key points to the theme and narrative of the game, while also encapsulating and being a point of access to functionalities and mechanics, which themselves, can act as tutorials for it. Companions NPCS, because of their (nearly) continuous presence throughout the gameplay, are the NPCs with the highest influence on the player's experiences and expectations [19]. These types of NPC have been implemented in the area of videogames for decades, and as stated by the literature study by Bouquet et al. *"They are an essential part of the player experience by ensuring that the player has fun and a sense of immersion in the game world"* (Bouquet, p. 2) [10].

Due to the benefits and impact NPCs have shown in video game contexts, the effects of their addition to non-game contexts has been widely studied. An example of this, as stated

in the 2 section, was the sudy carried out by Gabele et al. [24], who studied the use of NPCs as a Gamification mechanic that can be added to therapeutic healthcare contexts to provide a source of social relatedness and support to the user, while also improving the therapeutic process. The main reason the authors considered the use of an NPC in their application, was due to the nature of the condition their patients have, where existing social contacts can be reduced considerably. In the context of this thesis work, this social isolation also applies to users who experience the hemianopia condition [54]. Considering this context, the inclusion of an NPC companion on the redesign of Eye-Search was chosen, as the introduction of this kind of NPC significantly increases game enjoyment [20] and provide a source of social support for the users who are under the therapy provided by the application.

With this context in mind, an NPC companion was designed as a mechanic to be added to the gamified version of the Eye-Search application. For the design of this NPC, the guidelines provided by the study of Gabele et al. [24] were considered. Using these guidelines, this character was designed on par with the game theme and would have the role of a goal giver and tutor during therapy sessions, being a source of information and help if needed. Also, for its role as a tutor, the tutorial provided by the application, as well as feedback from the system towards the user, would be given by this character. In this way, the NPC companion enhances the user navigation on the application, the immersion and replayability of it [4].

Regarding its design, the results of a user study done by Gabele et al. [24] was also considered. The NPC was conceived as an older age doctor in order to fulfil two preferences from the users: (1) A companion in an age range similar to the users creates closeness with them, and (2) An authority figure, as is the case with a doctor, creating a sense of trust, making him trustworthy, which can accept its guidance without hesitation. With these considerations in mind, the NPC design is depicted in (Fig. 4.2). Lastly, in order to promote the closeness between the user and the NPC companion, the NPC was chosen as the target for the cosmetic rewards provided by the application. This is explained more in detail in section 4.1.7.

In summary the NPC companion was designed with the following characteristics and functions:

1. The companion is present in each scene and activity of the game, highlighting his/her role as a companion.
2. The tutorials and feedback of the application are delivered by the NPC.
3. The NPC is the target of the rewards given by the application, making the user "invest" in him as they obtain more rewards.
4. Its design is of a middle-aged doctor, to emphasise its image as a close companion to the user, and as an authority figure who can be trusted.

4.1.2 Sound Design

In order to ease the use of the application, as well as improving its accessibility to the target user population, design elements from the area of Audio Games can be borrowed. These are games in which the user interface and game events use primarily sounds instead of graphics to convey information to the player [25]. Despite Eye-Search not being exactly this kind of application, the target users can present the following visual disabilities, which, as stated

Figure 4.2
Design of the NPC companion for the redesigned Eye-Search. Art by Pablo Polaco.

and identified by the IGDA [7] game accessibility guidelines, do limit the condition on how these kind of users experience games:

- Partial Blindness, defined as a vision restriction on either one or both eyes, not correctable with lenses [23].
- Low Vision, which considers lower visual acuity and visual field [23].
- Colour Blindness, which is the inability to detect certain colours.

Additionally, the IGDA recommends that for visual disabilities, users could play and successfully interact with these games provided there was some degree of magnification of the screen, as well as, visual and sound cues.

In addition to IGDA recommendations, Garcia et al. [25] wrote design guidelines for the design of audio games, based on a literature review of both designs and implementation of existing audio games. Using these two sources as a basis, the following audio game mechanics were introduced on the redesign of Eye-Search:

- Use of audio cues for every game event, so the player knows what is happening, helping the immersion [7].
- Allow the repetition of information if requested by the user, as they might not get it the first time, as well as requesting additional information [25].
- Sound feedback for the player input, so they know the results of his/her input command or even if the game processed their action [7].
- Enumerate options in menus to ease navigation [7].
- For object representation, an object should be described by using a more accurate sound or combination of sounds. The sound must match the player's mental model to be recognised, and different objects should sound different [25].
- Use sounds of to describe the status of objects or characters, as well as their whereabouts in the scenario [25].

Given the context of the application with a deeper sound design, and audio game features designed for people with visual impairments of different degrees, greatly ease the use of the application and the overall game experience, directly impacting its accessibility.

4.1.3 Tutorials and Signposting

Following the guidelines for the development of Web-Based Interventions proposed by Barak et al. [5], upgrades were added to the tutorials and system feedback of the Eye-Search application. These upgrades were chosen for the redesign in order to further comply with two of the four key components for Web-Based interventions defined by Barak et al.:

1. In terms of the Program Content, improvements, in the form of more detailed steps, were designed to the tutorials for each activity featured on Eye-Search. Also, tutorials would need to be adjusted for the new Gamification related features that were added to the design. These tutorials would be associated with the NPC companion character, in order to emphasise its role as a tutor and a guide. The inclusion of improved tutorials and higher numbers of signposting also allows a smooth transition to the new application. New users can adapt to it easily, while easing the transfer of experienced users to the new version.
2. For the Multimedia Choices, between the improvements to the tutorials, animations inside the application were designed to explain the functionality of each activity in detail to the users.

The improvement of tutorials greatly benefits the application smooth transition of old and new users, as well as, easing the learning curve of the new Gamification features of the application, and, by making the NPC companion the one that delivers these tutorials and signposting, its role as a tutor is reinforced.

4.1.4 Theme and Narrative

Theme and narrative grant a purpose to the player's actions, giving him/her intrinsic motivation. For this same purpose, a unifying theme for all the interactions on the redesigned version of the application was designed, in order to increase user immersion and engagement, as the inclusion of narrative enhances gameplay and engenders compelling and interesting play [57]. The design of this narrative was done using Bizzcochi's narrative framework, which states that a narrative is split into storyworld, characters, emotion, narrative interface and micro-narrative [8]. Using this framework, the following theme and narrative design was made:

- For the story world, which is the environment within which the game unfolds [8], the interactions occur mainly in a cork board, where the user is informed that different items are displayed, which are strictly related to an online hemianopia therapy. Among these items there are daily goals, information cards, a user profile, and a menu for the NPC, this can be appreciated on figure (Fig. 4.3). The user is also informed that a hemianopia treatment centre is rewarding users with packages for completing the daily activities posted on the board.
- Regarding the characters, the application only features two other characters, in addition

to the user, the NPC companion, and the hemianopia treatment centre, with only the first interacting directly with the user.

- Respecting the emotions, these can be separated between the ones expressed by characters and the emotions generated by the play process [59]. For the first, the NPC companion always encourages and gives positive feedback to the user, by cheering him/her or congratulating him/her on their efforts. In the case of the emotions generated by using the application, it tries to generate a welcoming atmosphere, as well as making the user feel proud of accomplishment by completing the daily goals.
- For the narrative interface, the design strategy used was the incorporation of narrative into the design of the interface itself, in order to maintain the immersion. In this way, the interface was designed around the board of goals.
- Lastly, the micro-narrative element, can be visualised in the three types of goals presented by the application: The Daily, weekly and therapy goals. These goals are described in detail in section 4.1.8. In this narrative context, each of these goals act as a gameplay-driven localised arc, where the user finds a relationship between the successful completion of the micro-narrative, in this case the presented goal, and related pleasures of the interaction experience.

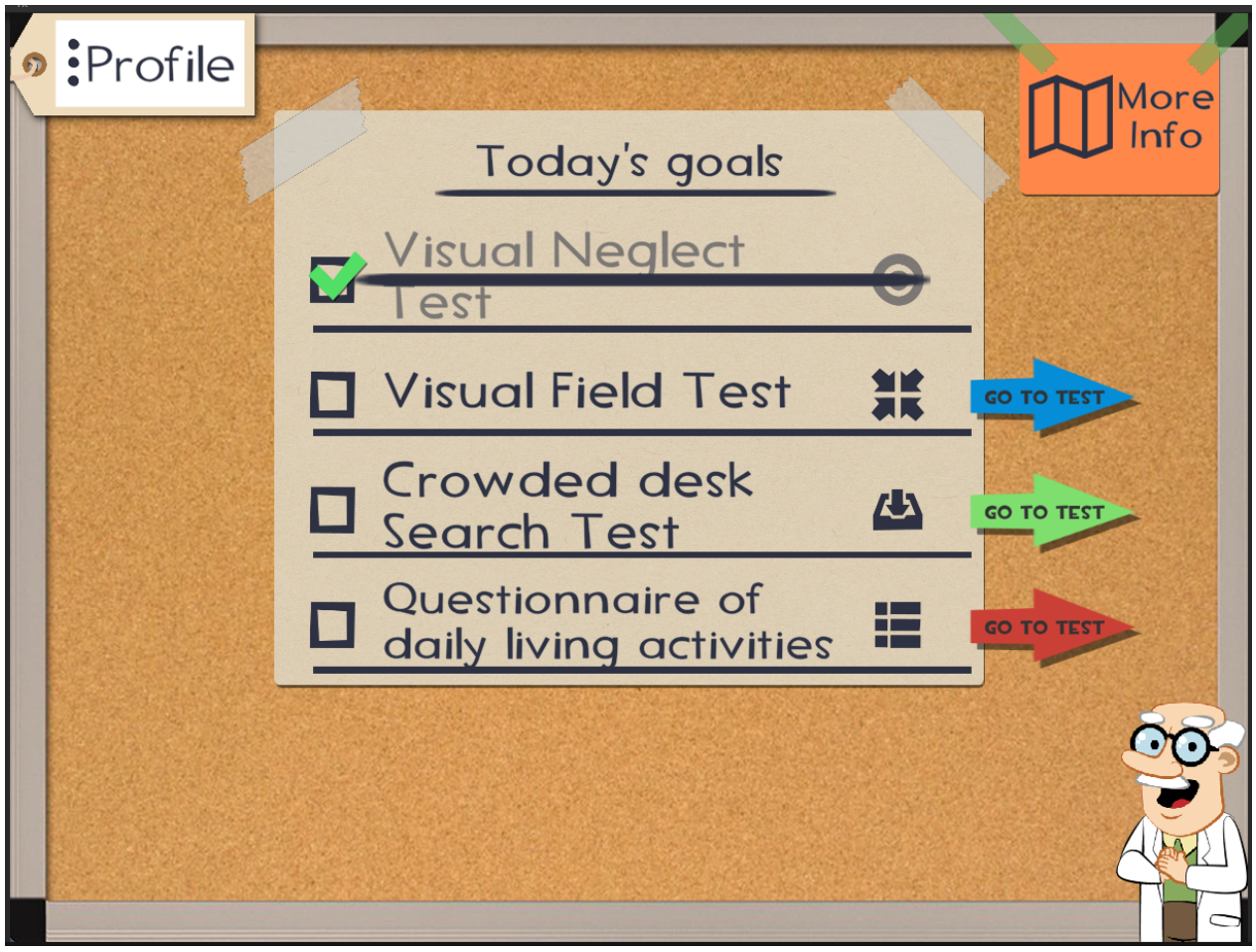


Figure 4.3
Capture of the main menu featured on the prototype of the second iteration of the solution.

4.1.5 Levels and Difficulty

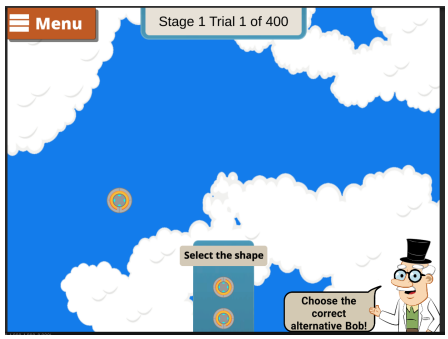
In a gameful context, a level is a game mechanic that works as a virtual space where an environment, assets and challenges are arranged in a way that engages the player in a fun and interesting experience [63]. These levels move the player between them, usually featuring a progressively-increasing difficulty, new concepts, and challenges to keep users interested and maintain them engaged [63]. Levels also serve as a marker for players to know where they stand in a gaming experience over time, marking their progress on the application [71]. In this same context, Zichermann et al. [71] propose that successful level design should be made with three concepts in mind: (1) Logical, that is, that the transition between levels in terms of difficulty or features should be easy for the player to understand; (2) Extensible, to easily add new levels to the game experience; and (3) Flexible, to appeal to players with different skill levels.

With these, the therapy activity of the application, i.e., the Visual Search Therapy Game was redesigned, in terms of visual themes, levels, and difficulty, to increase the overall engagement of this activity. First, three different visual themes were designed for the Visual Search Therapy game. Each of these themes had a specific visual motif in terms of theme, visual, and audio design, while conserving the same core gameplay and healthcare variables established for the activity. These visual themes contribute towards player engagement in that they make the process of doing multiple trials less exhausting and repetitive, as different aesthetics that are eye-catching and eye-pleasing are useful for drawing the players attention and help him/her maintain full immersion and engagement. With this, three designs were implemented: (1) a UFO; (2) a lily pad on a pond; and (3) a billiard themed one. These designs are depicted in figure (Fig. 4.4):

Second, regarding levels and difficulty, 16 levels were designed for this version of the Visual Search, each with increasing difficulty. These levels were designed considering the therapy flow on the application, which states that in order to fulfil the therapy, the user must complete 1,200 visual searches in the time lapse of 28 days. With this in mind, the 16 levels were designed to act as a progress of the user through each variance of the Visual Search game. For the user to progress to the next level, the pacing was distributed taking 25 visual searches to progress. To complete all levels, the user must do 400 visual searches for each activity. Each of these levels increase in difficulty in relation to the last. This variance in difficulty acts as an indicator of progress and the development of seamlessly difficult transitions for the improvement of replay value. With this in mind, six difficulty modifiers, which were also included in the previous version of the application, were used to design each of the difficulty levels. These six modifiers are:

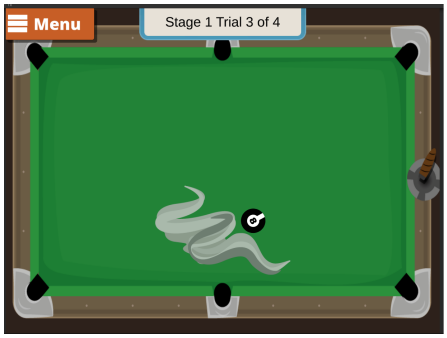
- Increasing game speed.
- Switching between linear and triangular trajectories.
- The addition of up to three distractor targets.
- Lowering the contrast of the target.
- Lowering the contrast of the background.

For the redesign, an adjustment to the growth of some values, such as game speed per level and contrast of the target, was made to this difficulty modifiers, in order to fit each visual motif of the different variances of the visual search game, as well as, tinkering with the



((a)) UFO visual theme variety

((b)) Lily pad visual theme variety.



((c)) Billiard visual theme variety.

Figure 4.4
The three visual varieties of the Visual Search Therapy activity featured on the second iteration of the redesign of the Eye-Search application.

difficulty of the activity, to make the difficulty in scaling more progressive and subtle.

4.1.6 System Feedback

To maintain the user informed on his/her progress, and also work as an intrinsic motivator, the application feedback as a whole was improved in the redesign. Complying with the 3rd core component of Web-Based Interventions as stated by Barak et al.[5], **Guidance and Supportive Feedback** was improved in the application through three main features:

1. Positive and Reinforcement Feedback: This type of feedback was designed to be incorporated into multiple instances of the application. In each of the five core activities of the application, positive feedback delivered by the NPC Companion was introduced. It would congratulate the user for each successful interaction, depending on the activity, and give reinforcement feedback for each mistake, reinforcing the role of a companion.
2. Weekly feedback: Each time the user completes a week of therapy (or 7 goals successfully) feedback is delivered to her/him by the NPC companion. It informs the user about the results of his/her last assessment tests, and how he/she has improved on each of them.
3. User Profile: In the main menu a user profile was introduced to the redesign. This profile is split into 2 categories: (1) The first gives the user information about their progress on the therapy as a whole, where information about the number of visual searches done, daily and weekly goals completed, rewards obtained and weekly goal

progress are displayed; (2) In the second category, the user can view their performance on the Visual Field and Crowded Desk Assessment Tests. For each of these tests, their latest three assessments are displayed, in the form of a table or chart, so the user themselves can monitor their progress.

4. Assessment Test Performance Feedback: After each assessment activity, the user is informed about their performance on the activity they just performed.

4.1.7 Unlockable Content and Customisation

Unlockable content refers to content that is available in video games but is not accessible unless something is performed by the player to get access to it. This content can either be new mechanics and features that are enabled for the player, to rewards in the form in-game prizes that can be collected by the users. This way, unlockable content allows for the introduction of in-game collections of virtual items, which, as stated by Zichermann et al., is one of the most powerful motivators among humans [71]. In this context, James Halpern [30] recognised ten motives for which the act of collecting is such a strong motivator:

1. Knowledge and learning.
2. Relaxation and stress reduction.
3. Personal pleasure (including appreciation of beauty and pride of ownership.
4. Social interaction with fellow collectors and others (i.e., sharing pleasure and knowledge).
5. Competitive challenge.
6. Recognition by fellow collectors and perhaps even noncollectors.
7. Altruism (since many great collections are ultimately donated to museums and learning institutions).
8. Desire to control, possess, and bring order to a small (or even a massive) part of the world.
9. Nostalgia and/or a connection to history.
10. Accumulation and diversification of wealth (which can ultimately provide a measure of security and freedom).

With this in mind, two types of unlockable contents were added into the gamified design of the application. The first comes in the form of in-game goods, which are rewarded to the user for completing a series of tasks given by the application. This reward mechanism is explained in detail in section 4.1.8. The goods rewarded come in two forms, which will be explained down below.

The first type of in-game goods corresponds to cosmetics objects of five different categories: Head, Neck, Body, Legs, and Chest. These cosmetics are stored on a collection menu, and can be equipped by the user, to the NPC companion, in order for him to wear them while he accompanies the user on the application. This type of good acts as an intrinsic motivator by motivating the user to collect for relaxation and stress reduction, personal pleasure and altruism, while also introducing customization in the application. This customization of the NPC companion to the user acts as a way to increase user commitment and value to his/her experience in the application [71]. An example of this customization process is depicted in figure (Fig. 4.5). The second type of good corresponds to four paper pieces which are

rewarded to the player each time the weekly goal is completed and are directly linked with the therapy goal. The purpose of this good is explained more in detail in section 4.1.8.

The second type of unlockable content added to the redesign version of the application corresponds to the difficulty levels of each of the visual search activities. To advance to the next level, the previous one has to be completed. With this in mind, unlockable and collectable content was included as mechanics on the redesigned version of the Eye-Search application in order to act as an intrinsic motivator, a source of commitment, and as a reward for the player's actions.

Figure 4.5
Capture of the collection menu on the prototype of the second iteration of the solution.

4.1.8 Reward System

A rewards system can be defined as a system which aims to motivate and engage its users by the distribution of rewards [18]. This motivation can be intrinsic, which are the motivations that derive from our core self, while extrinsic motivations are stated as the motivation driven mostly by the world around us, such as the desire to obtain goods[71]. Also, these two motivations systems are not exclusive, and both can be implemented to complement each other[51]. As stated in the problem statement, adherence to any kind of treatment is key and

a core modifier of health systems effectiveness. The reward system designed for this version of the application aims to address this issue, by *maintaining user adherence, until the habit of using the application daily is formed.* In this section the reward system design for the gamified version will be explained in two parts: first the intrinsic motivation system will be explained, and then the extrinsic reward system.

As stated in chapter 2, and described by Zicheran et al.:*"Intrinsic motivations are those that derive from our core self and are not necessarily based on the world around us"* (Zicheran, p. 26)[71]. The intrinsic motivation system added to the redesign of the Eye-Search application was designed considering five of the six components for meaningful Gamification proposed by Nicholson. In order to build this "Meaningful Gamification" into the system, the following game mechanics were added to contribute to these points:

- The **Play** and **Engagement** components were addressed by the addition of the three different game modes added to the Visual Search Therapy Game of the application, which contribute towards a more diverse and engaging experience.
- In the **Exposition** component, three micro-narrative elements were included along the daily, weekly and therapy goal. These goals will be explained in this section.
- The component of **Choice** was addressed by the addition of the three versions of the Visual Search therapy activity, as well as the different selectable difficulty settings for each one.
- Lastly, the **Information** component was addressed by the increased information regarding the hemianopia condition delivered by the informative loading screens, as well as information about the user performance in the form of feedback, delivered by the system and the NPC companion.

An intrinsic motivation system, allows users to engage and stay in a system, despite there not being any short-term rewards, acting as a transition element built into the Gamification system, where the players transition from enjoying the short-term bursts of engagement an extrinsic reward system can deliver, to engaging directly with the experience delivered by the gameful application [51].

As for the extrinsic reward system, it was built with the objective of creating immediate spikes of engagement to users, as they are rewarded with in-game goods or currency for their actions, and, as long as these rewards are continuously supplied, the user engagement will prevail [71]. A reward system excels in creating short term engagement, which can be directly applied to the relatively short-term play of the Eye-Search application, where recommended sessions go for 20-40 minutes. In this way, extrinsic rewards can act as motivators to ease the onboarding of the application for old and new users. Despite this, a short-term reach on the motivation is not always enough to make users adhere to the therapy to its very end, which takes about 28 days to fulfil, but, this type of motivation can be used to engage the users until the habit of using the therapy application is formed. When patients successfully initiate changes to their routines to adopt a new habit, they are discouraged, as the gains are often transient[41], as the behaviour change strategies do not usually have built-in mechanisms for maintenance, but, once the habit is formed, these are likely to persist even after conscious motivation or interest dissipates[26]. In other words, maintenance mechanisms, such as extrinsic rewards, can keep users engaged until habit formation is completed.

Taking all this into consideration, the redesigned Eye-Search extrinsic reward system was designed to deliver short-term engagement to users, as a maintenance mechanism, to keep them engaged until the habit of using the daily therapy provided by the application is formed. For the design of the extrinsic reward system, to maintain users interest through the continuous supply of rewards, the Hook Reward Framework[22] was used. As stated by Eyal et al. a useful or a reward system that *hooks* its user has 4 main components: (1) A trigger that makes the user begin using the application or come back to it; (2) actions or interactions between the user and the application; (3) variable rewards given to the user for his/her actions; and (4) user investment in the game, in order to make him/her commit to it and return to the experience.

As stated by Eyal et al., to successfully implement this reward design framework, the first step is to feature a trigger that gets the user on board and become invested in the application. In order to accomplish this, the Gamification mechanics of **Missions and Quests** were used on the redesign. Missions and Quests are defined as: *"A prescribed set of gameplay actions which follow a designed guided path"*(Duggan, p. 215) [18]. A mission or quest can involve singular or multiple steps, which can be unstructured or require a certain order in order to achieve completion, being this last case categorised as progression missions. These steps might revolve around the same gameplay behaviour or could be an around-the-world variety, where different gameplay behaviours featured on the game must be performed. Lastly, it is common for missions to reward for each step completed, or upon completion, while also allowing the unlocking of other missions. In addition, quests and missions can be used as a structured way to give players direction for what to do within the world of the gamified experience [71]. If beforehand the players are informed by the system of the possible rewards the mission might have, it helps to motivate the players by causing intrigue and anticipation [71], as they will associate the completion of the mission with the supply of rewards. Despite this, to avoid letting players down, a mission reward must be designed in a way that it balances its value with the effort paid/time spent to obtain it [71]. In summary, missions and quests can be used to act as an anticipation and be linked with rewards, while easing the playthrough of the users. These missions provide the player a sense of control, give direction and link pursuit of achievement to engagement in game mechanics, making this sense of accomplishment a source of intrinsic motivation [62].

Taking these frameworks and mechanics into consideration, three rewards systems were designed for the gamified version of Eye-Search: (1) A Daily Goal Reward; (2) A weekly Goal Reward; and (3) A therapy completion reward.

Daily Goal Reward System

The daily goal reward system consists in a Hook Framework Reward Loop, which is structured on the following way:

1. Trigger: In order to motivate the user to start using the application, or log in to it daily, a quest or goal Gamification mechanic was introduced. When the user logs in into the application for the first time in a day, he/she would be presented with a goal by the NPC companion. This goal is refreshed daily if accomplished by the user, and this process continues for a duration of 28 days, which is the duration of the therapy provided by the application.

2. Actions: The daily goal presented to the user consists of a series of in application tasks, which the user has to fulfil. The tasks, which constitute the goal are of the kind *around-the-world variety*, that is, different interactive activities on the application, chosen based on the recommended activities the user should do when using the application, based on how far they have progressed on the therapy. These quests can either be the four assessment tests, or a recommended amount of visual searches distributed between its three variances, in order to make the user interact with the application the recommended time between 20 to 40 minutes. In addition, when the tasks involve the visual search activity, these increase in difficulty each day, by requiring more total searches, in order to maintain user engagement through the days. Lastly, this task is always featured prominently on the centre of the screen on the main menu, where the progress of this task is also displayed.
3. Variable Reward: For the fulfilment of the daily goal, the user is rewarded with a new in-game good in the form of a cosmetic item, wearable by the NPC Companion. Each of these cosmetics is unique.
4. User Investment: Each of the rewards earned are added to the user collection, increasing it in size and therefore, the amount of combination of cosmetics the NPC companion wears. Also, each time a goal is completed, the user is notified that he/she comes a step closer to the Weekly Goal, which will be explained in the next section.

This daily reward system was designed with three purposes in mind: (1) Act as a hook or trigger so users log in into the application daily; (2) Give players direction of what to do when they begin a play session, working as a guidance towards the amount of play for which the therapy becomes effective; and (3) Motivate users to use the application for at least its recommended amount.

Weekly Goal Reward System

Also modelled with the Hook Reward Framework, the weekly goals track how many daily goals the user has completed, and reward them each time they complete 7 daily goals. This reward system is structured in the following way:

1. Trigger: In order to further motivate the user into using the application daily on a weekly basis, a weekly goal is given to the user for each of the 4 weeks the therapy lasts. These weekly goals are refreshed each time one is accomplished.
2. Actions: The steps of these kinds of goals consist of the completion of seven daily goals of the on Daily Reward System.
3. Variable Reward: Two rewards are supplied to the user for each weekly goal completed. First, a special cosmetic is awarded to the user, consisting of a medal from the following four categories: Bronze, Silver, Gold and Special Eye-Search Medal. For each weekly goal completed, a medal of higher value is awarded to the user. The second reward consists of a piece of paper with a number and a figure. Once four of these papers are gathered the user receives a reward for completing the therapy. This is further explained in the following section.
4. User Investment: Just like the Daily Goals, each medal obtained is added to the user collection, and the papers the user gathers are displayed on the user profile, symbolising how many weeks the user has completed.

This Weekly reward system was designed with the purpose of motivating and rewarding the user for continuous play during a week, while also being a visual representation of how much he/she has progressed during the therapy

Therapy Completion Reward

The long-term goal, represented by the number of weeks they have interacted with the application, or paper pieces they have collected, works as an intrinsic motivator as the user is informed that the compensatory therapy the application is based on, begins showing results after one month of use. This way, once all paper pieces are collected, i.e., the user has successfully completed 28 daily goals and 4 weekly goals, the user is informed on how much they have progressed since the start of the therapy, and are congratulated by the NPC companion, as well as, delivering a special message from him.

With these points into account, the rewards system aims to engage players and improve the application adherence by delivering extrinsic rewards for the short-term engagement through the daily and weekly goals, and intrinsic motivation by delivering a meaningful Gamification experience.

4.1.9 Game Breaks

Based on the study done by Johanson et al. [38], the implementation of spaced practice and scheduled breaks improves cognitive and motor skills development. With this study in mind, spaced practice was included in the redesign of the application through two features. The first is the addition of information cards that are displayed during the loading screens of the application, i.e., each time the user moves from one activity to another. These cards feature useful information regarding the hemianopia condition for the users to read, creating some space between each activity of the application. Lastly, spaced practice is also featured on the daily goals of the reward system, as they encourage the user to log in daily, and then wait until the next day to start another session of play of the recommended amount of 20 minutes.

4.2 Dynamics

Dynamics are defined as the player's interactions with the game mechanics, they determine what each player is doing in response to the mechanics of the system, both individually and with other players [71]. In this way, game dynamics influence what actions the player can take at a given moment, and how these actions can help them achieve their objectives inside the game [21]. With this in mind, in the context of this work, the following dynamics, generated by the user interaction with the already described mechanics, are explained down below.

4.2.1 Cooperation

In the context of this work, cooperation is given by the interaction between the player and the NPC companion. Specifically, cooperation is reflected on how the user and the NPC

companion share common goals and experiences, as the companion is always present as the user interacts with the application [20].

4.2.2 Accessibility

As stated, the mechanics of sound design, tutorials and signposting delivered by the NPC companion greatly improve the application accessibility. As stated by the IGDA, these mechanics aim to allow players with limiting conditions, such as low vision, to interact with the application, despite their condition.

4.2.3 Smooth On-Boarding

On boarding refers to the act of bringing new users into a system. And in the case of an evolving application with different versions of an application, easing the transition between versions for old users. The tutorials and signposting delivered by the NPC companion focus on easing this process.

4.2.4 Flow

Flow can be defined as *"a feeling of complete and energised focus in an activity, with a high level of enjoyment and fulfilment."* (Schell, p. 138) [63]. Many game mechanics aim to evoke this feeling of flow on the players by creating experiences interesting enough, it is possible to hold the player's focus as long and as intensely as possible [63]. As previously stated in chapter 2, games that are able to evoke this flow dynamic or state, are identified as flow activities, and in consequence a positive technology. In order to evoke flow, four key components [63] are considered as essential to be featured on a gameful application: clear goals, no distractions, direct feedback, and that the application is continuously challenging. Hereafter, each of these key components will be explained, and how the proposed mechanics aim to provide it:

1. Clear goals: Clear and specific goals allow users to more easily focus on the task at hand. If the user fully understands the goal, he/she gets "into" or absorbed into fulfilling the goal, as he/she does not need to think if his/her actions are useful and advance the user towards the goal, he/she is certain of [63]. The reward system mechanic designed for this version features three types of goals. These goals were designed with the following features in order to make them as clear as possible: (1) Each time the user makes progress towards the goal, he/she is notified and given feedback by the system and the NPC companion; and (2) The user can visualise his/her progress towards the goal on either on the main menu or on the profile.
2. No distractions: Distractions can steal focus from the task at hand. With this in mind, the NPC companion, which can be a source of distraction, is hidden during play or assessment tests, appearing only to give quick feedback to the user. Also, during activities, interfaces are as clean as possible in order to not display unnecessary information that could distract the user.
3. Direct feedback: This feedback is in terms of responsiveness, if there is a noticeable wait between a user input or action and its result or the system response, it can make the user lose focus. To acknowledge this component, the main five activities of the application

were made as responsive and quick as possible, as well as, adding audio feedback to each of the users' inputs, in order to acknowledge the system responsiveness.
4. Continuously challenging: The user must be challenged enough so as to not get bored, but not so overly-challenging that it causes frustration. For this, different levels of difficulty were added to the Visual Search Therapy. Not only the difficulty of these levels scales linearly as users progress through them, but also, a level select menu would be featured, in order to allow users to reduce the difficulty if they want to.

4.2.5 User Progress

Visual representations of progress through the application help users by informing them of where they are at the present time, ideally against a continuum of progress [71]. With this in mind, the user can visualise progress through the following mechanics:

1. Through the difficulty level mechanic, users can see how far they have come in each of the three Visual Search Activities.
2. By the collection mechanic, it is as big as how many daily and weekly goals they have completed, and therefore, how much they have progressed on the therapy.
3. Through the system feedback given to the users after each weekly goal is completed, contrasts user performance between his/her most recent assessment versus his/her previous one.
4. Lastly, through the user profile feature, which allows users to visualise their performance on all the assessment tests, statistics of their activities on the application, and information about their progress, like the week they are currently in, or how many daily goals they have completed.

Progress represented in a visual form, not only informs users of how far they have come, but also directly correlates to engagement, as visible progress is a driver of mood [2].

4.2.6 Habit Development

In order to foster user adherence to the month length therapy delivered by the Eye-Search application, mechanics, such as the reward system, were introduced on the redesign. Specifically, the reward system, which is developed with the hook-reward framework, aims to induce in users the habit of using the application daily, by the application of extrinsic rewards.

4.2.7 Skill Development

Skill development is one of the main purposes of the Eye-Search application. Training for the development of the motor skill of compensatory eye movement training is provided through the Visual Search Therapy Activity. Moreover, the Spaced Practice mechanic added in the redesign, further supporting the development of these skills.

4.3 Aesthetics

Aesthetics are defined by Hunicke et al. as: *"The desirable emotional responses evoked in the player, when she interacts with the game system."* (Hunicke et al., p. 2)[34] Aesthetics

correspond to the third layer of the MDA design, and the one that has direct impact over the user of the system. From the players perspective, aesthetics set the tone of the application, which is born out in observable dynamics of it [34]. Aesthetics describes a "fun" gameful experience through a series of evoked emotions or components in an experience of this kind. In the context of this work, each session of the aesthetics components that make up the evoked experience of the redesign version of the Eye-Search application will be explained.

4.3.1 Social Relatedness

Social relatedness describes the human need for integration into a social environment and belongingness [9], being this strictly related to intrinsic motivation, as reinforcing this feeling encourages people to become more involved themselves [24]. The NPC Companion aims to evoke this feeling of social relatedness by sharing common goals and experiences with the users, as well as cooperating with them during this walkthrough of the application.

4.3.2 Challenge

Challenges can be described as *"Game as obstacle course"* (Hunicke et al., p. 2), or the experience of struggling to fulfil a goal [63]. Challenge can be considered one of the core pleasures or sources of engagement of gameplay, since gameful mechanics often propose problems to the user that must be solved. Each type of player prefers bigger of easier challenges, thus, providing a flexible challenge that adapts to users experiences greatly improves their experience [63]. With this in mind, the Gamification design aims to provide challenge in the Visual Search Therapy activity through multiple levels of linear scaling difficulty, which can also be lowered by the users if desired. As well as proposing the challenge of completing the in-game goods collection the gamified application offers.

4.3.3 Expression

The gamified redesign of the Eye-Search application aims to allow players to express themselves through three fronts.

- The collection mechanics featured, evokes the feeling of accumulation, a basic human feeling which is a powerful motivator because it can be a vehicle for *self-expression* [63]. The collection of in-game goods can reflect who the player is, as well as, the act itself of collecting can be felt as being on a treasure hunt—they feel richer for the experience [63].
- The customisation of the appearance of the NPC Companion, acts as a way of self-expression, as the user can express themselves through the way they dress the NPC, greatly adding value to their experience and increasing their commitment with the therap [71].

By giving the players the opportunity to express themselves, it makes them feel alive, proud, important, and connected [63].

4.3.4 Submission

Submission is described as *"the game as pastime"* (Hunicke et al., p. 2)[34] The gamified redesign of the Eye-Search application aims to provide a set of daily engaging activities, which can act as a pastime for users. The characteristics that allow these activities to act as such, is that they do not require a large time effort to fulfil, as recommended. Average daily play time goes on for around 20 to 30 minutes, making them convenient for the daily lives of users.

4.4 User Validation

In order to validate the developed gamified redesign of the Eye-Search application, a formative qualitative user validation was held. The guideline used for this study is featured on appendix Annexed A. The process will be described in detail later in this chapter.

4.4.1 Methodology

The methodology used for the study consisted of a qualitative study in the form of a semi-structured personal interview, which aimed to validate the Gamification redesign of the application through the perceived usefulness of the user towards the new features added. This study aimed to address three main topics: (1) Obtain information about the users perception of the current implementation of Eye-Search; (2) Perceived utility of the Gamification mechanics of the NPC companion, as well as the reward system; and (3) How motivational the different rewards are perceived by the users.

4.4.2 Participants

The participants chosen for this interview corresponded to six *"experienced"* users from the previous Eye-Search application who agreed to collaborate with this study. The participants' mean age was approximately 55 years old, and out of the six participants, five were male. These users were categorised as such, because they had completed the therapy provided by the previous application. In order to contact these participants, the UCL Department of Neurology shared the email of these patients.

4.4.3 Equipment and tools

The wireframe prototype used for the demonstration of new features was developed on the Unity Engine. This wireframe only consisted of interface elements which interacted between them and no further functionality was included in the prototype. Unity was used for the development of the prototype in order to reuse the developed interface for the future iteration. Lastly, the interviews were held remotely through the Zoom platform, where the users were invited to a previously arranged Zoom meeting.

4.4.4 Procedure

The procedure taken for the interview consisted of first an introduction with a question regarding their experience with the previous application. Followed then by a demonstration

of the wireframe prototype, which showcases the Gamification features and mechanics proposed for the redesign of the Eye-Search application. Lastly, the participants were asked two rounds of questions regarding their perceived usefulness of the Gamification mechanics of the redesign. This procedure will be explained in detail below:

1. First, an introduction to the interview is done, where the user is explained the structure that the interview will follow. Also, the user is told that there are no right or wrong answers, and that all feedback and answers given will be anonymised for the study.
2. There is then a warm up done, where the user is asked to describe a "typical" session on the previous version of Eye-Search, acknowledging the research topic 1.
3. Next, the walkthrough of the wireframe prototype is done. This goes as following:
    - First, a greetings window featuring the NPC Companion is shown. In this window the NPC introduces himself and the daily goal of the day is presented by him. This goal corresponds to making two of the four assessments tests, these being the visual neglect test and the visual field test respectively.
    - The main menu is presented and described in detail.
    - In order to showcase the customization and collection mechanics, the collection menu is accessed and a cosmetic hat is equipped to the NPC.
    - The two assessment activities required for the competition of the daily goal are accessed from the main menu and are completed. Doing these activities will show how the main menu displays the progress towards the daily goal.
    - When the two assessment tests are completed, so is the daily goal. This causes a congratulations window to pop up on the main menu, displaying the reward of the daily goal, these being a new cosmetic.
    - The collection menu is accessed again and the new earned cosmetic is equipped to the NPC.
    - The user profile window will be accessed from the main menu and will be explained.
    - As the daily goal is completed, the menu now displays the availability to do the different visual searches featured on this version of the application.
    - From the visual searches displayed on the main menu, the UFO variety of the visual search activity is selected, and a couple of searches are made as a form of demonstration.
4. After the demonstration is over, the following three questions are asked to the participant: (1) What is your perception or attitude toward the NPC companion? (2) What are the advantages/disadvantages you perceive in the reward system? (3) If the features shown would be implemented on the current Eye-Search application, would you be comfortable using it?
5. Next, the participant was asked to answer the four questions on a scale from 1 to 10, being 1 Strongly Disagree and 10 Strongly Agree. The questions were the following: (1) The featured rewards motivate me to keep using the application; (2) The NPC contributes positively to the experience of using the application; (3) The new version of Eye-Search is user friendly and seems simple to use; (4) The new version of Eye-Search looks fun to use.
6. Lastly, a space for open discussion is left, where the participant is asked if he/she has anything to add or give feedback, to later thank her/him for collaborating with the study.

4.4.5 Data collection and analysis

For this user study, data was collected from three sources: (1) The qualitative answers from the participants on the four questions asked; (2) The qualitative user rating from the four affirmations asked; and finally (3) User feedback given during the interviews. From these sources, the qualitative data obtained aimed to measure users perceived usefulness towards the Gamification design of the Eye-Search application, while also granting insight towards the three main topics of research of this user study. Lastly, this study also aimed to utilise the feedback given by the users, regarding their experience with the previous application, as well as, their impressions of the redesign.

4.4.6 Results

For this study, five experienced users were interviewed, and in this section, a qualitative analysis of their answers is made. This analysis is split in four sections, one for each key topic addressed, and a section of additional feedback given by users.

User perception towards the previous Eye-Search

Regarding the experienced users' perception towards the previous version of the Eye-Search application, the general consensus obtained from the users was that the application is good as it delivers the treatment it proposes, but the therapy itself is very tiring. Users found that the Visual Search Therapy Activity is very long and repetitive, thus, requiring high levels of concentration and attention in order to fulfil the 400 searches needed for each assessment, making the whole process a real struggle. The second common feedback given about the past version of the application was that there was a lack of guidance and feedback coming from the system. The guidance was in terms of information about the process, like insight about the therapy, how it works and the conditions for its effectiveness. And the feedback in terms of user progress on the therapy.

Perceived utility of the Gamification mechanics

In this section, the user perception towards each of the Gamification mechanics showcased on the wireframe prototype demonstration will be analysed. The user perception is measured in terms of perceived utility of these mechanics. Regarding the rewards systems with in-game goods, users found that this mechanic encourages them to use the application. They considered that this feature added an element of fun to a process that previously lacked it at all, acting as a reward and a happiness source after all the struggle that the therapy involves. Concerning the collection of the in-game goods, users perceived that this mechanic acted as an analogy to their progress on the therapy, as the collection grows in size, more they have progressed on their treatment. Despite the positive reception towards the reward mechanics added to the gamified design, users made clear that the main motivator for using the application was self-improvement and the treatment of their condition, making intrinsic the main source of their motivation, and the extrinsic motivators added an additional motivator.

Regarding the NPC Companion, it was perceived by the users as an additional support while interacting with the application, giving the feeling that someone was there accompanying them. As the NPC is the source of feedback, signposting, and tutorials in the application,

they considered it as a source of trust and reliance in the application. Lastly the users also considered the customization of the NPC as a reflection of their improvement and progress on the therapy, as, the more cosmetics they had for him, the more they have progressed.

Lastly, with regard to the different thematic Visual Search Therapy activities featured on the redesign, users found them as an engaging way to keep them interested over the 1200 searches the therapy entails. They also pointed out that these different themes made the activity much less repetitive, and consequently, making it easier to focus on the activity at hand and avoid making mistakes due to too much repetitiveness.

Additional feedback

Users delivered additional feedback regarding features or improvements that could enhance their experience while using the application. One of the principal concerns users presented was that the application needed more information and some insight regarding the therapy it delivered, how it worked, and what rules they had to follow in order for the therapy to become effective. Another concern was about making sessions shorter, with the purpose of making it easier to include the daily therapy into their lives.

4.5 Iteration Results and discussion

In this iteration, a gamified redesign of the Eye-Search application was developed using the MDA framework. This redesign was developed with the objective of developing a Gamification design which improved user experience, in terms of short-term engagement, while also obtaining information about what Gamification mechanics are effective in the context of a Web-Therapy treatment application.

This design was validated through a qualitative formative user study, conducted with experienced users. From the analysis of the qualitative results, it could be concluded that the mechanics were successfully able to evoke the designed feelings or aesthetics on users. The NPC companion featured on the prototype was perceived by users as a companion, a figure of authority, and a social support, successfully fulfilling its role as a tutor, and aesthetic of social relatedness. Users also expressed fondness for the extrinsic reward system designed, considering it as an engaging and fun addition to a context which lacks it, successfully acting as a short-term engagement for users. Overall, users were able to perceive usefulness on the designed Gamification mechanics, emphasising that if added, they would improve their overall experience of using the application. In addition, users expressed their interest in the application featuring further information and insights of the therapy it provides.

Once the gamified redesign of the application was successfully validated, it was followed up, along with the feedback given by the users, as a template for the implementation of the Gamification features on the prototype, which corresponds to the next iteration of the solution.

Chapter 5

Solution Design Iteration III: Implementation of Conceived Gamification Mechanics

Once the Gamification design was completed and validated, the next step taken in the iterative development of the solution of this present work was the implementation of the mentioned design. For this implementation, the prototype, resulting from the first iteration, was used as a foundation, and built upon. This prototype, developed in Unity on its version 2019.4.0f1, featured the core healthcare requirements needed for the therapy provided by the Eye-Search application. Considering this, the implementation of the Gamification features on the available foundation will be explained in this chapter, as well as the design of the architecture needed for the development of this project.

5.1 Application Architecture Design

The Eye-Search application to be developed consists mainly of a Web Application of the type of Self-Guided Web-Based Therapeutic Interventions. This needed to be served from a public server, where any user could access the therapy provided by it. The application would need a login system using Google Sign-In identification. And, not only user progress needs to be saved, but also user performance statistics for each of the activities, as described in Chapter 3. Moreover, to validate hypotheses posed, as well as answering the questions posed in section 1.7.1, additional data would need to be logged, in terms of users' use time on the application.

With the main characteristics of the application, as well as the new Gamification features to be designed and implemented, a three-layer architecture design was used for its development. This architecture organises applications into three logical computing layers:

- The presentation layer, which is the user interface and communication layer of the application, where the end user interacts with the application.
- The logic layer, where information collected in the presentation layer is processed, and

can also add, delete or modify information on the data layer.
- The data layer, where the information processed by the application is stored and managed.

This architecture allows the separation of application layers, both logically and in functionality. This separation allows for a greater decoupling between different modules of an application, so each layer can be developed, updated or scaled as needed without impacting the other layers, as each one runs on its own infrastructure, adding an extra factor of reliability to the application. It also improves its security, as the presentation and the data layers can be communicated directly, making the logic tier act as a barrier towards injections and other malicious exploits. The three-layer architecture is commonly used for web development, as web applications often are structured on three-layers depending on their functionality: A front-end web server, serving static content; a middle dynamic content processing application server; and a back-end database or data store.

The Eye-Search application, as being a web application, does feature a static file which must be served and a database that must be used to store the application data. The middle or logic layer added to the application not only was added to implement the three-layer architecture with all its benefits, but rather due to a limitation on Unity WebGL. Web applications in general do not have access to IP sockets because of how web browsers are designed. For this reason, in order to communicate the application with its backend, a networking system based on HTTP requests had to be designed. And, in order to work and process these requests, a Node.Js Restful API was made as the logic layer of the application. The application architecture design is depicted in (Fig. 5.1).

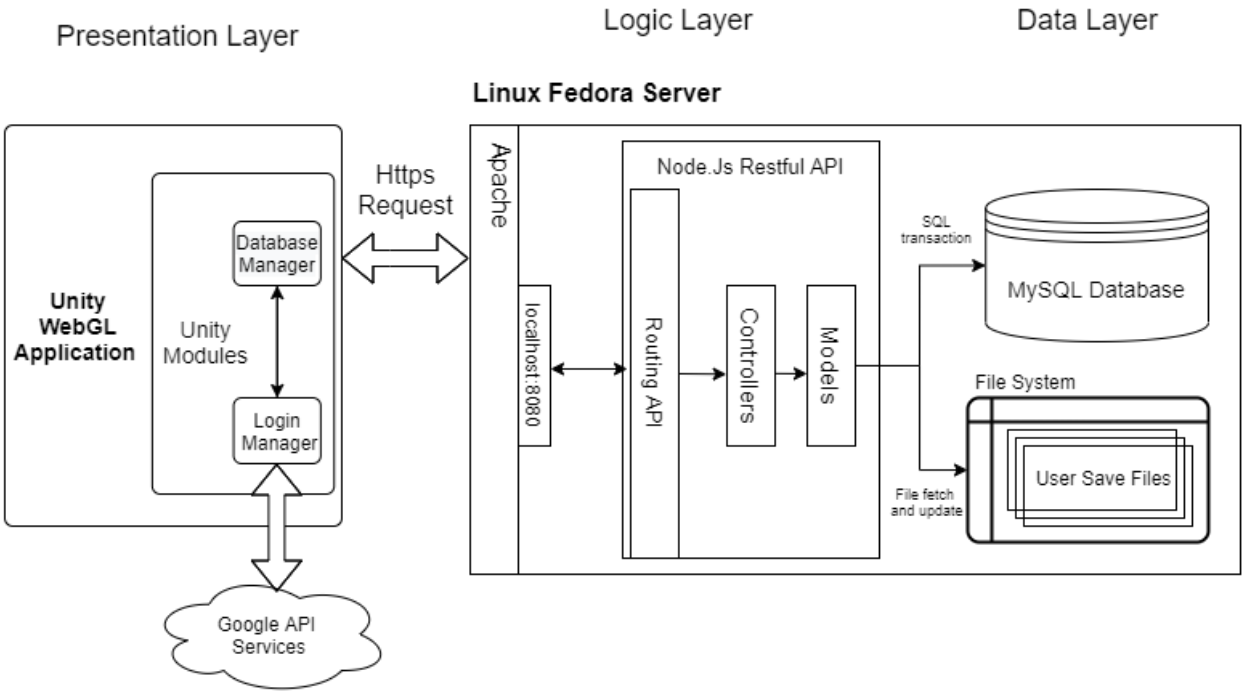


Figure 5.1
Three-layer design of the redesigned version of the Eye-Search application.

In this chapter, each of the layers will be explained in detail, as well as the components that comprise them.

5.2 Presentation Layer

The presentation layer consists of the topmost level of the application, which users can access and interact with directly. It displays information related to the services provided by the application and communicates with the business logic tier. In web development, the presentation usually consists of the *"front-end"* of a web application, whose content may be static or generated dynamically.

In the case of the present work, the presentation layer consists of the Unity WebGL build of the developed application. As stated in chapter 3, WebGL corresponds to a JavaScript application programming interface (API) for rendering high-performance interactive 3D and 2D graphics within any compatible web browser without the need to use plug-ins. WebGL is based on OpenGL, and allows for GPU accelerated usage of physics and image processing and effects as part of the web page canvas. Its elements can be mixed with other HTML elements.

In order to develop a WebGL application, all code used on it must be on Javascript. For this, Unity uses a compiler toolchain to cross-compile, both the Unity runtime code and into asm.js JavaScript, which is a subset of JavaScript designed to allow computer software written in languages such as C to be run as web applications while maintaining performance characteristics. And the .NET game code, such as the Unity scripts made for the application into Javascript. In this way, any Unity application can be easily built for WebGL. With these complement toolchain, a Unity WebGL application consists of:

- An HTML document, named *index.html*, which browsers can navigate to load the application content.
- A folder named *TemplateData*, containing all the assets and resources used by the *index.html* document.
- A *Build* compiled asm.js Javascript build of the application.

With this, the Unity WebGL application can be served as a static file from a server, allowing its access from a browser.

Despite the accessibility provided by Unity, to build any application into a WebGL build, when developing an application of this kind, the following considerations must be considered:

1. Threads are not supported due to the lack of threading support in JavaScript. This applies to both Unity's internal use of threads to speed up performance, and to the use of threads in script code.
2. Browsers do not allow direct access to IP sockets for networking, making native C# methods for networking unusable.
3. WebGL applications do not feature a persistent data directory where applications can be stored between sessions or updates.

With these considerations, the Eye-Search application was developed over the prototype results from the first iteration of the solution, which focuses on the implementation of the healthcare component of the application. Over this foundation, the Gamification features, validated on the second iteration of the application, were implemented. For the implementation of these features, the MDA design of the application, as well as the wireframe prototype, a result of the second iteration, were used for it, acting as the interface for the final iteration of the application. The implemented application interaction flow is depicted in (Fig. 5.2). The process behind the design and development of this application will be explained in this chapter.

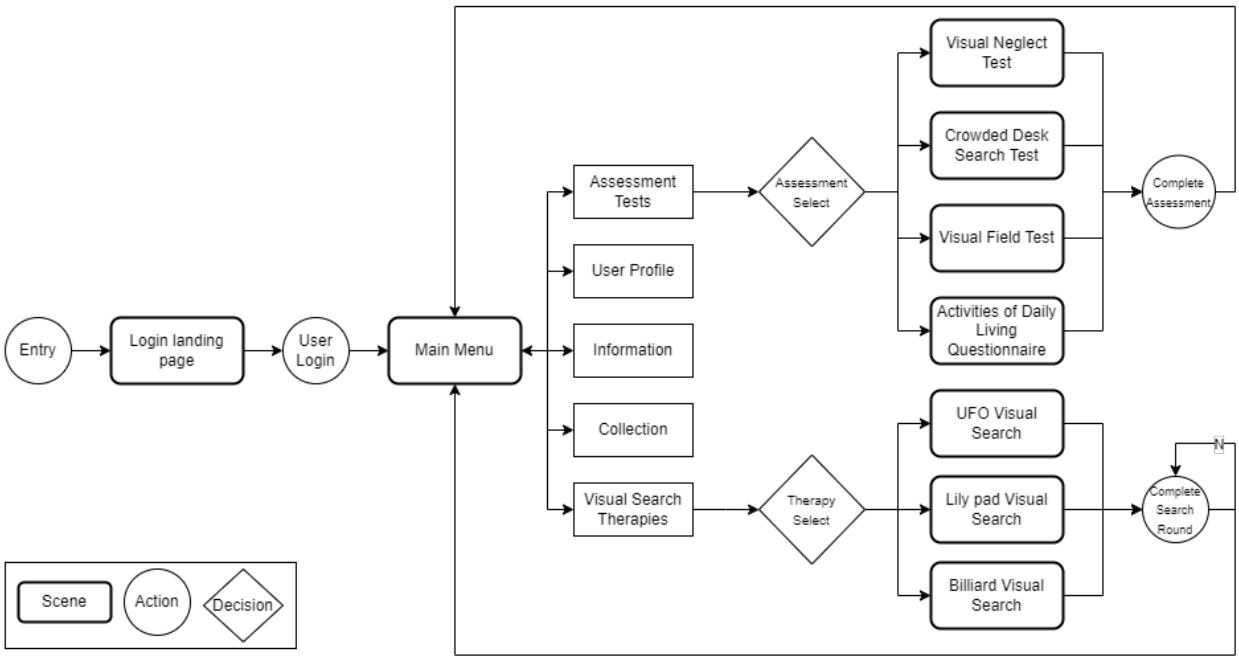


Figure 5.2
Interaction flow of the different scenes of the Eye-Search application.

5.2.1 Application Design

As stated in the previous section, the application developed was built upon the prototype developed on the first iteration of the solution, and its visual elements, such as games and UI, designed using the wireframe prototype as a base. This basis consisted of, each of the core therapeutic activities, such as the Visual Neglect Test, Crowded Desk Test, Visual Field Test, Activities of daily living questionnaire and Visual Search therapy activity, featured its own Unity `Scene` each. Some of these `Scenes` feature multiple views and interfaces, using the iteration two as basis, thus, creating an application as depicted in (Fig. 5.2).

As depicted in the flow diagram, the application features nice Unity Scenes, three for each Visual Search Therapy activity, four for each assessment test, a main menu which allows access to the activities of the application, and a login and landing page.

As the design of the assessment activities is already explained on 3, and the for the implementation of the three different Visual Search activities, use the same implementation

also described on 3, in this section the following components of the presentation layer of the application will be described in detail: Project structure, Data and Save System, Networking, NPC Companion, Goal and Reward system and Google Login.

For the design of the Unity project, this was expanded upon the original design depicted in (Fig. 3.11). on 3. In the initial design, the application consisted of six assembly modules, one called `System.dll` the parent assembly of the application. For this iteration, five new modules were added: Networking, Login, NPC, Gamification, and Save System. These are depicted in the picture (Fig. 5.3).

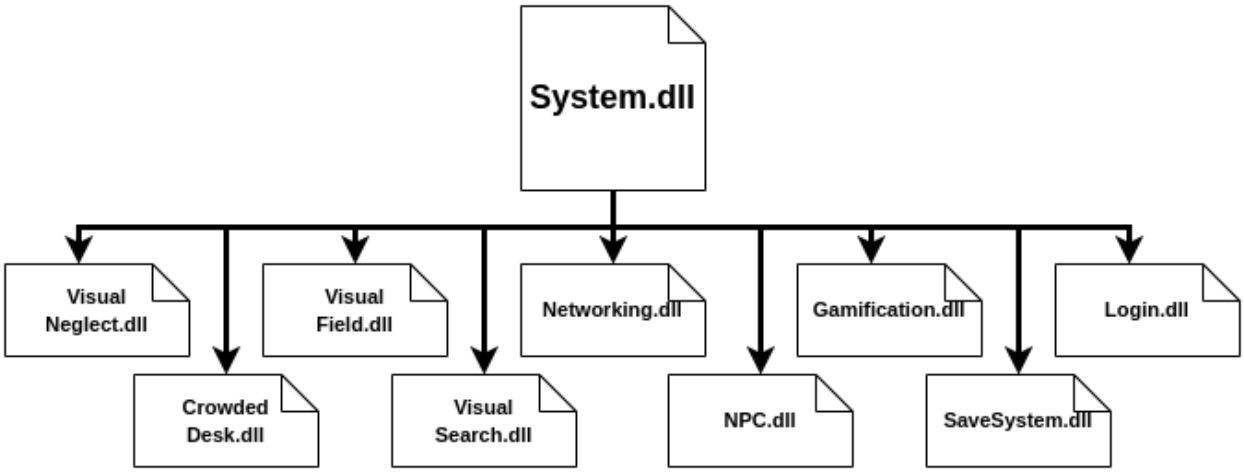


Figure 5.3
Assemblies

5.2.2 Data and Save System

As stated in Chapter 3, the statistics regarding user performance are saved in a database. But, due to the new features implemented, new tables and data structures had to be created. As stated on 3, a C# data structure can be easily serialised into a JSON format and back, making also these structures, easily translated into SQL database tables. This concept will be explored more in detail on 5.4.

As stated in the introduction of this chapter, to validate the present study, user adherence to the application had to be measured. A new data structure was created in order to perform such measures. This structure has three fields: a user ID, a timestamp and a boolean value, which represents if the action was a login or logout of the application. With this, for each session, two insertions are made, the first one, when the users log into the application with a true value. In order to register when the user logs out, Unity for most of its platforms offers a `OnApplicationClose` callback, which allows it to run a specific code before the application closes. Unfortunately, this feature is not available to browsers because of the way browser tabs close, nor it is possible to call an asynchronous function to register this event as, for security reasons, browsers can not delay the closing of their tabs, nor do more than deliver warning messages, which pause the application while these are displayed. For this reason, a workaround was implemented using Unity *Coroutines*. In Unity, when a function is called, it

runs to completion before returning, this effectively means that any action taking place in a function must happen within a single frame update. On the other hand, a *Coroutines* is like a function that has the ability to pause execution and return control to Unity, but then to continue where it left off on the following frame. Given this, to register the timestamp of the user logout, when the user logs in, both records are instantly created, and the *Coroutine* is responsible for making a query, which updates the timestamp of the user logout every minute. More information on the function of *Coroutines* is explained in the following section. With this implementation, it is possible to measure users' play time by comparing both registers with an error of up to one minute.

Besides the measured statistics, user progress through the therapy had to be saved. This progress is reflected on a structure with the following fields:

- User ID.
- Unlocked Cosmetics: A list with cosmetic IDs unlocked so far by the user.
- Current NPC Cosmetic Loadout: A list with cosmetics IDs which were equipped to the NPC by the user.
- Current Goal Type: Assessment tests or Visual Searches
- Current goals progress.
- Current goals reached.
- Current goals requirement.
- Visual Searches done for each type.
- Number of goals completed.
- Number of assessments completed.

In order to save such data, Unity often gives developers the option of writing and managing files in a directory where the application resides, which is a variable known as `PersistentDataPath`. Here, data can be stored and kept between runs or updates of the application. But as stated in the previous section, WebGL applications are not able to use this persistent data feature. For this reason, two approaches could be taken to solve this limitation. The first, was to save this data into the user browser or computer using *LocalStorage*, which allows for saving of up to 5MB of data on the Web document, or cookies. But, both methods have the limitation of being able to save a small amount of data, only in the form of strings, and not being suitable for the constant editing of this data. As for both methods, writing and reading of the storage of the web document is synchronous, for which the main thread of the application must be blocked until the process is finished, interrupting the flow of the application each time new data must be saved. The second approach is the use of the server for the storage of the user data, in the form of a JSON file. This was the approach taken as not only it allows for the easy and direct access of data from the application, but also for the monitoring and editing of users' progress whenever users have problems with the application.

5.2.3 Networking

As stated in the introduction. One of the limitations of developing a Unity WebGL Application is the lack of access to IP sockets due to how web browsers are designed. For this reason, a networking system based on HTTP requests had to be designed. Before detailing the design

of this component of the application, the networking requirements of the application will be described.

First, as stated on 3, each of the five activities featured on the application registers and saves the users performance, on C# structs, which later are transformed on JSON files to finally be inserted into a database. In addition, not only do these five activities generate data that must be stored, but also information about user play time, as well as, their progress on the goal system, as specified on section 5.2.2. Secondly, as stated in chapter 2, the application features feedback regarding user performance on the therapy, on both the user profile menu, and on the weekly feedback provided by the NPC companion. In order to display such feedback, the user statistics on the respective tests must be fetched from the database by the application. With these first two requirements, it is noticed that the different modules and scripts of the application require constant access to the database, to insert and fetch data related to the users. Also, as the module can only use HTTP requests to fulfil this, it must implement methods that allow for GET, PUT and POST requests. It is also worth mentioning that, in the case of user therapy progress data, and information about user use time of the application, these must be constantly updated. Considering this demand, the network module must feature the following characteristics:

1. The module must allow the insertion of data in JSON format into the database.
2. The module must allow fetching of data to be used by the different modules of the application.
3. The module must allow the updating of data in the database.
4. The module must use GET, POST and PUT HTTP requests in order to interact with the database.
5. The module must be able to process multiple concurrent requests coming from the application.

We next explain how this module was implemented, and how each of these requirements is fulfilled by the design.

First, in order to fulfil the ability to insert, update and fetch data from the business layer using HTTP requests, the `UnityWebRequest` class was utilised. This class proper to the Unity engine provides a modular system for composing HTTP requests and handling HTTP responses. The primary goal of the `UnityWebRequest` system is to allow Unity games to interact with web browser back-ends. It also supports high-demand features such as chunked HTTP requests, streaming POST/PUT operations, and full control over HTTP headers and verbs. With `UnityWebRequest`, it is possible to implement an ecosystem that breaks down an HTTP transaction into three distinct operations: (1) Supplying data to the server; (2) Receiving data from the server; (3) HTTP flow control, in the form of redirects and error handling.

Secondly, in order to fetch data from the database and use it on a script in the application, a promise pattern was used. In this way, further actions can be deferred until a previous action is completed, which, in the context of this solution, would be until the application receives the data back from the server. In order to implement promises into the module, the `DownloadHandler` object was used. This helper object of the `UnityWebRequest` class defines how to handle HTTP response body data received from a remote server. Generally, they are

used to buffer, stream and/or process response bodies. With this `DownloadHandler` acting as a buffer for the server response, and using deserialization functions, a function on a script can be called as soon as the `DownloadHandler` notifies that the data has been correctly received.

Lastly, in order for the network module to handle concurrent requests, while also being accessible by all the scripts that need it, a class named `NetworkManager` was created. This class has three main characteristics which will be explained. First, this class was designed using the *singleton design pattern*. This pattern restricts the instantiation of a class to one single instance, allowing access to global variables of this class, as well as easing the access to this sole instance by other classes. By instantiating this class only once when the application starts, it can act as a global and easily accessible service for other classes to request data to the database of the application. Next, to handle multiple concurrent requests, two features were added into this class. First, a queue was added to its properties. This queue corresponds to a first-in, first-out collection of tuple objects, being this tuple objects an instance of the `UnityWebRequest` class, and a function to callback if the `UnityWebRequest` corresponds to the GET method. In order to process this queue, a *Coroutine* was implemented. Despite not having access to threads to create a Network service, a *Coroutine* is able to fulfil this role, by processing the incoming requests as they are inserted into the queue, and pausing its execution while this queue is empty, in order to optimise the application performance. Ultimately, a dictionary was added as a parameter to the `NetworkManager` class, to map the destination table on the database, needed by the requesting script, to the URL route in the API, in the business layer.

On the whole, the `NetworkManager` class works in the following way:

1. When a script needs to request the database, for fetching, they enqueue new requests into the requests queue. The request is created as follows:
   - First, an object from the `UnityWebRequest` class is instantiated.
   - This object is then configured, in terms of: Destination URL on the API, HTTP verb (GET, POST or PUT) and timeout time.
   - After being configured, an Upload Handler is created, which manages the buffering and transmission of body data during HTTP requests, allowing the addition of content of the type application/JSON to the body of the request.
   - A download Handler is created and attached to the `UnityWebRequest`.
   - Lastly, the request is enqueued.
2. `NetworkManager` is notified that the queue is not empty, and it proceeds to send it to the server. item The following scenarios can happen next: (1) If the request fails with HTTP code 408, which informs that the server did not receive a complete request message within the time that it was prepared to wait, the request sent is retried once; (2) If the request was of the POST method, it does not wait for a response and the execution of the program resumes; and (3) If the request was a GET method, then the callback function related to the request is invoked with the received data.

5.2.4 NPC Companion

As stated in 4, the NPC companion was included into the application to act as a tutor, a source of guidance, and as a social support to the user. For the implementation of the NPC

companion, the following requirements had to be met:

1. The NPC must deliver quick positive feedback when the user successfully interacts which each of the activities:
   (a) In the Visual Neglect Test, after successfully pinpointing 5 targets, the user will be congratulated by the NPC, as well as be noticed by it when there are only 30 seconds left on the timer.
   (b) In the Crowded desk test, in each round, the NPC will give the user feedback the first time they click on an incorrect item, as well as when they find the item, and finally, when there are 15 seconds left on the timer.
   (c) In the visual field assessment test, the user is given positive feedback after each alternative is clicked on.
   (d) In the activities of daily living questionnaire, the user is given notice when there are three questions left, that is, when the user has answered half of the activities, and when there is only one activity left to answer.
   (e) In the Visual Search Therapy Activity, in each search round, the user is given feedback each time they select an alternative: it is either wrong or right.
2. To be more expressive, the NPC must feature different animations
3. The NPC changes its position on the screen depending on the activity.
4. The NPC has speech bubbles which must be filled.
5. The NPC displays audio.
6. The NPC must be able to wear cosmetic objects.

First, the base requirements of (1) The Speech Bubbles; (2) The NPC animations; (3) The Movement of the NPC, through the screen, were implemented, to build the feedback requirements upon them. To implement this NPC and fulfil these three basic requirements, the following procedure was followed. First, A Unity `GameObject` was created. This object acts as a container to the needed components that needed to be added to the object. The first added component corresponded to `Transform`. This class gives the properties of position, rotation and scale to an attached `GameObject`, making it possible to store and manipulate the rotation, position and scale of an object on a unity `Scene`, allowing to move the NPC `GameObject` on a given scene.

Next, in order to give the NPC shape and visual characteristics, a set of `SpriteRenderer` were attached to it. `SpriteRenderer` is a UnityEngine class that allows the rendering of a *Sprite*, which is a two-dimensional bitmap, for 2D graphics. Each instance of this class attached to a `GameObject` allows for the rendering of one *Sprite*, while also allowing for the manipulation of properties like its colour, rotation, scale, between others. With this in mind, a set of this class was needed as the NPC *Sprite* was split into a *Sprite Sheet*. This *Sprite Sheet* consists of an image that contains several smaller *Sprites* and/or animations. Combining the small images in one big image improves the game performance, reduces the memory usage and speeds up the startup and loading time of the game. A depiction of the NPC *Sprite Sheet* is shown in figure (Fig. 5.4).

For each *Sprite* of the NPC *Sprite Sheet*, a `SpriteRenderer` was attached. In order to animate the NPC and give it different emotions, these `SpriteRenderer` instances had to be ordered and positioned on the scene considering its position relative to the other

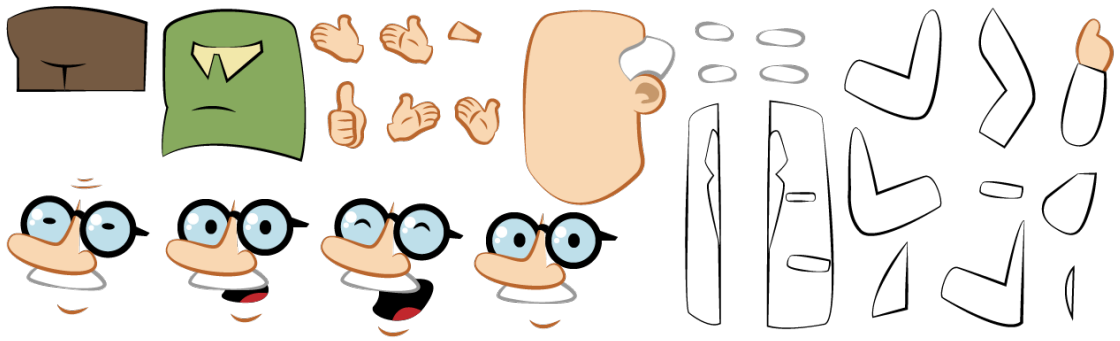


Figure 5.4
Sprite sheet with individual sprites that make up the NPC character appearance.

`SpriteRenderer`, in terms of the X, Y and Z axis. The X and Y position can be edited through the `Transform` class attached to each sprite, while its Z position has to be edited through a Unity system called `Sorting Layer`. This Z position adjustment is done using the Unity 2D sorting system, which sorts Renderers according to a priority order that depends on their types and usages. In order to tell Unity which sprite to sort first, their place on Unity's Render Queue must be edited. One way to do this is through the `Sorting Layer`. In unity, each sprite must be assigned to a sorting layer. Unity has some predefined ones, but an indefinite number of custom ones has to be added. With each layer, it is possible to assign a sprite priority among other Renderers within the same Sorting Layer, using the Change the value of the Order in Layer. With this, each of the sprites of the NPC was sorted in order to not cover each other, making it possible to create seven NPC animations as depicted in (Fig. 5.5).

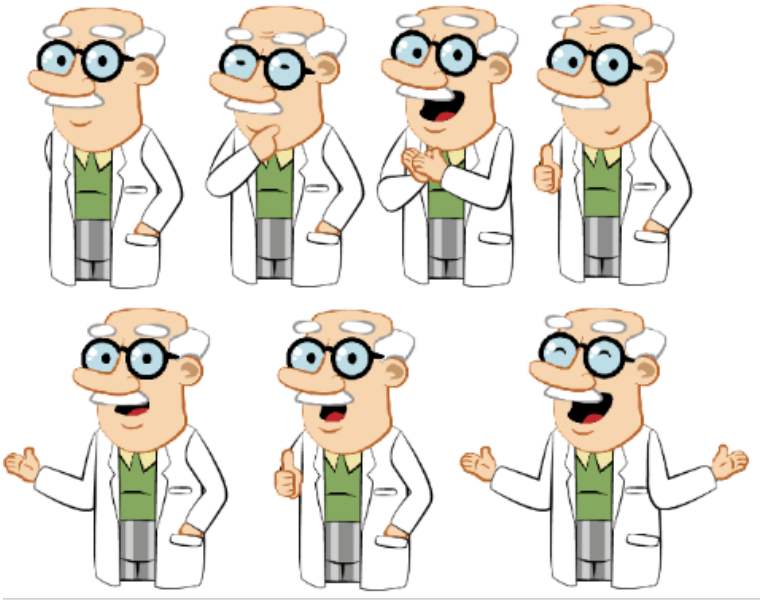


Figure 5.5
The seven animations that the NPC companion can display

For the implementation of the requirements stated, interactions of the NPC had first to

be implemented. These interactions are formed by the following four components:

1. Multiple speech bubbles of different shape and position are featured on the scenes of the application. These must display the text dialogue associated with the NPC.
2. The position of the NPC can change in the same scene for each interaction.
3. Each interaction of the NPC can feature a sound effect.
4. The interactions can feature different animations given the context of the interaction.

The animation and sound effects of these interactions are properties on the NPC that are used through all the scenes and interfaces of the application. While the speech, speech bubbles, and NPC position are scene dependent. We will explain how the NPC properties were implemented

First, in order to animate the NPC, and cycle through its different animations, the Unity Animation features were used. This feature allows for the implementation of state machines for transitioning between animation states. With this in mind, the animations of the NPC were implemented through the following workflow: Unity's animation system is based on the concept of Animation Clips, which are Unity Objects which contain information about how certain objects should change their position, rotation, or other properties over time. Animation Clips are then organised into a structured flowchart-like system called an Animator Controller. The Animator Controller acts as a "State Machine" which keeps track of which clip should currently be playing, and when the animations should change or blend together.

Considering this, in order to animate the NPC, individual Animation Clips were made for each of the eight animations initially conceived. These Animation Clips mainly feature information about which of the `SpriteRenderer` instances, which are already prearranged in terms of position on the X, Y and Z axis, should be visible in each given time. With this, each clip would have control over each of the sprites associated with the NPC object, and render only the needed sprites for each animation of the NPC, finally making one clip for each animation depicted in (Fig. 5.5). In addition, a special Animation Clip was made to "hide" the NPC, meaning, to disable its sprite, in case it is needed. Lastly, for creating transitions between these animations, as well as making it possible to activate an animation from a script, an Animation Controller component was added to the NPC `GameObject`. This Animation Controller is made up of a state machine of nine states for each Animation Clip created to the attached `GameObject`. Once the states are defined, the next step is to define the transitions between each one. In Unity, a state or animation transitions allow the state machine to switch or blend from one animation state to another. Transitions define not only how long the blend between states should take, but also under what conditions they should activate. With this, the state machine was organised as follows:

1. The base state of the NPC is the idle state, and while no transition trigger is activated, the animation will remain in this base state.
2. Once the state machine is instantiated, it by default transits towards the base state.
3. Each of the eight states, excluding the base state, have a transition from the base state to them, which is activated by a trigger defined for each of these transitions.
4. Each non-base state has only a transition to the idle state.
5. If a trigger is activated and the current state is the idle base state, the state transitions to the related state, and remains there for a random amount of time, from 1 to 3

seconds, which after, returns to the idle state.
6. If the transition is towards the hidden state, the machine remains in that state while no trigger is activated.
7. If a trigger is activated, and the current state is not the idle base state, the animation ends immediately, and a transition to the idle state is made, for which after, transits to the corresponding state.

A depiction of this system is depicted in the (Fig. 5.6). With this implementation, a script can activate any of the animations defined just by activating the associated trigger.

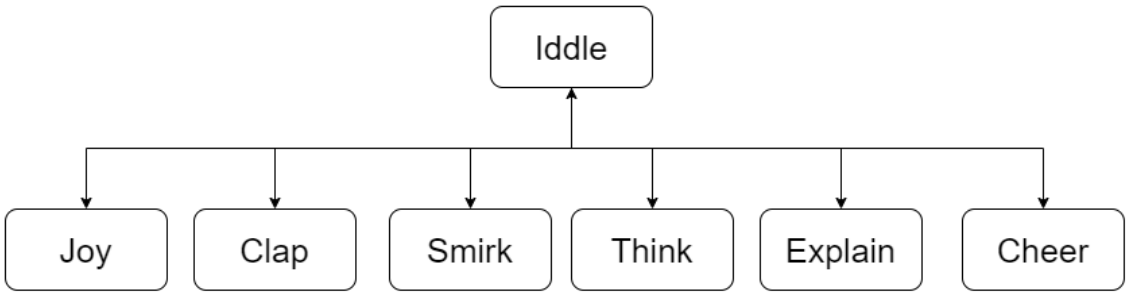


Figure 5.6
Representation of the NPC animation state machine.

Secondly, for the implementation of the scene dependent components of the interactions, two C# structs were created to encapsulate the data for the interactions of the NPC. First, a struct named `NPCDialogue` was created with three `string` fields: (1) A field for the name of an animation, (2) A field for a dialogue to be displayed, and (3) A field for the name of a sound effect. This struct aims to encapsulate the data needed for one interaction of the NPC, as it features what animation the NPC should play, its dialogue and associated sound effect. The second structure corresponds to `NPCInteraction`. This struct features five fields:

- `InteractionKey`, a `string` which is used as an identification of the interaction.
- `ScenePositionKey`, a `string` which is related to a position on the scene.
- `DialogueBoxKey`, a `string` which relates to a dialogue box on the scene.
- `NPCDialogueCollection`, which is a collection of the struct `NPCDialogue`.
- `AutoTransition`, a boolean value which displays the dialogues of the interaction should transit from one to the other automatically after a time period, or if it must wait for user input.

These structures allow for the encapsulation of the NPC interactions, for each scene, statically. As this struct is saved as a static JSON file, in order to allow the easy editing of the dialogues if needed, without needing to completely rebuild the application for it.

To load and use these interactions on a scene, a class named `NPCManager` was created. One instance of this class is featured on each scene of the application, and its purpose is to load the `NPCInteraction` file of the scene it is in, and map each field key of the `NPCInteraction` to an object on the scene. Given this, `NPCManager` features two dictionaries as fields: A `ScenePositionDictionary`, in which, the keys are represented by strings and values are transform2d, to represents positions on the space of the `Scene`, signed through

the editor; and DialogueBoxDictionary in which, the keys are represented by strings and values are of the DialogueBoxController, also assigned through the editor. It is worth mentioning that DialogueBoxController is a simple class which was created to encapsulate all the functionalities a dialogue on the application should feature. These are, to appear and disappear as needed on the scene and to write a given text on a space defined on it.

Using this implementation, to trigger an interaction on a scene, the following procedure is followed:

- A script calls a method on NPCManager, with an InteractionKey, proper to the NPCInteraction file.
- NPCManager loads the given interaction from the NPCInteraction file.
- NPCManager maps each key with a value on its dictionaries:
  - ScenePositionKey is mapped to a position on the scene through the ScenePositionDictionary.
  - DialogueBoxKey is mapped to a dialogue box on the scene through the DialogueBoxDictionary.
- The NPC is given the position, dialogue box, and NPCDialogueCollection in order to display it on the given dialogue box and position.

Following this same line of thought, NPCController follows the following procedure in order to play an interaction of the NPC:

- NPCController receives as parameters a NPCDialogueCollection, a DialogueBoxController instance, a transform2d and an autoTransition boolean value.
- NPCController saves a reference to the DialogueBox.
- The NPC transform2d component is moved to the transform 2d cordinates given.
- For each NPCDialogue on the NPCDialogueCollection:
  - The trigger associated with the animation ID is activated on AnimationControllerComponent, making the controller to change state to the associated with the AnimationClip.
  - The dialogue text given in the interaction is given to the referenced DialogueBox.
  - AudioController is called to play the associated audio
  - If autot ransition is true, every 5 seconds the next dialogue is loaded, or else, it is loaded upon user input.

Once the interactions were implemented. The last feature associated with the NPC that needed implementation was the quick feedback, i.e., for the NPC to react to users inputs or given actions. The given actions that require NPC reactions are:

1. In assessment tests with time, notify the users when half of the available time has passed, and when there are 10 seconds left.
2. In the assessment tests: Visual Neglect Test, and Crowded Desk Test, upon 3 successive failed attempts, the NPC delivers an encouraging message.
3. In the assessment tests: Visual Neglect Test, and Crowded Desk Test, upon five successful attempts, the NPC gives a positive feedback message to the user.
4. In the Activities of Daily Living questionnaire, the NPC notifies the user when half of the items have been completed, and when there is one left.

5. In the Visual Search Therapy Activity, the NPC gives a different message to the user depending on how fast they found the target. Which goes from an encouraging message to a congratulatory one.

Due to the diverse nature of the conditions which trigger different interactions on the NPC, the observer programming pattern was used for this task. Observer is a behavioural design pattern that allows for the definition of a subscription mechanism to notify multiple objects about any events that happen to the object they're observing. This pattern consists of two types of objects: The *publisher*, which features an interesting state and notifies its state change events to the objects it is observing such state, and the *subscribers*, which are all the objects that want to track changes to the publisher's state.

In order to implement this pattern, Unity's delegate and events were used. A delegate is a reference pointer to a method that allows us to treat a method as a variable and pass method as a variable for a callback. When it gets called, it notifies all methods that reference the delegate. In the observer pattern, the delegate acts as the broadcast function to inform all observers of a state change. In order to add a layer of abstraction to the defined delegate, events are used. Events are a special kind of delegate, that can only be invoked from within the class where they are declared, which in the observer pattern corresponds to the publisher class. This adds a protection to the delegate, preventing an observer from resetting the delegate and invocation list. Events only allow adding and removing methods from the invocation list. Lastly, for observers to share a common interface to receive the notification, a class named `GameEventObserver` was created. This class features two properties, a Boolean function, and an Action, which is an encapsulation of a method that has a single parameter and does not return any value. The advantages of defining a boolean function as a property and not as a method of the class is that, when instantiating the class, the function can evaluate parameters proper to the class it is instantiating it, allowing for a greater flexibility at the moment of evaluating if the conditions are met or not. Lastly, in C# each property of a class features the *get* and *set* methods. Allowing for the call of additional functions when these properties are assigned a value, has both the get and set fields. This allows for the call of additional functions when this property is assigned a new value, or its value is retrieved. Using these functions, it is possible to notify the observers of such property.

With this, in each test controller scripts for each of the NPC interactions, the observer pattern was implemented as follows:

1. First, a static delegate, an event associated with it, and a list of `GameEventObserver` is created in the publisher class.
2. For each variable whose state will be observed, a call of the event is added.
3. For each function that needs to observe a variable of that script, a `GameEventObserver` is created.
4. The observer must feature a boolean function associated to a condition to meet, or a true function if it always proceeds, and an action in the form of a function call from the same or other script.
5. Lastly, when the scene ends, each `GameEventObserver` of the list is unsubscribed, as Unity does not do this automatically, which can produce performance issues if not done.

5.2.5 Goal and Reward system

As explained on 4, in order to implement an extrinsic motivation system using Hook's framework, three goal systems were implemented. First, the daily goal system, consists of a series of tasks presented to the user each time he/she logins into the application, for a period of 28 days. Each time one of these goals is completed, it rewards the player with a cosmetic for the NPC. In order to implement daily goals, first, 28 unique daily goals along with its rewards given had to be designed. To design these goals, three factors were considered:

- Users performance on the Visual Search Activity is meant to improve over time, in terms of reaction time, making it necessary that the number of searches needed to make users interact with the application for the recommended amount of 20 minutes, increase over time.
- The difficulty of the Visual Search Activities increases over time, up to 16 stages of difficulty.
- The 28 days of therapy pacing had to consider that, between assessment sessions, users should have done 400 Visual Searches.

Taking these factors into consideration, 28 daily goals were manually created. In order to establish the number of visual searches needed for the goals in order to make the users use the application for the recommended amount, data from the Eye-Search study of 2020[**?**] was utilised. In this study, one of the results presented is the evolution of users' average reaction speed throughout each of the four assessments, in the therapy provided by the previous version of the application. Using these reaction speeds as a reference, and making a linear interpolation between reaction speeds, a user's mean reaction speed for each day of the therapy was estimated. Using this estimation, and given that, if users do at least the daily goals for each day, it can be estimated in which stage of each visual search the user is in, as well as obtaining an approximation of the time it would take for the user to complete one visual search. With this, goals were created using these estimations, and calculating how many searches the user should do for such a day, in order for him/her to use the application for at least the recommended 20 minutes. Using this estimation, and considering that 400 visual searches must be done between assessment tests, the four assessment sessions (T0, T1, T2 and T3) were distributed in the following way: T0 is done on the first day, T1 on day 14, T2 on day 21, and T3 on day 28. Lastly, in order to preserve the surprise and expectation towards therapy, these were distributed over the daily goal days in a way in which, no two similar cosmetics, in terms of shape and kind, were to be given out in consecutive days.

For the implementation of the daily goal assignment system, as the goals are handmade, a static file with the data for each daily goal was created. This file consists on a JSON collection with the following structure:

- Goal type: Assessment of Visual Search.
- Cosmetic Reward Id.
- A collection of individual goals, with an ID and a requirement.

With this, in the transition of the loading screen between the user login and the main menu, the following function is run:

- First, it is checked if this is the first time that the user logins into the application. This is done by querying the database and searching for any login registers. If it is indeed hihe/sher first time, a save data is created and stored in the server and the goal for the first day is loaded into it.
- If it is a recurrent user, his/her save file is retrieved from the server and loaded into the `GoalController`
- Once the file has been loaded, it is checked for the completion of the last goal loaded into his/her save, given by the progress id. If he/she has not yet completed the goal, no new goal is assigned.
- If the goal on this save has been completed, a query is done to the API in order to retrieve information about the activities that had to be done to complete the goal. Once the activity's information timestamps have been retrieved, it is checked if 8 hours have passed since the last activity related to the goal has been completed. If that is the case, the progress counter is increased by one, and the corresponding goal is loaded from the static file.
- Else, if 8 hours have not passed since the completion of the goal, the user is prompted to the freeplay section of the application.
- Lastly, if the user counter is 28, it means he/she has finished the therapy, for which he/she is prompted to the after-therapy section.

Lastly, in order to inform the user about his/her progress on his/her goals, or check if the reward must be given, a check is made each time a scene transitions towards the main menu scene. This checks if the goals progressing on the user save file, are equal to the goals requirements field. If this is the case, a reward event is prompted and it is delivered to the user, as well as added to the reward ID to the user save file. If the goal is not completed yet, user progress is updated, by making a "scratch" effect over finished tasks, or updating the number of searches left for completing the goal. This is depicted in (Fig. 5.7).

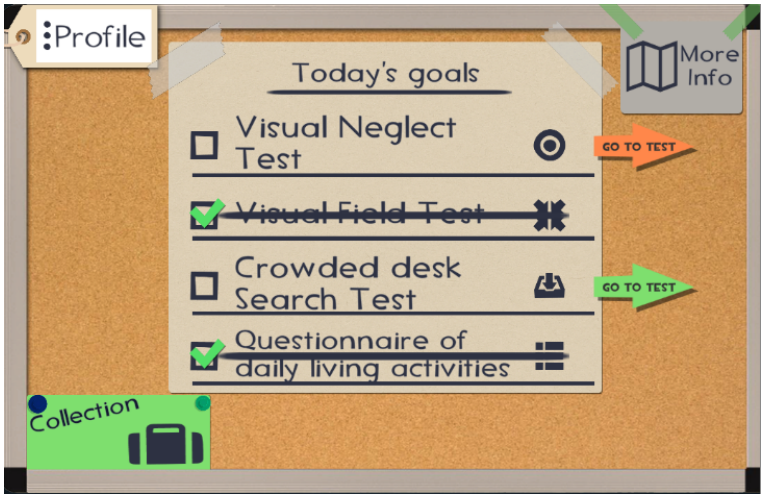


Figure 5.7
Screenshot of the main menu of the Eye-Search application with two of the four daily goals completed.

For the weekly goal, after a daily goal is completed, a check is made to verify if the goal corresponds to a multiple of 7, if this is the case, the weekly goal dialogue is activated. The

weekly goal dialogue can go two ways, if the user has done at least two assessment tests, information regarding their performance in the Visual Neglect, Crowded Desk Search, and Visual Field assessment tests is delivered. This information comes in the form of a comparison of their performance with their previous result, informing them in percentage how much they have improved since their last assessment. In the case of there being no improvement, or there only being one instance of assessment, their last result on such tests is shown in detail. After the feedback dialogue, the user is prompted to the weekly reward, which is a medal of scaling rarity, going from, bronze to platinum, depending on the week the user is going through in the therapy. Lastly, a piece of paper associated with the therapy goal is delivered. Upon collecting four of these papers, the user is prompted to a special dialogue from the NPC as explained on 4.

Regarding the cosmetic system, each of the 32 cosmetics present on the application feature a unique ID. This not only allows for their easy identification, but also acts as a reference towards the cosmetic sprite. As mentioned on the data section, a collection of the unlocked cosmetics IDs is saved on the user progress, as well as a collection which represents the current cosmetics equipped to the NPC companion. The implementation of the cosmetics was done through `GameObjects` with an attached `SpriteRenderer`, and the `Sorting Layer` properties of them. Each cosmetic `GameObject` is positioned on top of the NPC, on the higher sorting layer, in order to be on top of the NPC `sprite`. These cosmetic sprites are not referenced on any of the NPC animations, as, in the body parts of the NPC that the cosmetics are positioned, do not move during its animations. With this, the `NPCController` features a cosmetics dictionary for each carriable slot (Hats, Neck, Sweater, Chest and Pants). In these dictionaries, the key is the cosmetic Id, and the value is the `SpriteRenderer` of the associated cosmetics. With this, each cosmetic is positioned on the associated slot, and their alpha channel is set to 0,making it not visible to the user. And, in order to equip a new cosmetic, the function `EquipCosmetic` of `NPCController` is called. This function receives a string which states what kind of cosmetic is going to be equipped, to look for it in the correct dictionary, and its id, in order to set its alpha channel of its sprite to 1 to make it visible. Using this same procedure, when the user accesses the application, and hihe/sher save data is retrieved from the backend, the NPC is equipped with all the cosmetics featured on its cosmetic loadout list.

5.2.6 Google Login

The redesign version of Eye-Search implemented a login system, using Google sign-in authentication system. The choice to use this system instead of a more traditional login system was for two reasons: Higher security: in the backend of the application it is only worked with the users associated token id, and not directly with hihe/sher personal data; and secondly, to facilitate the login of the application to its users, as, there is no need to create a new account on the platform, but rather, user an already google email account they have. Google login also only requests the users to login through their email the first time they login into the application, making the subsequent logins easier, as they only need to select the google account they want to use to access the application.

To integrate Google sign-in into the application, one must, first create a Google Cloud Platform (GCP) application. This platform is a suite of cloud computing services that runs

on the same infrastructure that Google uses internally for its end-user products, offering services of computing, storage, networking, security, access to Google API's, among others. Creating a GCP application has no cost, and depending on the service used, it charges on demand.

For the use of Google sign-in, no extra cost is associated, and the only requirement is to create an application, and inside of it, request for a Google OAuth 2.0 credential, in order to incorporate the sign-in system into the application. Once the application and the credential are created, this can be incorporated into an HTML document by loading the Google Platform Library, creating a Google Sign-in button, that comes with the imported library, and specifying the application credential on the document. If the sign-in is successful, a user token is sent as a callback. This token contains profile information of the user, like its Google Id, Google Account Name, among other data.

The described procedure was implemented in the index HTML document of the WebGL application, and, to send the information of this token to the backend of the application, a call to the `NetworkController` is made from the Javascript file. This is done thanks to a property of the window object of the browser called `unityInstance`, which is added to Unity WebGL applications. This property allows for the calling of Unity scripts functions from JavaScript, by sending a message to a Unity `GameObject` present on the current displayed scene. This message specifies the object name, the method to be called, and a value to be used as input. In the context of the application, the user token is sent to the `NetworkController` singleton, which proceeds to retrieve the user data if it exists, or create new data if it is the user's first login.

With the main features described on this section implemented, the rest of the Gamification mechanics were implemented, using the described components, such as the serialisation, networking and observer pattern systems, to complete the MDA design proposed.

5.3 Logic Layer and server configuration

The logic layer corresponds to the part of the architectural design of the application that establishes and encodes the real-world business rules that determine how data can be created, stored, and changed, while enforcing the routes and the methods by which business objects are accessed and updated.

Before describing the design and implementation of the logic layer, the software requirements it had to fulfil were identified, these being the following:

- It must allow for receiving and processing HTTPs requests coming from the Unity WebGL application.
- It must define an interface, which allows for the Creation, Read and Update of the data layer, by the Unity WebGL application.

To fulfil these requirements, the business logic design consisted of a web service, which features an Application Programming Interface (API), implemented with a Representational State Transfer (REST) architecture, using the Node.js framework. In this section, it is

explained in detail the implementation of this layer, as well as the thoughts behind its design.

Node.js framework is an open-source, cross-platform, back-end JavaScript runtime environment that executes JavaScript code outside a web-browser. Node.js allows the creation of web servers and networking tools using JavaScript and a collection of modules that handle various core functionalities. Modules are provided for file system I/O, networking, data streams, and other core functions. The advantage and the reasoning behind choosing Node.js for the logic layer of the Eye-Search application, is due to its high flexibility, as a result of the flexibility and large number of available modules, able to incorporate multiple functionalities that the logic layer might need to fulfil. Additionally, Node.js is characterised for its high scalability due to its focus on implementing event-driven programming web servers. This programming paradigm is based on establishing that events, in the form of actions or messages from other programs or threads , determine the flow of the program. When developing with this paradigm there is generally a main loop that listens for events and then triggers a callback function when one of those events is detected. Node.js eases the incorporation of this paradigm to an application design due to the feature that, functions on this framework are non-blocking. This allows for commands to execute concurrently or even in parallel, and use callbacks to signal completion or failure. Therefore, this approach to concurrent computing, facilitating the creation of scalable servers without using threading, by using a simplified model of event-driven programming that uses callbacks to signal the completion of a task.

Regarding the REST architecture, it is focus on creating a layer of abstraction on the server by defining resources that encapsulate entities on the server, and consequently, hiding the underlying implementation details. To access this layer, clients can only access resources using specified uniform resource identifiers (URIs) exposed by the web service. These exposed URIs can be encapsulated on a series of methods exposed by the web application, defining in this way an API, which, in contrast with URIs that are used to directly identify resources, API defines web services methods that can return resources.

With all these characteristics considered, the main purpose for the implementation of this web service is to allow for the Unity WebGL application, which makes up the presentation layer, to access and modify resources of the server, being these in the form of user save files, and data stored on the MySQL database of the application.

The implementation of the web application is split into two main components, the API, and the Model-View-Controller (MVC) implementation of the application.

5.3.1 Web Application Model-View-Controller Implementation

The MVC is a software design pattern which splits the data and the business logic of an application, of its representation, communication, and event management. This design allows for the internal representations of information from the ways information is presented to and accepted from the user, as well as greatly increasing the application extensibility. Using this design pattern, it will be explained how each of these three components were implemented into the application.

First, the **Model** component corresponds to the part of the application that deals with the database or any data-related functionality. In a Node.js application, **Models** works as

a way to structure and serialise the data and all the needed functions to work with it. In the context of the web-service made, a model was created for each of the resources provided by the server, these being collection of data stored on a table on the MySQL database, and static files. Following this line of thought, the following models were created:

- One for each of the assessment tests: ADLQuestionnaire, VisualNeglect, VisualField, CrowdedDesk.
- Two for the visual search activities: VisualSearch to register the performance of the user on a singular round of the Visual Search activity, and VisualSearchSession, to register user play statistics regarding a session of use of any of the Visual Searches.
- UserApplicationActivity: to measure user adherence and user time on the application.
- User, to create new users or fetch their profile data.
- UserTherapyProgress: manages the users static save files on the server.

Each model has a constructor, with one parameter for each of the properties associated with the database table columns it represents. This allows for the serialisation of the database information into the model, for it to then be sent to the presentation layer, or, *serializating* the JSON structure sent on the body of an HTTP request from the Unity WebGL application, into a database table row. For each model, three methods were created, the first is the insert function, which for a model, inserts such model to the associated table on the database through a SQL query, or, if the model is associated to a file resource, such file is created. The second is fetch, which allows a request for all associated rows, of the associated table of the model, which feature a specific user Id, sorted in descending order by the insertion date. This second method has an optional parameter which represents the number of rows to be fetched. If no specific value is specified, the default value is one. Finally, the third method is update, which depending on the resource, an UPDATE query to the database is done, or the associated file is overwritten. Each model has a constructor, with one parameter for each of the properties associated with the database table columns it represents. This allows for the serialisation of the database information into the model, for it to then be sent to the presentation layer, or, serializating the JSON structure sent on the body of an HTTP request from the Unity WebGL application, into a database table row. For each model, three methods were created, the first is the insert function, which for a model, inserts such model to the associated table on the database through a SQL query, or, if the model is associated to a file resource, such file is created. The second is fetch, which allows to request for all associated rows, of the associated table of the model, which feature an specific user ID, sorted in descending order by the insertion date. This second method has an optional parameter which represents the number of rows to be fetched. If no specific value is specified, the default value is one. Finally, the third method is update, which depending on the resource, an UPDATE query to the database is done, or the associated file is overwritten.

For the second component, **Controllers** are the logic of the application, and the connection between models and views, as it is in charge of accepting the input received by the application, and converting it into commands for either the model or the view. In the context of the developed web-service, **Controllers** are Node.js functions that accept HTTP requests that contain information about the requested resource, and reply thus requested information to the client. Thereby, a **Controller** was created for each of the resources, and consequently, for each one of the **Models** presents the web-service. The functionality of controllers and its

interactions with the other components of the application goes as follows:

1. If a HTTP request is received, first it is validated if its content is empty, returning a status code 204 to the client if it is the case.
2. Then, depending on the HTTP request method of the received request, a different method on the controller is called.
    - For GET, the request purpose is to fetch individual or multiple values. For this case, first it is checked if a User ID is featured on parameters of the request, sending a code 400 if it is not the case. If the user ID is present, then it is checked if the optional numeric parameter is featured or it adopts its default value of one. After this check, the fetch method is called on the model, and the result is serialised and sent back to the requester.
    - For POST, the request purpose is to create new resources on the server, or update an existing one. For this purpose, and to verify if all the parameters needed are present on the received request, an instance of the associated model is created and initialised with the parameters available on the body of the request. If any of the needed parameters is missing, a response code 400 is sent back to the client. In the case of a successful initialization, the creation method is called on the model. If this is carried out satisfactorily, a status code of 201 is sent back to the client. For the update case, the same procedure is followed, but the update method is called instead, returning a response code 200 upon succeeding on updating the resource.

Lastly, for the **View** of the web-service, this is represented by the serialised resource that is sent back to the client, in the form of a JSON object, or a collection of these.

It is worth pointing out that Node.js uses a MySQL module in order to convert the models into SQL queries for the Eye-Search database, and for such operation, a SQL user is needed. For security reasons the user created only can perform UPDATE, SELECT AND INSERT operations, adding an extra layer of security and preventing any data from being deleted.

Once the MVC design was implemented, the next step taken was configuration and definition of the web service. In order to establish a Node.js service, an *application* object must be created. This object is able to start a server and listen in a given port for connection. Once the Node.js application is created, the API for the exposure of the different URIs was defined. This was done through Node.js **Routing**. This feature allows for the definition of endpoints in which the application responds to requests, as well as defining which responses are given in each one. To create a new **Route**, the parameters are needed: (1) The type of HTTP protocol that is accepted on the route; (2) The route path, which can be Route paths of strings, string patterns, or regular expressions, and these defining paths are suffixes of the base route the application is running on; and (3) The function that is called to process the received request, which, for the case of this web-service, are a call to the associated controller. For this, for each resource that the Unity WebGL application needs access to, a route was created.

With the logic layer implemented in the form of a Node.js Restful API, communication could be created between the Unity WebGL application and the data layer, which will be explained on the following section:

5.4 Data Layer

The data layer enforces rules regarding the access of the data, providing simplified access to data stored in persistent storage mechanisms. In the context of the developed application, the data layer consists of two storage mechanisms: A MySQL database, and a file system. The details of each one will be explained in this section.

5.4.1 MySQL database

MySQL is an open-source relational database management system. MySQL has stand-alone clients that allow users to interact directly with a MySQL database using SQL, but more often, MySQL is used with other programs to implement applications that need relational database capability, which corresponds to the case of the developed application. In this engine, a database with the name of *Eye-Search* was created. In this database, a table was created for each of the data structures that needed to be stored. Throughout the present document, many of the data structures stored have already been explained, thus, this will be only described briefly, and the emphasis of the explanation will be focused on the structuring of the database.

For the design of the relational database, this was split into two types of tables: (1) The user table, which features information about the user profile as well as having the user google ID token as primary key, and (2) the second type is all the other tables that feature a dependency towards the user table. This dependency is reflected on their composite primary key, which is made of a foreign key which references a User google id, and an ID proper of the table. This structure is depicted in (Fig. 5.8). The main consideration taken for this approach was that each table encapsulates each of the measured metrics of the application.

For the static file system, write and read permissions were granted to the Unix user, only on a folder created to host the user's progress data files. This folder is organised so there is a folder for each of the users, being the name of the folder the user google id, and each folder contains the user save data JSON static file.

5.5 Server Configuration and Deployment

The server provided to deploy and serve the Eye-Search application was a Linux Fedora server, which featured Apache HTTP Server. Apache is a free and open-source cross-platform web server software, making it possible for the host and management of multiple web applications.

Using apache, two routes under the application domain were configured. The first, which corresponds to the root, was configured to serve the static files for the WebGL Unity application, and , secondly, the domain */api* was configured to be the endpoint in which the Node.js web application will communicate throughout. In order to serve the Node.js application, a reverse proxy paradigm was used. In this paradigm, not only data can be served by a server, but, an application or other servers which have no direct connection to the external network are exposed. With this, the Node.Js application runs locally on the server, and Apache redirects all requests done to the route /api, to the application. This not only adds a layer of

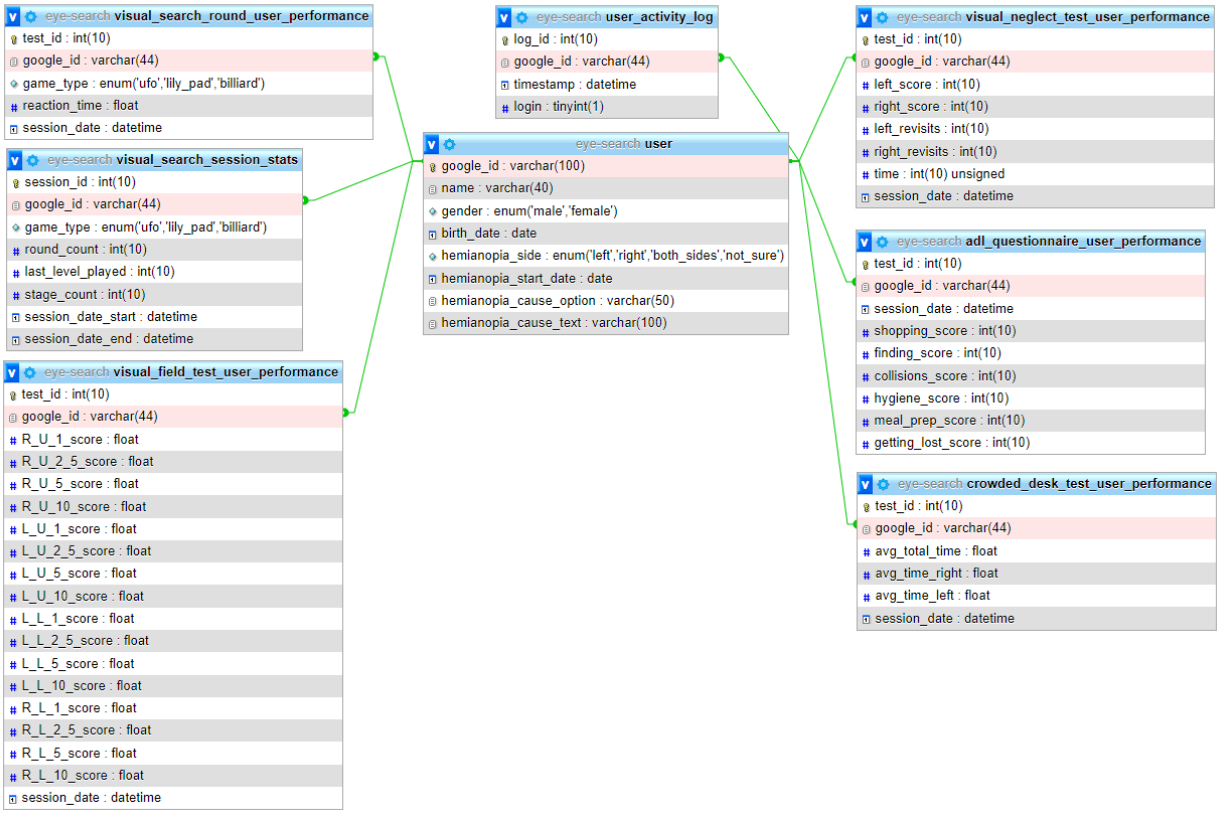


Figure 5.8
Schema of the database created for the data layer of the Eye-Search application.

security to the logic layer, at not exposing the application and data directly, but also allows for a greater control in terms of weight balance, workers and resources distribution.

5.6 User Validation

Once the development of the application was completed, and it was deployed on the server, a user validation was planned before the release of the application to the public. The principal objective of this validation was to detect possible usability problems featured on the application, and evaluate user experience as a whole when using the application.

5.6.1 Methodology

For this study, the methodology chosen was the Thinking aloud protocol. This methodology involves participants thinking out loud, that is, verbalising their thoughts, as they are performing a set of specified tasks on a system. The tasks to perform are designed beforehand, and delivered to the users before starting the study. Participants are asked to say whatever comes into their mind as they complete the task, which might include what they are looking at, thinking, doing, and feeling. This protocol studies analyses participant's cognitive processes while they are interacting with the system, and what they really think about its design.

Taking this into account, the first step taken to design this user study was to define which sources of data to gather or register for each of the user's actions. The sources and their purpose were the following: (1) To measure the applications usability, quantitative data regarding user performance while interacting with the tasks was logged; and (2) Qualitative data in the form of the user feedback, and notes about their mental process, in order to evaluate how the application performs in front of its targeted demographic. For the execution of the protocol, the series of tasks devised were designed after the actions that make up a daily session, on the new version of the application. With this in mind, the tasks a new user would have to accomplish in order to complete hihe/sher first daily goal are the following:

- Log into the application.
- Create a user account.
- Complete the introduction tutorial.
- Complete the daily goal, which, in this case, corresponds to the four assessment tests.
- Receive and interact with the reward received for achieving the daily goal.
- And finally, interact with the Visual Searches activities through the free play section.

Each of these tasks are split into individual steps, of singular actions, users should follow in order to fulfil their goal. For each of these steps, the quantitative and qualitative data is logged. In order to carry out a study using this methodology, personal interviews with users were scheduled. In these interviews, the participants were granted access to the developed Eye-Search application.

5.6.2 Participants

For this validation, the participants who agreed to collaborate with this study were three *"experienced"* users who completed the therapy provided by the previous Eye-Search application. The mean participant's age was 60 years-old, and the three participants were male. These users were contacted by email, provided by the UCL Department of Neurology.

5.6.3 Equipment and tools

Regarding the equipment, the developed Eye-Search application was used for the validation. This involves the Unity WebGL build, the Node.js application and the MySQL database, as well as the server in which this application is being served from. Lastly, the interviews were held remotely through the Zoom platform, where the users were invited to a previously arranged Zoom meeting.

5.6.4 Procedure

As mentioned on the methodology, the user study was carried out through semi-structured personal interviews. In this interview, first the thinking aloud protocol is explained to the user, and he/she is asked to verbalise his/her actions, thoughts, and mental processes that arise while interacting with the system. After this, the users were delivered a pdf file with a series of steps they must follow, and the link to the web page where the Eye-Search application is being hosted. The tasks and steps designed are modelled after the actions and interactions a user would do in a normal session of using the new version of the application. These goes

as follows:

1. Log into Eye-Search, by opening a web browser, accessing the web page delivered to them, and successfully login through google login system.
2. Create an account, in this application section, the user is asked to fill the following data:
    - Type their name in a textbox input.
    - Select their gender in a 2-checkbox input.
    - Select their date of birth in a three drop down input.
    - Select their visual area which features trouble in a 4-checkbox input.
    - Select the date in which their visual problems started in a 2-dropdown input.
    - Select their cause of visual problem in 4 multi-input fields.
    - Read and Accept the Terms and Conditions of Eye-Search, though 3 checkbox inputs.
3. Interact with the NPC, as it introduces itself and gives the user a brief introduction and explanation about the application.
4. Complete each of the four assessment tests.
5. Interact with the reward dialogue, where they are granted a reward cosmetic.
6. Proceed to equip the new obtained cosmetic to the NPC, by interacting with the collection.
7. Free play on any of the three visual searches.

5.6.5 Data collection and analysis

For this study, in order to evaluate the application's user experience, two quantitative data sources, and one qualitative were logged as the user interacted with each of the steps given to him/her:

- Number of errors that the user encounters, assessing where they are critical or non-critical.
- Completion time of each task.
- User feedback, taking notes of the mental process as verbalised by the users.

And, after the validation, for each of the steps, four questions were to be answered, each measuring a different metric, to further analyse the application usability:

- Has the user achieved the right outcome? (correct solution)
- Has the user noticed that the correct action is available to them? (visibility)
- Has the user associated the correct action with the outcome they expect to achieve? (rotulation)
- If the correct action was performed; has the user seen that progress is being made towards their intended outcome? (feedback)

5.6.6 Results

The results of the study will be presented in four parts: (1) Average completion time analysis, (2) Average user error analysis, (3) Steps classification, and (4) User feedback and annotations.

Regarding the first results, of user average completion time per task, as depicted in (Fig. 5.9), which visualises the average time taken by users in seconds to complete each of the tasks of the Talking aloud validation, it can be appreciated that, users take the longest time on the core activities, for example in the realisation of the tests, but most importantly, the time greatly increases when facing tasks or steps that were not present on the previous version. Down below each of the high time-consuming steps will be analysed:

- For the time taken to access the Eye-Search Web Page, despite most browsers being able to load WebGL applications, their loading time of them is highly dependent on the computer hardware. The older or less powerful it is, the longer it takes to load.
- Regarding the log in into the application, in the case of the study, users took their time to look for, or remember their personal information in order to login to the google system. It is worth pointing out that, using the google login system facilitates the introduction of new users, as the email and account they create does not need further verification.
- For the introduction tutorial, this introduces most of the new features of the new version of Eye-Search, explaining the time it consumes.

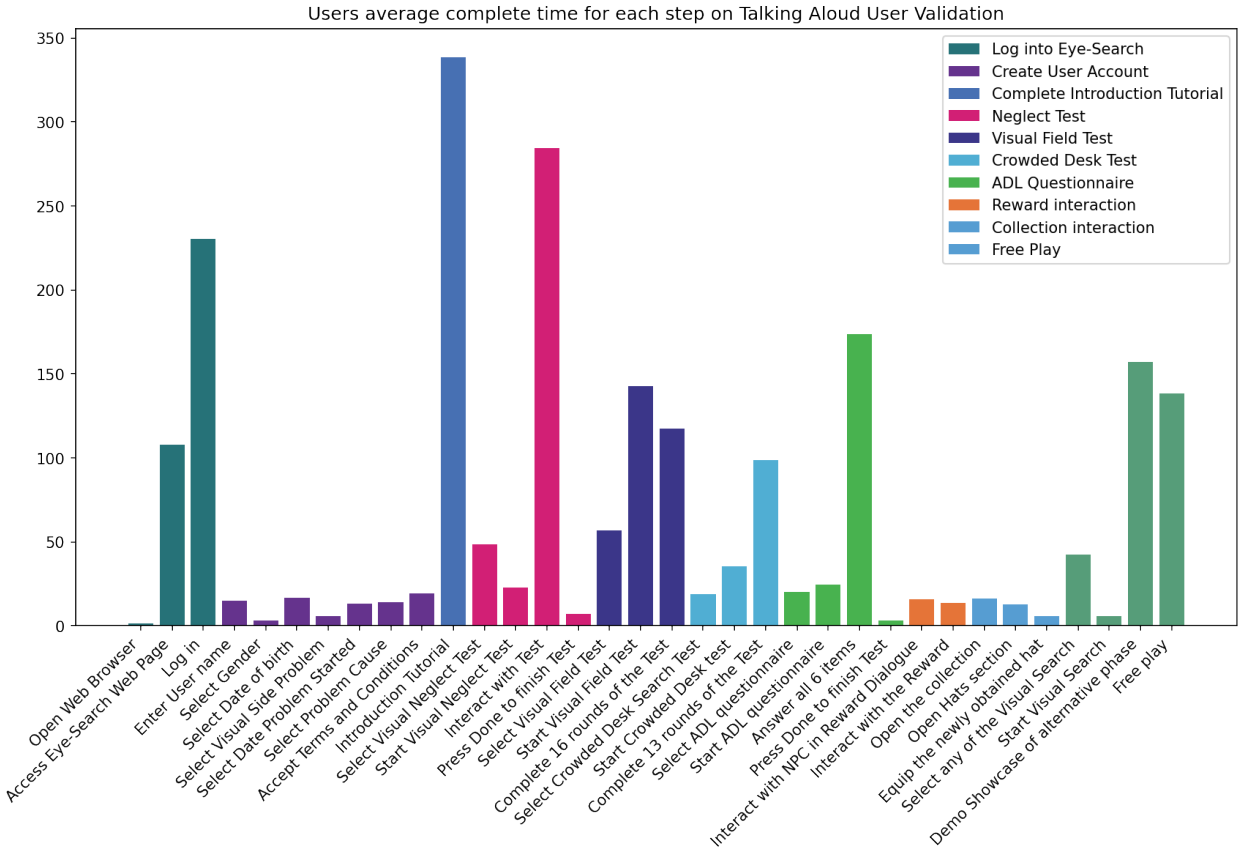


Figure 5.9
Visualisation of time taken per task on the Talking Aloud validation.

For the errors registered, as depicted in (Fig. 5.10), which depicts the users errors, both critical and non-critical, for each task of the validation, the following observations were made:

- Regarding the user login into the application, the errors are mostly due to users not remembering their google credentials, being this not relevant for the study.
- Despite the introduction of many new features for the new version of the application, users did not show signs of having trouble with most of them, with the exception of the tutorials and NPC dialogues. The issue presented was that, during these tutorials, where the NPC makes a walkthrough with the user, the application is only interactable though a "*next*" button, being the other interactions, such as buttons and menus disabled during this process. This is something that confuses some users.
- For the critical errors found on the NPC interaction, these are directly related to the previous analysis, as users were not sure how to proceed, or what options were interactable, some ended up closing the tab, and opening the application again. This situation was also featured on the Visual Search activity, where, they were not able to find the button to return to the main menu.

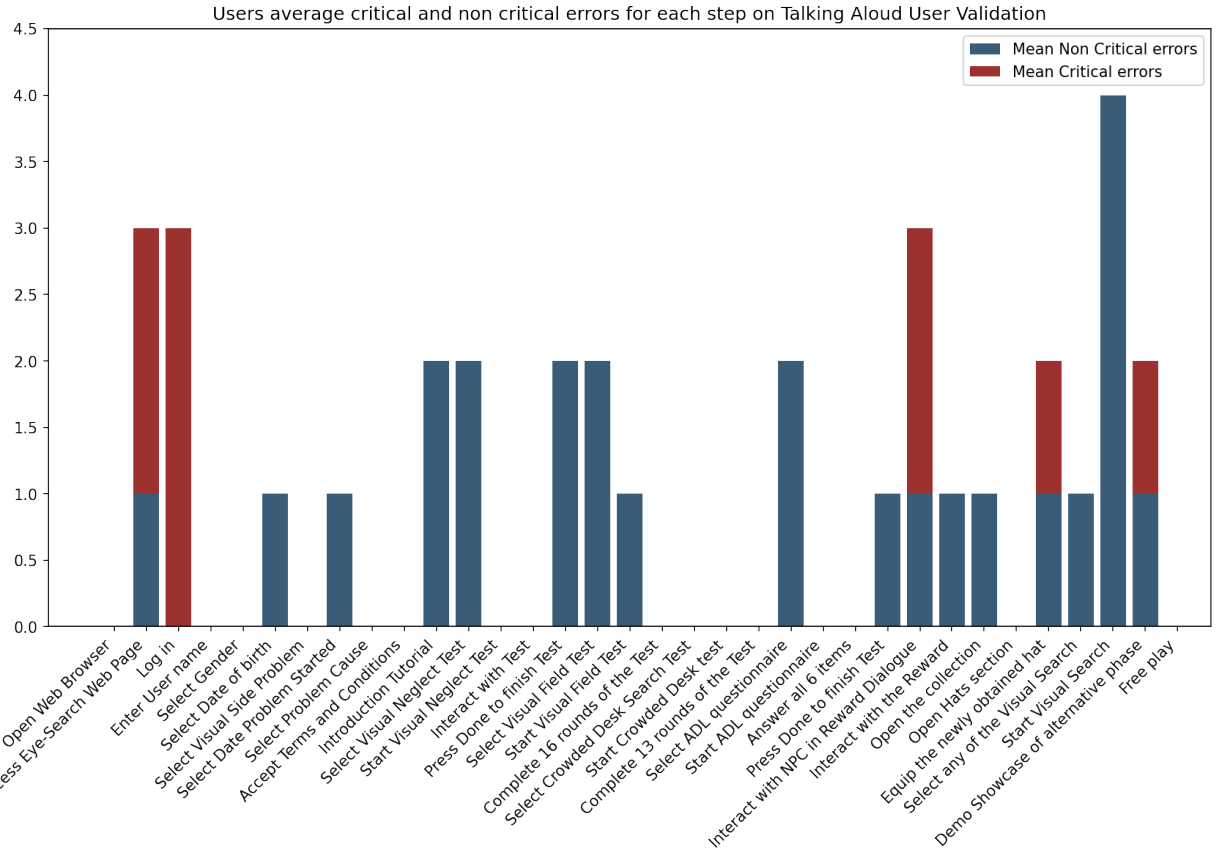


Figure 5.10
Visualisation of number of critical and non-critical errors per task on the Talking Aloud validation.

In terms of task classification, most users in almost all the cases were able to achieve the right outcome for all the steps, as well as the steps featuring a good level of rotulation. In contrast visibility, that is, the users noticing that the correct action is available to them, was identified in the interactions with the NPC. As already stated on the error analysis, users became confused during walkthroughs, and even sometimes, were not able to find the "*next*" button on the screen, making them unable to continue unless they searched for it. Lastly,

despite showcasing a good level of feedback, in terms of the visual and auditory kind, buttons in general did not feature enough visual feedback, often making it difficult to know if they were clicking them right.

For the user feedback, despite the application they knew went through an overall overhaul,users greatly valued that it remained as a web application, and raised the distinctive and unique look and features that were introducing, highlighting the different thematics on Visual Searches, and showcasing interest on the daily goal system. Two main complaints were featured in the studies: first was that the information screens change automatically when the loading ends, not always allowing users to read them fully. The second observation was that, as the application focus is on the Visual Search activities, users made an emphasis on making the application as responsive as possible, and reduced the amount of time between rounds as well, as, the positive or reinforcement feedback delivered by the NPC and the system itself would take some of this highly precious time to the users.

Lastly, regarding the observations made during the user studies held, one main remark made was that users would sometimes have the pointer of their mouse very close to buttons or clickable objects, but, as they were not directly on top of them, they were not able to successfully interact, making them spend time readjusting their pointer and searching again on the screen for the interaction they were aiming at. Despite this, auditive feedback was observed to be a useful tool in assisting the user navigation through the application.

5.7 Iteration Results and discussion

In this third iteration, the gamified redesign of the Eye-Search application was fully implemented in a three-layer architecture, splitting the application in three components: The Unity WebGL application served to the users, the Node.js Restful API that acts as an intermediary with the communication with the last component, the MySQL database.

In order to evaluate the application usability and identify possible issues before launching it to the public, a validation was made using the Thinking Aloud protocol. This formative validation, held with experienced users, provided quantitative and qualitative information about the application usability, and insights of users' perception of the application. Analysing the data gathered from the study, on the whole, the application worked successfully from an operational standpoint, as users were able to interact and successfully fulfil their sessions, which consisted of creating an account, completing a daily goal, and interacting with the Visual Searches. In addition, its stability was also tested, as the amount of critical errors encountered was mostly due to user end mistakes, like closing the tab of the application.

Regarding usability, the application proved to feature a minimum level of usability, users satisfactorily navigated through it, without the need of external help, nor spending extended amounts of time looking in the interface for their objective. Thanks to the data gathered, the following improvements to the application were planned and implemented to tackle the usability problems the users encountered:

- An increase of contrast between sections of the interface that are interactable and those that are not. This to further highlight what actions and buttons users can interact with,

in for example, tutorial sections.

- The informative screens will not transition automatically between scenes, rather, when the loading is finished, a button to continue to the next scene will be displayed at the bottom of the screen, waiting for user interaction.
- The overall clickable areas of objects in the application were increased, in order to make them more forgiving and easily clickable. This change is reflected in the following sections:
    1. All clickable areas of buttons on the application are enlarged.
    2. Circular targets, such as the Visual Search target, and the Visual Neglect rings have a larger clickable area, which covers beyond what the sprite image shows.
    3. The assets of the Crowded Desk Test have a larger surface, and it covers all the objects, even though it has holes. This is reflected in (Fig. 5.11).

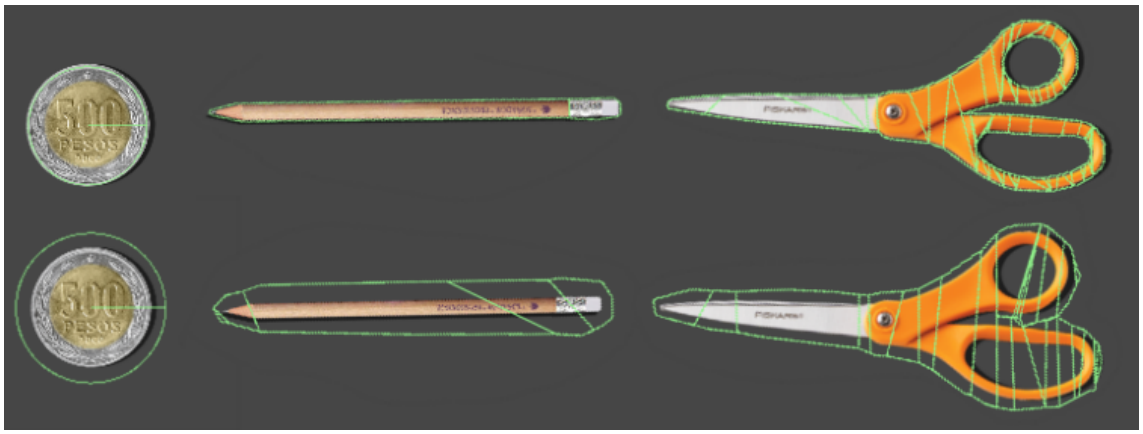


Figure 5.11
Examples of the changes of clickable areas of the objects in the Crowded Desk Test.

Once this iteration revision was implemented, and the application usability was endorsed by the study conducted, the application was launched to the public in order for it to gather data to perform a proof of concept study, which directly aims to acknowledge the hypothesis raised in this thesis, as well as answer the related research questions posed.

Chapter 6

Proof of concept

With the Eye-Search application developed, and its usability verified, the next step taken was the realisation of studies in order to verify the hypothesis raised in the present thesis work, as well as answering the research questions stated. With this in mind, the study consisted of a mixed method study over the quantitative data analysis over the users' performance on the therapy, gathered by the application. Together with qualitative data analysis from semi-structured personal interviews with users that had finished the therapy provided by the application. The explanation of this study will be split in these two parts, and explained in detail in the following sections.

As detailed in chapter 5, the Eye-Search application gathered information about user performance on the therapeutic activities provided by the application, as well as, data from user usage of the application. With this data, studies validated the two hypotheses raised. Each of these studies will be explained in detail.

6.1 User adherence

The first hypothesis raised was: "*The application of Gamification strategies and mechanics to the design of an web-therapy hemianopia healthcare application improves patients' adherence*". The first analysis conducted, related to the study of user adherence, was on the number of users in each of the time sections of the application, and compared it to statistics measured on the previous Eye-Search. The statistics provided by UCL institute of neurology, represent the earliest data registered of this kind of study, which corresponded to the first 24 months of operation of the original Eye-Search application.

By comparing and classifying the users by time section, or number of visual searches done, in amounts of 400, the following table displayed on (Tab. 6.1) was obtained. In this table, the first column corresponds to the range of Visual Searches users are being classified through, which goes from 0 to more than 2000. The second column displays the number of users at the time of measuring in the original application. The third, is the same statistic but on the implemented application, on a time lapse of three months. The last column is an estimation of the amount of users the original application would have had in its first three months.

Table 6.1
Number of users per therapy section on the original and the redesigned Eye-Search.

Range of Visual Searches	Original E-S user data [24 months]	Redesigned E-S user data [3 months]	User data estimation between versions
0	4,682	275	195
0-400	1,660	71	69
400-800	656	9	27
800-1200	251	4	11
1,200-1600	189	5	7
1,600-2,000	144	0	6
2,000+	725	1	30*
Total number of users	8307	365	346

The second analysis conducted was on the logging of users' playtime in the application. As explained in section 5.2.2 of chapter 5, in order to gather this information, two data structures were created each time a user logged into the application, being the latter one updated every 30 seconds. With this, by subtracting the timestamp on both structures, usage time of the application could be measured within an error of 30 seconds. The users in this study corresponded to those who had registers of completing any of the activities offered by the application, i.e., had an above minimum time of usage in the application.

This information about their usage of the application was checked against the activities of users on the registered time. This way, it could be verified in each session if the user indeed completed the therapy day, or if he/she took multiple sessions. Taking these considerations, we analysed users' average use time of the application for each therapy day. This is depicted in figure (Fig. 6.1), where in addition to study the trend of the data gathered, a linear regression was performed with equation $F(1, 20) = 0.5559$. This linear regression study was performed using Python 3.9.7, with the library `statsmodels` [58].

Lastly, adherence was studied in terms of user activity on the Visual Search activity. Following the same line of thought of the playtime analysis, the number of rounds done on the Visual Search activity was contrasted against the therapy days of the same users, doing a linear regression over the result, where a significant regression equation was found $F(1, 896) = 3.939$. This analysis is displayed on figure (Fig. 6.2).

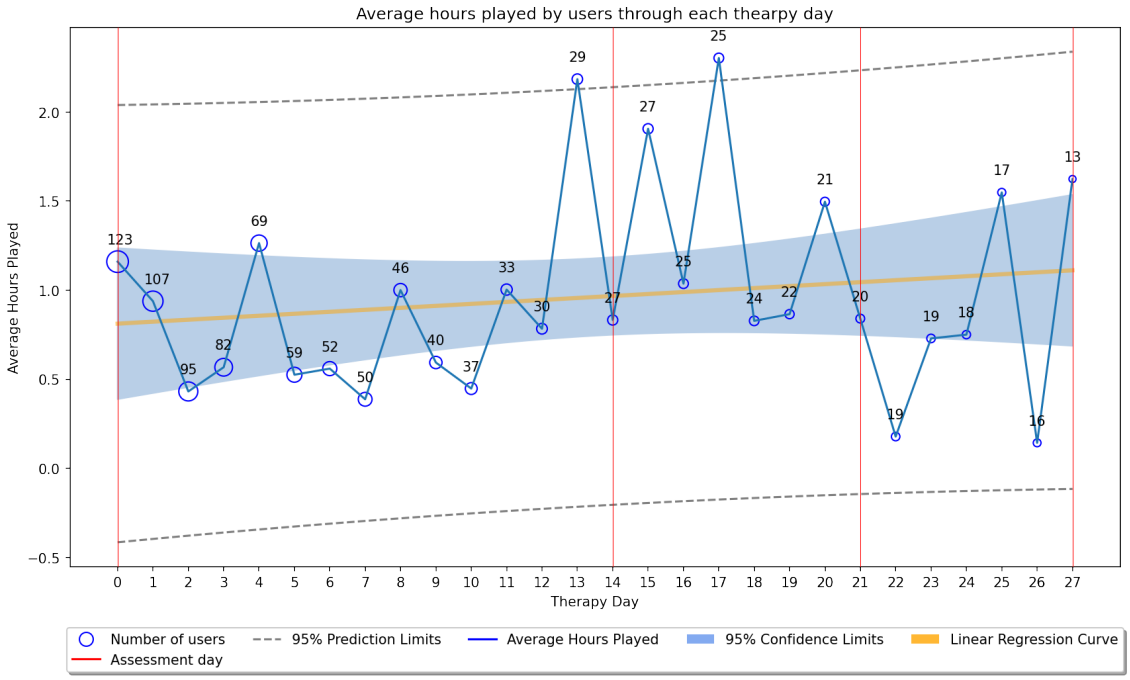


Figure 6.1
Visualisation with linear regression of User average use time per therapy day.

6.2 User performance and therapeutic effectiveness

The second hypothesis raised was: "*The application of Gamification strategies and mechanics to the design of an web-therapy hemianopia healthcare application does not degrade its treatment component*". In order to establish if the therapeutic component was not negatively affected by the Gamification of the application, a comparison of user performance was made between the implemented application, and results obtained on a 2014 paper published about the effectiveness of the original Eye-Search application [54]. In these papers, users are classified depending on their performance on the assessment tests Visual Neglect test and Visual Field test, and their average performance is measured for each time section, in the tests Crowded Desk test and Activities of daily living questionnaire. Lastly an analysis of variance (ANOVA) test is held with the statistics of the two last tests.

In order to perform such a comparison, first, the same procedure to select participants stated on the 2014 paper was followed. In this procedure, first, the participants chosen for the analysis were all users that had completed up to the second assessment test, which happens after completing 800 visual searches. With this, data about their performance can be measured in three time stages: T0 for the baseline performance, T1 after 400 searches, and T2 after 800 of them. Using their performance on the Visual Field test, users with a "clear" hemianopia were chosen. As explained on section 3.2.3, the Visual Field test measures a users' field of view by displaying 16 points distributed at 1, 2.5, 5 and 10°on the screen from both the horizontal and vertical meridians. Each point is tested four times over 36 different stimuli, and hemanopia, either it being left, right, is diagnosed if two or more points were missed in the same hemifield, at either T0 or T1. Hemanopia that is Homonymous, that is, users suffer from vision loss on both visual hemifields or no clear results were excluded.

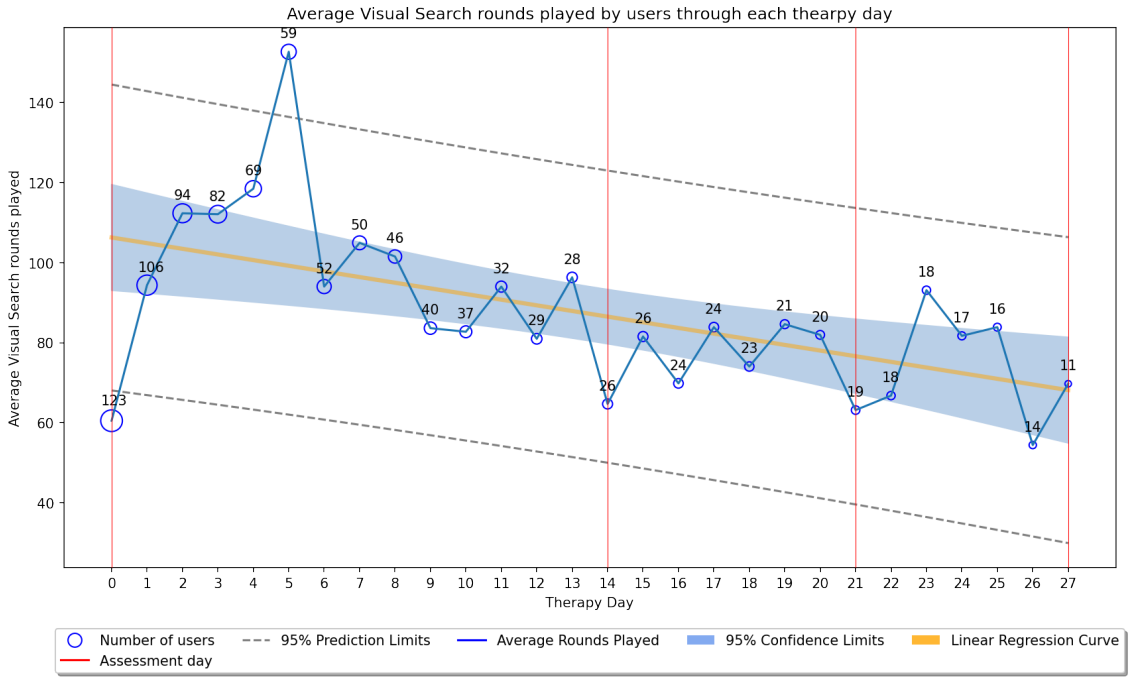


Figure 6.2
Visualisation with linear regression of User average visual search rounds done per therapy day.

Subsequently, users are classified by their performance on the Visual Neglect test, which, as explained on section 3.2.2, they are diagnosed with this condition if in either T0 or T1 they missed twice as many targets to one side compared with the other, or if they had a similar ratio of revisits. Patients that had no evidence of neglect were selected.

Lastly, from the remaining patients, their performance in terms of reaction speed on the Visual Search activity was analysed. As these users are already diagnosed with either left or right hemianopia, their "affected" side can be determined. With this information, users that featured a difference of 10% or higher in search time, between their affected and unaffected side, were selected for the study. Applying these steps on the measured data of this works application, the following number of users were filtered:

1. Users who had completed up to T2: (20)
2. Users who display a clear left or right hemianopia: (12)
3. Users that do not display a clear visual neglect. (9)
4. Users that feature a difference of 10% or more on search time between their affected and unaffected side: (9)

Once the users able to participate in the study were selected, the next step taken was to calculate their average performance on the Crowded Desk Test and the Activities of daily living questionnaire. For the crowded desk test, statistics of the users' reaction speed for their left and right side is logged. With this, users' average reaction speed on their affected and unaffected side was calculated, for each time section of the therapy. These results are displayed on figure (Fig. 6.3). For this same data, the effect size of the main outcome, or

the improvement on users reaction speed on their affected side was measured, this being this approximately 44%.

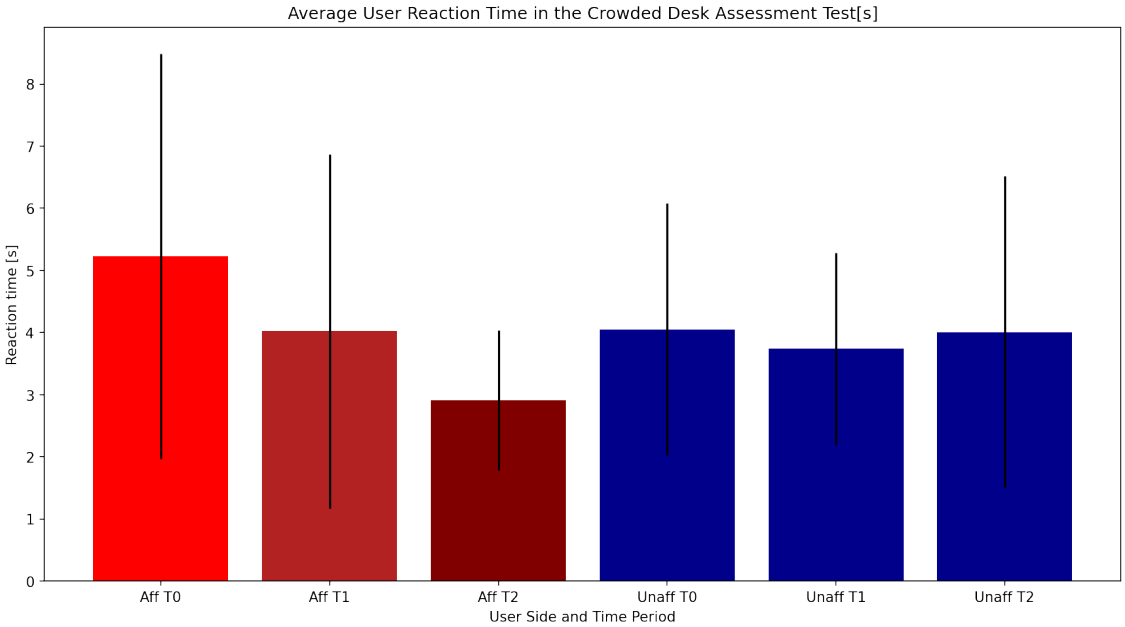


Figure 6.3
Visualisation of users average reaction speed per vision side and time section.

Lastly, before proceeding with the ANOVA test, user performance data was checked for the requirements needed for such a study, which corresponds to verifying if the groups for which ANOVA will be applied, feature a normal distribution. For this, a Saphiro-Wilk test was carried out, verifying that the data has a Gaussian distribution. Once that the normality was checked, a two factor within-subject ANOVA test was carried out for the Crowded desk statistics gathered. In this test, time was used as the within-group factor, and the additional within-group factor entered was the field (affected/unaffected). With these, the results obtained are displayed on the table (Table. 6.2).

Table 6.2
Results of the two factor within-subject ANOVA test over user average reaction speed.

Time interaction	Side Interaction:	Time x side interaction:
p = 0.028	p = 0.154	p = 0.167
F(2, 18) = 4.41	F(1, 9) = 0.7	F(2, 18) = 1.98

In the case of the Activities of Daily living questionnaire results, we studied the users' average self-rated difficulty for performing each of the six tasks, for the three time sections. The results are in figure (Fig. 6.4), where red shaded bars depict the activities of daily living where users on average expressed improvements.

Regarding detected improvements, in the relevant activities of *Collisions* and *Finding things* an improvement of 36 and 15% were respectively observed. An ANOVA test could

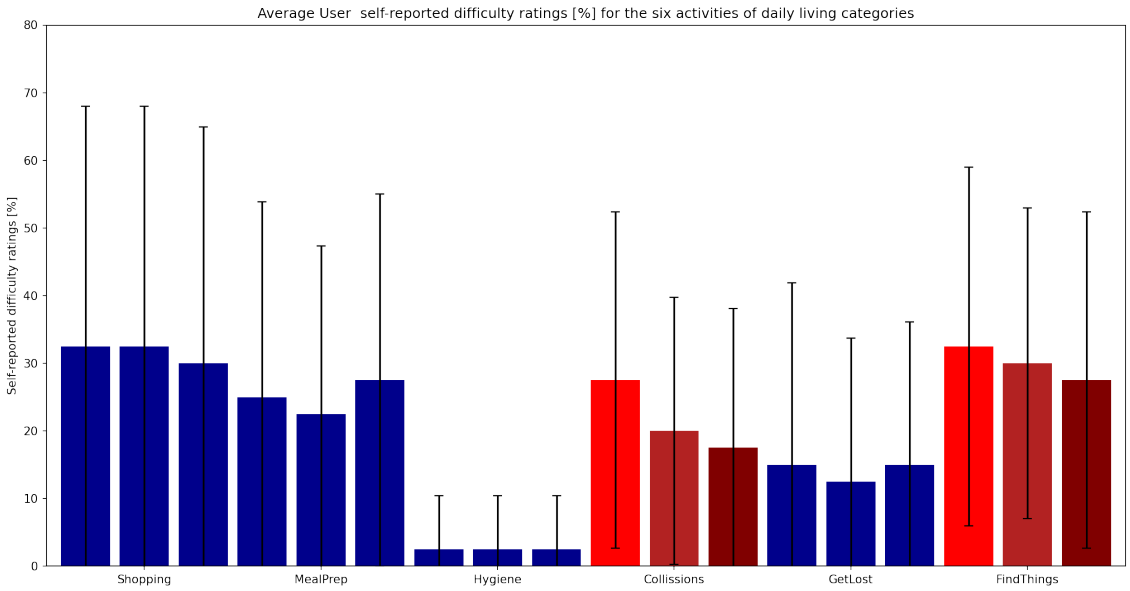


Figure 6.4
Visualisation of users' self rated difficulty per ADL and time section.

not be carried out with this data, as after analysing it with a Saphiro-Wilk test, its normal distribution could not be verified.

Lastly, users' performance evolution was studied through the results of the Visual Search Activity. This is depicted in figure (Fig. 6.5), where following the same procedure used for the study of adherence was followed. Therapy days were matched to users' performance, being in this case the average reaction speed on the Visual Search activity. A linear regression was performed over the data, founding a significant regression equation $F(1, 799) = 23.50$.

6.3 Perceived usefulness of Gamification mechanics

As stated in chapter 2, two research questions were raised in the present thesis work: (1) How are Gamification tools and mechanics taken into account for improving the design of short-term engagement in an hemianopia web-therapy treatment application? and (2) How does a Gamified hemianopia web-therapy treatment application need to be designed, in terms of mechanics and interactions, in order to maintain its core treatment functionality?

We carried out a qualitative study to obtain these answers, as well as insight on user perception of the Gamificaion mechanics introduced and perceived usefulness of the application as a whole. We next proceed to explain in detail this qualitative component of the study.

6.3.1 Methodology

The qualitative user study carried out consisted of a summative evaluation in the form of a thematic analysis over data gathered through semi-structured interviews conducted with users. The carried out interview comprises a set of questions that cover the key-topics aim to be investigated, while leaving some space open for conversations and discussions with

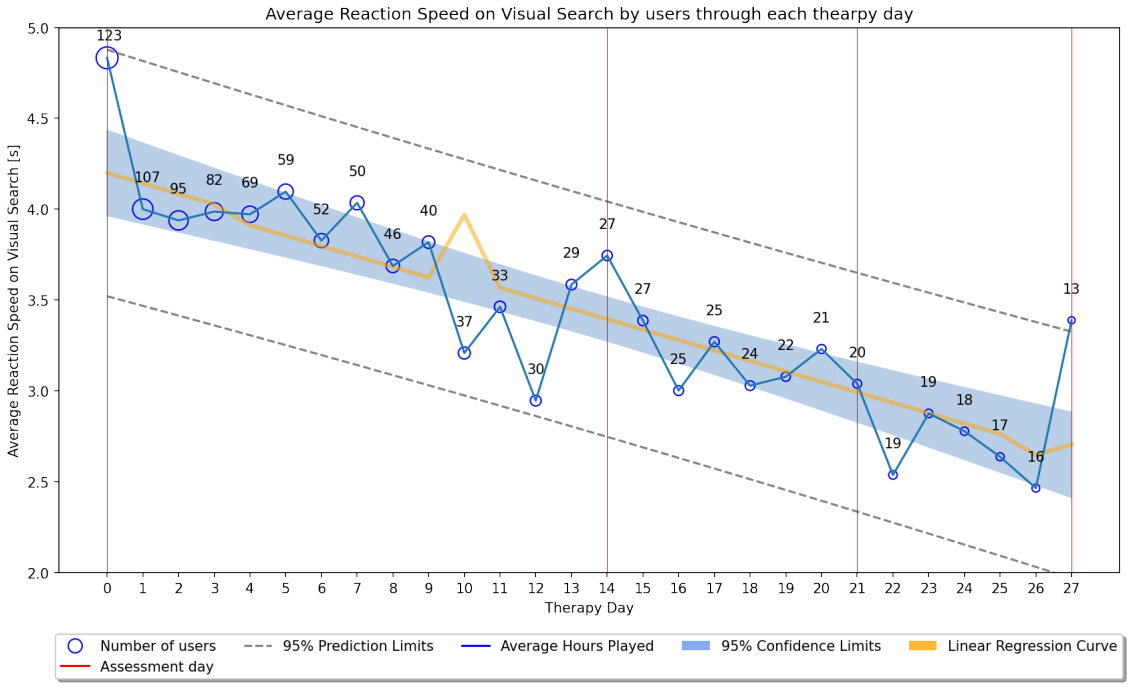


Figure 6.5
Visualisation of users average reaction speed on visual search per therapy day.

the interviewed users regarding some of the characteristics of the redesigned version of Eye-Search. This study aims to validate and obtain information of the following research topics:

1. User perception towards the goals and rewards mechanics, in terms of motivation and engagement.
2. Perception towards the NPC companion character, in terms of social relatedness and perceived utility.
3. Perceived usefulness of the redesigned application.

6.3.2 Participants

For the participants, the population consisted of users who have completed the therapy provided by the application, which takes around 28 days, and who are willing or able to collaborate in this type of procedure. Seven users participated in this study. The mean participant age was 62 years and six of the seven participants were male. A sociodemographic description of the participants of the study are depicted on table (Table. 6.3).

6.3.3 Equipment and Tools

The interview will consist of an online call through the Zoom platform, where the interviewer and the participant had to use a computer system or a mobile device which can run this application over the Internet.

Table 6.3
Sociodemographic descriptive table of the participants sample used for the qualitative component of the study.

Identifier	Age	Profession	Genre	Hemianopia Start Year
A	72	Financial Services	M	2021
B	76	Civil Servant	M	2021
C	70	Civil Servant	M	2021
D	38	Engineer	M	2021
E	64	Engineer	M	2021
F	77	RMN	F	2014
G	67	Engineer	M	2018

6.3.4 Procedure

The first part of the study, the semi-structured interview with users, will follow the guideline,that addresses key research topics and considers space for discussion:

Introduction

The following points will be addressed during the introduction:

- The interviewer acts in the name of the Eye-Search team, which he belongs to. He has been commissioned with this investigation and will conduct the interview that day.
- There are no incorrect answers', and all your opinions are useful and we greatly appreciate your feedback.
- The information obtained will be used for analysis and studies, but all collected data will be completely anonymised, thus making it impossible to track the participant.

Warm Up

To warm up, the participant will be asked how a "typical" session on the redesigned version of Eye-Search is.

Questions Phase

During the question phase, the following key questions will be addressed, while allowing discussion and opinions with the participant

1. What motivates you to use the Eye-Search application?
2. During this version we added many features that were not present on the previous version, for example the NPC, reward system, cosmetics and different visual motifs. Considering this, what features did you feel more comfortable with?
3. Which features of this new version did you find most useful?
4. Which features of this new version did you find unnecessary?

5. How often did you use the application?
6. Would you describe this version of the application as engaging?
7. Why or what motivated you to finish the therapy?
8. What is your perception about the rewards and goal system?
9. Regarding the rewards given by the application, how motivating did you find them?
10. What is your perception of the NPC companion?
11. Did you feel supported by the NPC companion while interacting with the application?
12. What is your perception of the therapy (visual search) on this new version of the application?
13. What are your feelings about the different visual motifs on the therapy activities?
14. Regarding the application as a whole, which features or parts of it did you use the least? Did you find them unnecessary?
15. Overall, what was your experience when interacting with the application?

Wrap up

Space for open answers and comments with the participant.

6.3.5 Thematic analysis

For the thematic analysis carried out, the following procedure was followed. First, all of the interviews were transcribed, in order to work with the data in text form. After this, the first processing of the data was done, an open coding approach was utilised, in order to uncover concepts, ideas, meanings and create codes. In this first iteration over the data, the codes defined were inductive codes, that is, the labels used to assign meaning to small bodies of text are concepts that came from the interpretation and analysis of the text itself, and were not previously defined. Two levels of analysis were used over the text, as, for each one, codes were grouped into themes, which assigned meaning to groups of codes. Subsequently, after each interview was processed by extracting inductive codes, an axial coding procedure was used, i.e., data, codes and themes defined in each text were related together, in order to further reveal new codes and common themes displayed over the texts. Axial coding allows for identifying central themes on the data. Following this procedure, the following themes were identified:

1. Application was recommended to the user by a health professional
2. Users greatly value the free therapy provided
3. Self-improvement of sight as an intrinsic motivator
4. Visual Search activity is engaging
5. Visual Search activity is easy
6. Visual Search activity functionality is repetitive
7. Visual Search activity could feature a score or mark system
8. NPC is likeable, helpful, and encouraging
9. NPC is annoying and somewhat naive
10. Could do without cosmetic reward
11. Reward perceived as naïve
12. Dressing feature perceived as redundant
13. Visual cues and stimuli is valued

14. Would rather have performance feedback as reward
15. Positive Perception of Daily Goal and Reward System
16. Daily goals as guide for recommended play time
17. Application daily login adherence
18. Doing the application daily goal was integrated into users rehab routine
19. Application used beyond daily goal
20. Application used beyond therapy offered
21. User wishes application was longer
22. New features improved the application
23. Condition improvement perceived during therapy
24. Application used as a self-assessment and monitoring tool
25. Application perceived as enjoyable, engaging and useful
26. Confusion about therapy flow
27. Suggestion that all activities should feature trials after their demo and tutorial

6.4 Results and discussion

From the quantitative study of therapy adherence, it was observed that users on average would use the application, for the whole duration of the therapy, between 0.5 and 1.5 hours per therapy day, ensuring that users interacted with the application for at least the recommended amount, showing that in the redesign version of the application, a constancy from the users is displayed. It is worth noting that, in some assessment days—14 and 21—users time use of the application lowered against the average until those points. This can be because after doing the assessment tests, users did not use the application beyond those days, which in contrast, in normal days users would interact with the freeplay function. This can be explained by the fact that the assessment activities can be much more cognitively demanding than the Visual Search activities.

When analysing adherence through the number of rounds of Visual Searches done by therapy day, it was observed that, when starting the therapy, there is a peak of Visual Search rounds played, where users play beyond what is stated on the daily goals of the first days. From this peak that occurs on the first week, the number of rounds gradually decreases, until a point in which users begin doing the daily number requested by the application, with the exception of the assessment days, where, along with the analysis of use time of the application, users do not go beyond the assessment daily goals.

Regarding the number of those that started using the application, we noticed that when comparing the data from the original application, the numbers are quite close in the range from 0 to 1600 searches, that correspond to the 28 therapy days. The greater divergence occurs in the 2000+ searches, where participants continue using the application far beyond the 28 days, something that cannot be observed yet on the developed version, due to the short-term reach of the present study, being only three months.

As for the study of the application's therapeutic component, in order to verify that it was not degraded, the users' performance was compared between the developed and the previous version. In this juxtaposition, it could be verified that, as with the original version, users' average reaction time on the Crowded Desk Search assessment test decreased for their affected

side, with each assessment. In order to verify correlations between time and the improvement of users performance, a two factor ANOVA was conducted, showing that there is a clear effect of time on users improved performance $F(2, 18) = 4.414932$, and when studying the time and side interaction, we observed that, despite not being able to establish a correlation due to the values obtained $F(2, 18) = 1.982572.$, these are close and tending to the desired results, showcasing that, in a study with a larger time reach, this correlation could be established. In addition, when comparing the percentage of improvement in both versions, the developed one has a 20% higher value, while due to its short time reach it cannot be confirmed that one version is more effective than the other. It can be established that the developed version does feature effectiveness in users' performance improvement.

Despite that it was not possible to carry out a comparison study of the user performance on the Activities of Daily Living questionnaire, due to its self-rating nature, and the small amount of the participants of the study, it could be observed that, in this version users reported an improvement on the collisions and finding things activity, being the improvements of 36 and 15% respectively, confirming that, users do perceive improvements on their condition after interacting with the application.

For the qualitative analysis of users' perception of the application and the Gamification mechanics included, from the thematic analysis carried out, the following user story was paraphrased:

Most of the users were introduced to the Eye-Search application after it was recommended by a health professional, who was treating them for their stroke condition. Those who use the application are motivated intrinsically to start using it. With the hope of improving their vision as much as possible, users commit to multiple treatments, Eye-Search being one more of them. It is also worth noting that all of the users interviewed had the motivation of recovering their driving licence once their visual capabilities improved. As one of the users stated: *"I also continue using it (Eye-Search application) past the daily goal presented, as I wanted to get my vision back, and therefore I wanted to do as many searches as possible, As I would like to be allowed to drive again."* Patient C, male, 70 years old.

A main complaint by most users is that the Visual Search Therapy Activity is too easy and slow at first, as this activity features 16 difficulty levels the users must progress through. Users also find that the difficulty progression is alright and makes the activity more engaging as they progress through the stages. The users who find that the difficulty progression is *ok* are users with notable visual defects, while the users who want a harder challenge feature have very few visual defects. For instance, one of the interviewed users stated: *"Well, at the start I found them(Visual Searches) a bit boring, a bit slow you know. But as you get into it, the difficulty was alright. They were all part of it, you know, all made my eyes move and train, so I used it daily and did all the daily goals."* Patient A, male, 74 years old. Also, this second type of users propose multiple difficulty settings to add to the activity. The following is the most commented on: A timer to give the user a limited time to find the target, add more distractions and obstructions, faster movement, and some changes to the gameplay which will be explained below.

Users not only find the activity easy due to limited difficulty settings, but they find it repetitive from a gameplay and/or functional standpoint. As the target always starts in

one of two predetermined positions, and will move to the other side, and will always end up looking down or up, users note that there is not enough variety gameplay wise, and gets repetitive and tedious fast. With this in mind, the following changes were proposed among users: give the object more final pointing destinations (currently, only two), make the trajectories more diverse and not only from one side to the other, give the different visual motifs different gameplay elements to differentiate them even more between each other. This also goes hand in hand with daily goals offering more variety if each visual motif acted as a different interactive experience. As explained by one of the users: *"As one of the participants explained I enjoyed them (Visual Searches) But, you could vary how the searches work. Maybe you could turn the object sideways or in other directions, to make it more challenging. As it's always left to right, right to left, and then picks out where it ends up, it gets repetitive after a while. It is fine, but you could add another way of doing it that is different, as well as changing the games (different visual motifs on visual search) between them, altering them so they aren't played the same way, to make them more appealing and stimulating."* Patient C, male, 70 years old.

A common feedback was that the Visual Search Activity could really use a scoring system, to rate the user's performance on the activity after a session, evaluating and informing his/her performance versus what is normal or should be expected. This score system could also be used to reward players after obtaining a certain score.

The NPC character was described in two ways. The first is a likeable, cheerful and positive figure with a distinguished look, a source of encouragement for the user due to his quick feedback dialogue, funny and a help to users with very low vision when navigating through the application.

The second is that users find it somewhat annoying, in terms of it being shown too often (in terms of dialogue) and it producing too much noise, sometimes causing fatigue to the users. In addition, its animations can sometimes be distracting. Despite this feedback, these kind of users don't find it as an obstacle towards using the application, as they opt for ignoring it or being indifferent towards its existence.

For the extrinsic reward system implemented, users mostly stated that they could do without its reward, as their attitude towards it is of indifference. Some of the users stated that they were not looking for rewards, or to be rewarded for their actions. Regarding the type of reward given, some users described them as naive, but not because of the appearance, but the use that is given to them; to equip them as cosmetics to the NPC. This impression is mainly caused by their indifference to this feature, not using it much, or letting their kids use it, concluding that they could use it without them. Regarding the rewards themselves, abstracting them from their use, users found them to be a cute addition, and something unique that differentiate the application. Users also valued the visual cues and stimulation that came from being delivered or being showcased the rewards, suggesting that the reward could only consist of visual stimulation, as it is the characteristic they value the most. Lastly, other users considered that the collection feature gave a feeling of progression as they accumulated the daily rewards.

Users also suggested that another kind of reward they would value, would be a form of detailed feedback of their performance per day, after finishing a daily goal, which also relates

to the score or mark system suggested. They also emphasised how useful this could be, as it could act as a middle assessment or performance check between assessment sessions.

Regarding the daily goal system, it was a generally liked feature, being the one most praised by the users when asked which new addition improved the application experience. No user had any suggestions or complaints about the feature, and they also claimed that getting them done and progressing through the therapy was very enjoyable, as it gives a pleasant feeling when completed. Users stated that they used the goals as a guide for the therapy, as they would login and do the daily goals knowing that they were using the application for at least the recommended amount, or interacting with it as they should be doing to expect results.

Given the daily goals, users mentioned that they would consistently login in to the application daily to do them, to the extent that users who had daily rehab exercises would add the doing of the daily goal to their rehab routine. Despite goals giving users a guide towards how much they should interact with the application to expect results, users often interacted with the application beyond performing the daily goal. Motivated to improve, they used the *freeplay* section of the application to continue doing even more visual search rounds until they felt tired.

Regarding the therapy adherence, users claim that they would interact with the application daily, as much as they could, being this process only interrupted by changes in their hemianopia condition, which sometimes would make them take a break from the Eye-Search therapy. Users also pointed out that, even after finishing the 28-day therapy, they continue to use the application daily, and some of them wish that the therapy process of the application was longer than 28 days.

Overall, when asked how they feel about the new features added, they claim that they are a general improvement to the application experience. Highlighting the mechanics of: feedback and performance stats, the daily goals system, the NPC, the sound design of the application, and the information screens between activities. One factor that all users pointed out was that, as they interacted with the application daily, they would perceive improvements on their vision. These were reflected as improvement of reaction speed and concentration. This motivated them to continue using the application and to go beyond the daily goal activities.

One of the most mentioned points by the interviewed users, was that they highly value the application as they can use it as a self-assessment and monitoring tool for their condition. *"The application has and continues to be a useful and user-friendly programme in assisting with my vision and providing valuable feedback through the four(Assessment) tests. I have an annual check-up with my eye specialist and the visual field enables me to monitor my situation between these check-ups."* Patient F, female, 77 years old.

Users greatly appreciate the feedback and stats delivered by the application regarding their performance on the assessment tests, and they highlight how useful it is for them to see if their condition is improving. Users rate the application as an enjoyable, engaging and very useful experience for them. They greatly value the activities they can interact within the application, and the visual stimulation delivered by it, and sometimes used as relaxation from their other rehab exercises.

One factor that was a common point acknowledged in the interview, was that while users interacted with the application, they became confused about how the therapy itself worked. Most users did not understand that the therapy consisted of a base assessment phase and three other phases of this same kind, separated by 400 visual searches each one. As they use the application as an assessment and self-monitoring tool, most of them would expect to see daily the assessment activities enabled. Regarding user suggestions, users emphasised that, after the tutorial and demo before each activity, they could have some trial rounds, in order to further understand the activity and not make mistakes when first interacting with it.

6.5 Design Implications

From the results of the proof of concept, the following guidelines for developing a Self-Guided Web-Based Therapeutic Intervention for the treatment of hemianopia were extracted:

In order to develop a Self-Guided Web-Based Therapeutic Intervention, which aims to offer or supplement face-to-face therapeutic interventions, the four main components for Internet-supported interventions, proposed by Barak et al. [5], which are **Program Content**, **Multimedia choices**, **Provision of Interactive Online Activities** and **Guidance and Supportive Feedback**, must be included in the following way: In terms of **Program Content**, users greatly value knowing what they will encounter when using the Web-Based Intervention. Providing them information about, what to expect from the treatment, what activities they will encounter, and an insight over the therapeutic background of the application can greatly increase user commitment and trust towards the therapy, and even make them start using the Web-Based Intervention. If not enough information is provided, users might not even give the therapy a chance.

Regarding the **Provision of Interactive Online Activities**, two considerations must be considered. First, allow users to interact and view feedback about their performance, if this does not affect the therapy flow of the application. Users that interact with these kinds of Web-Based Interventions, not only use the application for the provided therapy and its benefits, but they also greatly value if they can use the software as a self-monitoring tool. Allowing users to self-evaluate at any time greatly increases their engagement to the therapy, as if the visualisation of progress is a strong intrinsic motivator. Secondly, if the Web-Based Intervention is highly focused on one activity, consider diversifying the experience by dividing the activity into multiple ones. This division should be both visually and in functionality. Different visual motifs can reduce user boredom or exhaustion while interacting too long for the same activity, also allowing the users to distribute their therapy between multiple activities, for which they can rest between interacting with each of them. In order to keep users interested through these multiple activities, the changes should not only be visual, but functional too. If the activities scale on difficulty with time, give each one a different difficulty modifier. This allow for a different user experience in each activity, further improving the therapy engagement. For **Multimedia choices**, for the feedback and performance statistics delivered by the application, consider delivering it in multiple formats, so users can view their progress as it suits them best. For example, deliver evolution over time statistics in both line chart visualisations and in table form.

Lastly, for the fourth key component of **Guidance and Supportive Feedback**, adding to

the feedback explained on **Provision of Interactive Online Activities**, to further support and guide users, consider the addition of an NPC companion to the Web-Based Intervention. By delegating the Web-Based Intervention tutorials and system messages to the NPC, it starts acting as a source of guidance for the users, and its addition also acknowledges a key topic when dealing with users of different degrees of visual blindness. These users can suffer from social isolation due to their condition, directly affecting negatively one of the main intrinsic motivators. The addition of an NPC can act as a source of social relatedness for them if the following considerations are met. First, delegate messages of quick feedback to the system, such as congratulating users after completing a task, so it can also be a source of encouragement and support for the user. Also, featuring the NPC in the different activities offered by the application, it can evoke feelings of social relatedness, as the user can share experiences and common goals with it, offering a sense of cooperation. Lastly, the character visual design should inspire respect and authority, making it a figure that users can trust while dealing with the Web-Based Intervention. The inclusion of an NPC can positively affect users' experience, as long as it is used carefully, avoiding the over expression of this character, and avoiding interrupting or acting as a distraction while the user is interacting with the therapy.

When developing this kind of Web-Based Intervention, a key component that must be acknowledged is user commitment, adherence, and engagement to the therapy. One way to approach these three fundamentals, is suggested to add a reward system to the application, which is designed using the Hook reward framework [22]. This system based on loops, whether weekly or daily, boost users' adherence to the application, by making them return every day or week to the therapy provided. First, for the daily loop, design it with the following considerations for each of its step:

1. For the trigger, when the user logs in to the application, give them a daily objective or goal they should achieve. These goals should be composed of tasks that consist of interacting with the different interactive activities offered by the Web-Based Intervention.
2. For the interactive activities chosen for each daily goal, these should encapsulate the recommended or desired amount of use time or activities, done on the Web-Based Intervention that users should do to expect results from the therapy. These activities can be designed individually for each day, in order to adjust them to the desired "ideal" therapy the users should follow.
3. After completing each goal, two rewards should be given to users: An extrinsic reward should be given.From out study, users shown a preference towards rewards that consist of a visual stimuli or visual cue, something that the target users greatly value. This extrinsic reward must be something the user accumulates and returns to, such that, when looking back at them, it gives them a feeling of progress. The second should be in the form of an intrinsic reward, composed of feedback from the application about their performance on that day, acting as an intrinsic motivator and as a tool of self-assessment.
4. Both rewards will motivate users to come back to the application. The accumulation of the extrinsic rewards will be a showcase of their time investment on the application, making them want to continue such an investment. And the intrinsic reward will motivate them as the application can display to them how they are improving on the

therapy.

A daily goal not only gives users a sense of expectation towards interacting with the therapy, but also helps them create a routine around using the expectation, for example, adding it to their list of rehab activities. Also, giving the users a list of daily tasks helps them as they can use the daily goal as a guide of the recommended activities they should be doing for the therapy to take effect.

In addition to the daily loop, to further encourage adherence and engagement, consider the addition of a weekly loop, designed around the daily goal. This is, considering each completed daily goal, a progress towards the weekly goal, in this way users are further motivated as they can expect a bigger reward for their efforts once a week. The reward given can be an improved version of the daily loop reward, i.e., a deluxe or special version of the extrinsic reward, and an intrinsic feedback reward in the form of a week retrospective, where the user performance over the week is analysed. Lastly, if the duration of the therapy goes for a month or more, a monthly loop can be added following the same described format, where its activities are the weekly goals, and the rewards are an improved version of the weekly loop.

For cognitive demanding Web-Based Intervention, consider the addition of spaced breaks and rests. This can be done between activities or tasks belonging to the daily goal, giving the users time to rest, so fatigue can be reduced, making it not affect the performance of users. The breaks also help develop both cognitive and mechanical skills the users can acquire by interacting with the Web-Based Intervention activities. These breaks can be integrated into the application as a consequence of using a daily goal system, as rests between daily sessions contributes towards spaced practice.

Lastly, when dealing with users with conditions of visual disabilities, consider the audio design of the application, for which, mechanics from the area of audio games can be considered. Based on the guidelines provided by the IGDA [7], the following mechanics are advised: For each action the user does in the application, always provide input feedback, for example when clicking a button or interacting with an element. Also, these types of users can have difficulties when navigating the application using a mouse, for which adding sound effects for the hovering of interactive elements can greatly help them with the use of the mouse input. And, consider utilising sound effects to characterise game entities, that is, assign different sound effects for interactive elements that have different purposes. In this way, users' navigation can be eased as they can associate different sound effects to actions in the application.

Chapter 7

Conclusions and Future Work

In HCI, Gamification has proven successful in improving users' experience and engagement by applying game mechanics in multiple and diverse non-game contexts. However, in order to choose which game mechanics should be included in a given context, these must be intrinsically related to the context and the type of user the Gamification application is aiming, as a "one-size-fits-all" approach towards Gamification tends to present mixed results on its effectiveness, which, depending on the context it can not only negatively affect the users experience, but also compromise the application it was applied on for its initial purpose. As there is not a general approach to Gamification, each context and user type must be approached as a different case, thus displaying gaps in the literature, in which studies that produce replicable knowledge have not been broadly conducted.

In light of this gap, in the present work Gamification tools and mechanics were designed and evaluated for the improvement of short-term engagement and adherence to the context of therapy for users in a Self-Guided Web-Based Therapeutic Intervention for the treatment of hemianopia, without compromising or degrading its healthcare component. This study has the aim of not only improving the user experiences of the application, but also providing reusable knowledge about the application of Gamification on this specific context, as there is a lack of design guidelines for the application of Gamification in Web-Based interventions, and even more in the case of hemianopia rehabilitation therapies.

In order to perform this study, and craft reusable knowledge and guidelines to contribute to the area of Gamification, first, the Web-Based Intervention for the treatment of hemianopia was developed in three incremental iterations, following the prototyped development methodology. In the first iteration, the healthcare background behind the treatment component of Eye-Search was thoroughly studied and implemented, being this core component validated with the subject matter expert. In the second iteration, a gamified design, using the *Mechanics, Dynamics and Aesthetics* framework, for the application was conceived. This design focused on introducing Gamification mechanics that acknowledged the main issues found on the original version of Eye-Search, these being the lack of engaging and interesting experiences, the perception of the application as exhausting, and the compromise of user adherence to the therapy due to these factors. Taking this into consideration, the gamified design consisted of four main components: (1) A daily task extrinsic reward system designed

using the Hook framework, (2) A Non-playable Character Companion, and (3) A spaced break system. This design was validated with experienced users of the original application.

Lastly, in the third iteration, the Gamification design was implemented, built upon the prototype result of the first iteration. The web application was implemented using a three-layer architecture, which consisted of a Unity WebGL application, a Node.js Restful API and a MySQL database. Before releasing the developed application to the public, a user validation using the *Thinking Aloud* protocol was carried out with expert users, to further verify the application usability and integrity.

Once the application was released, to perform an evaluation over the Gamification design of the gamified web application, as well as obtaining information and data for the validation of the proposed hypotheses and the having research questions formulated, a proof of concept in the form of a mixed method study was carried out. This study analysed data from two sources. The first corresponds to quantitative data logged by the application about users' performance and their use statistics of the application, over a time span of three months. And the second source came from a user study in the form of a semi-structured personal interview held with users that had completed the therapy provided by the application.

The results of the quantitative component of the study indicate that, in terms of user adherence, it was possible to state that it was not compromised by the addition of Gamification into the application. By comparing the number of users that utilised the application on its diverse stages through the three months it has been available, with the estimated users that the original application had on its first three months, it is showcased that the user population of the application was maintained through the versions. Additionally, the application adherence was further analysed. As mentioned on section 6.4, the amount of time per therapy day users spend on the application, was estimated in average to be between 0.5 and 1.5 hours. This demonstrated that with the Gamification mechanics added, the application was able to induce users to interact with it for at least the recommended amount of 20 minutes, for the therapy to take effect. These findings support the first hypothesis assumed in this thesis work: *The application of Gamification strategies and mechanics to the design of a web-therapy hemianopia healthcare application does not degrade patients' adherence*.

For the second hypothesis, *the application of Gamification strategies and mechanics to the design of an web-therapy hemianopia healthcare application does not degrade its treatment component*. It was possible to ensure that the therapeutic component was not degraded by studying users performance on the assessment tests of the application and juxtaposition it with the results obtained by the original version of the application. As analysed in section 6.4, users' performance in terms of their average reaction speed on their affected visual hemifield side improved by 44% between their first and third assessment while using the application. This value is 20% higher than the one reported by the 2014 version. To further validate these results, a two factor within-subject ANOVA test was performed over this data, confirming that there is an effect of time on users improved performance. Moreover, users' performance on the Visual Search therapeutic activity was measured per therapy day, highlighting that users' average reaction speed improves as they progress over the therapy. These two findings about user improvement, further support the second hypothesis of this thesis.

For the second component of the proof of concept study, a thematic analysis carried

out over the data obtained from personal interviews with users offered, insights about user perception towards the Gamification mechanics added, as well as their perceived utility of the application. The results that emerged from this analysis directly acknowledge the first research question raised in this thesis work: *How are Gamification tools and mechanics taken into account for improving the design of short-term engagement in a hemianopia web-therapy treatment application?* The findings support that the mechanics of the daily task extrinsic reward system based on the Hook reward framework, and the diversification of the main therapeutic activity of the application, positively affected the short-term engagement factor. The daily reward system not only motivates the users to log in daily to the application, but also motivates them to engage with the application at least until they complete the tasks that were given to them. The users were engaged to complete the daily tasks for two reasons: (1) To be extrinsically rewarded by the application, appreciating the visual stimuli that came with it, and (2) To use the application for at least the recommended amount of time, using the tasks given as a guide towards their daily therapy. The reward system was able to engage the users for the duration of the therapy by making the users return daily to the application, and displaying to them the investment they have done into the application, in terms of extrinsic rewards accumulated and intrinsic growth, as they could visualise how much they have improved over the therapy days. Secondly, the diversification of the main therapeutic activity of the application greatly improves users experience and engagement, as users greatly value a change of pace when dealing with a physically exhausting activity. This division, despite being only aesthetic, was described by users as one that reduced the monotony of the activity, and their exhaustion when dealing with it, as they could reset between activities.

For the second research question raised of *How does a Gamified hemianopia web-therapy treatment application need to be designed, in terms of mechanics and interactions, in order to maintain its core treatment functionality?* It directly acknowledges the contribution of this thesis work to the literature, which is to provide reusable guidelines for the implementation of Gamification in a Web-Based Interventions for the treatment of hemianopia context. By abstracting the results of the thematic analysis done, the following guideline was crafted:

1. Consider the addition of a daily reward system based on the Hook reward framework. These mechanics should provide the users new tasks daily, which are designed as the recommended tasks users should be doing in order to expect results from the therapy. The reward from this system should come in two forms: (1) an extrinsic reward in the form of a cumulative visual stimuli, and (2) an intrinsic reward in the form of feedback towards the user performance on the tasks s/he performed. This mechanic acts as: A guide to the users, by providing them with the recommended activities they should be doing, a source of engagement, as users are "hooked" to interact daily with the application for its rewards and as a source of spaced practice, to further assist in the development of users motor and cognitive abilities.
2. For users that suffer from a condition which directly reduces their existing social interaction, causing them to be in a state of social isolation, consider the addition of a NPC companion to the Web-Based Interventions. This character can act as a source of social relatedness to the user, as the system messages can be delivered through it. For its design, it is recommended that it represents a figure of authority, making it a character the users can respect and that can act as a guide they can trust. In this way,

this mechanic can act as a source of social relatedness, support and encouragement for the users, which are factors of utmost importance for therapeutic processes.

3. If the Interactive Online Activities of the Web-Based Intervention is concentrated in one activity, try to diversify this activity by dividing it into multiple ones. These activities should maintain the core therapeutic component of the original activity, but they should vary in aesthetic, for example visuals and audio design, and in functionality. For this variable, if the activity features a scaling difficulty, consider adding different difficulty modifiers to each of the variants, so the experience in each one is different. This diversification keeps the user's engagement through the activities, while also decreasing his/her boredom and exhaustion.

While the results of this thesis work provide reusable guidelines for the implementation of Gamification mechanics in the context of Self-Guided Web-Based Therapeutic Intervention for the treatment of hemianopia, several limitations still exist. First, the quantitative analysis produced results that showcased that user reaction speed improved over the therapy, and that was 20% better than the one measured on the previous application. It must be considered that the sample size utilised for the study was relatively small, being it of 10 people, opposed to the 56 users featured in the 2014 study. Due to the short time span of the study, of just three months, it was not possible to establish a clear interaction between time and side through the two factor within-subject ANOVA test. This limitation is also present while studying user performance in the Activities of Daily Living questionnaire assessment test. As, for this study, as a Gaussian could not be evidenced in the groups, so ANOVA study could not be not carried out. It is worth noting that, as in the 2014 study, users that feature the visual neglect condition are not included in the sample. It also does not distinguish users by which side they have vision loss. With a larger time span, a quantitative study could be carried out where user performance is compared with the one showcased in the 2020 Eye-Search study. In this research, users were split into four groups depending on their condition: (1) Visual Neglect and Hemianopia, (2) Only Visual Neglect, (3) Hemianopia on the right, and (4) Hemianopia on the left. The small sample also affects the validity of the reusable guidelines, as the number of users interviewed was only 7.

Although this study explored the implementation of Gamification mechanics in a Self-Guided Web-Based Therapeutic Intervention for the treatment of hemianopia, one factor that was not considered was the type of users of the application, in terms of the kind of user based on one's player type, and sociodemographic characteristics. As stated by Zicherman et al, when choosing which game mechanics should be included in a given context, these must be intrinsically related to the type of user or player the Gamification application is aiming for, as each individual responds and perceives Gamification differently according to individual attributes. For this, a study could be carried out over the users of the application in order to study which players use the application, and how each type responds to the implemented mechanics. For a study of this kind, player classification models could be use. The state of the art focuses on the BrainHex model [50], which is a neurobiology-based typology for classifying players, and the HEXAD Gamification user types model [67], which characterises users by their receptivity to varying Gamification strategies. In this way, the Gamification guidelines posed can be further reused in different contexts depending on the type of users. In addition, a gamified application that classifies its users before they start using it, for example by asking them to answer a questionnaire, can dynamically choose which

Gamification mechanics should be showcased for that kind of user, presenting a dynamic Gamification. And in terms of sociodemographic characteristics, a further study can be done where each of the implemented game mechanics can be analysed based on the user age group, profession, or genre.

In this thesis work study, we successfully developed a Self-Guided Web-Based Therapeutic Intervention for the treatment of hemianopia, which produced results that verified the hypothesis raised in this work. The Gamification mechanics designed and implemented through an MDA redesign of the application were able to adhere users to the therapy, and also improve its engagement. Despite adding multiple Gamification mechanics, the therapeutic component of the application was not compromised, as the results of the mixed method study demonstrate.

Nevertheless, there is room for improvements to the application and the study carried out. Using the feedback obtained from the qualitative study with users, the application of Gamification mechanics can be further polished, by following the recommendations of the extracted guidelines. And in the case of this specific application, implementing user suggestions, the Visual Search activity engagement is improved by the following changes: (1) To diversify the activity, and address user suggestion about the target always starting on the same two locations, the following change is proposed that the target starts in one of the two locations, but, it does not wait for user input to start moving. Rather, it moves slowly at first by itself and then the round starts; (2) Diversify the trajectory of the target, while the core movement must be one that starts on one side and ends up in the opposite one. It is suggested that the trajectory the target takes is diversified in many ways, such as making it do a loop before stopping, or moving in a staggering motion; and (3) Make each activity functionality different in terms of difficulty modifiers. Lastly, regarding the NPC character, a summative qualitative evaluation can be carried out to further gather more user points of view regarding this feature, as well as allowing for the customisation of its presence, so each user can enable or disable its audio features, or the NPC as a whole depending on a user's preferences.

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Annexes

Annexed A User study of the second iteration of the solution

Eye-Search Interview guideline

A.1 Introduction

This document acts as a guideline for the interview that will be done to validate some of the gamification mechanics implemented on the new version of Eye-Search. These validation will be in the form of perceived usefulness of these new mechanics on the application.

The main research topics that we want to address are:

1. Obtain information about the users perception of the current implementation of Eye-Search.
2. Perceived utility of the gamification mechanic's: NPC and the reward system.
3. How motivational the rewards are perceived by the users.

A.2 Guideline

A.2.1 Interview Introduction [5 Minutes]

The following points will be addressed during the introduction:

- The interviewer acts in the name of the Eye-Search team, which he belongs to. He's been commissioned with this investigation and will conduct the interview that day.
- There are no right or wrong answers, all your opinions are useful and we greatly appreciate your feedback.
- As a disclaimer, the visual aspects of this application are work in progress, we mainly will ask your opinion and point of view regarding some of the features present on the application.

A.2.2 Warm Up [5 Minutes]

The participant will be asked about how is a "typical" session on the current version of Eye-Search, this address key topic 1.

A.2.3 Demo Presentation [15 Minutes]

The following is the flow of the user story that will be shown on the demo. Most of these points will be explained in detail during the presentation:

- Greetings window featuring the NPC and the quest of the day (assessment tests).
- Description of the components of the main menu.
- Access the NPC customisation window and equip a hat.
- Two assessment activities will be done to show how the progress bar fills, these can be neglect test and a few instances of the visual field test, the other will already be done.
- When the tests are completed, the congratulations window will pop with a new cosmetic.
- The new cosmetic will be equipped.
- The user profile window will be shown and explained.
- The UFO variety of the visual field test will be shown briefly.

A.2.4 Question Phase [10 Minutes]

After the demo, the following questions will be asked to the participant.

1. What is your perception or attitude toward the NPC companion.
2. What are the advantages/disadvantages you perceive on the reward system?U
3. If the features shown would be implemented on the current Eye-Search application, would you be comfortable using it?

A.2.5 Wrap Up [5 Minutes]

Open discussion with the participant, where all opinions are appreciated.

A.2.6 Quantitative Questions [5 Minutes]

After the open discussion, the participant will be asked the following quantitative questions, where he must answer in a scale from 1 to 10, being 1 Strongly Disagree and 10 Strongly Agree:

1. The featured rewards motivate me to keep using the application.
2. The NPC contributes positively to the experience of using the application.
3. The new version of Eye-Search is user friendly and seems simple to use.
4. The new version of Eye-Search looks fun to use.

A.2.7 Summary and close up

The users will be thanked for their participation in the name of the Eye-Search team and will be asked if there is anything else they want to add.

Annexed B Proof of concept second iteration

Three months after the first proof of concept was carried out, a second iteration was conducted. This version of the study was performed with data gathered from two additional months compared to the three months of the initial study. In this section, details from the quantitative component of the study will be depicted and explained.

B.1 User Adherence

B.1.1 User performance and therapeutic effectiveness

For this study, we utilised the same procedure described in chapter 6 for the analysis of user performance of users average reaction speed per side through the Crowded Desk Assessment Test. For this instance, the number of users that had finished the therapy had grown from 20 to 53. Following the same selection procedure, the following number of users were selected as the sample of the study:

1. Users who had completed up to T2: (53)
2. Users who display a clear left or right hemianopia: (32)
3. Users that do not display a clear visual neglect. (29)
4. Users that feature a difference of 10% or more on search time between their affected and unaffected side: (29)
5. Filter according to interquartile range: (19)

With this, the sample for the qualitative analysis grew from 9 to 19 users. The next step taken was the verification of the ANOVA test assumptions, being verified first if the data featured normally-distributed response variables. After running the ShapiroWilk normality test, the following values were obtained:

Table 1
Results of the Saphiro-Wilk test over the groups of the users reaction speed dataset.

Group	W	p-value
Affected Side	0.933	0.0065
Unaffected Side	0.975	0.3467

As it can be observed on (Table. 1), despite the unaffected side featuring a normal distribution, with a p-value greater than the significance level of 0.05, the affected side group does not display a Gaussian distribution, as its p-value is higher that the significance level. Further confirmation of the non normal distribution of the affected side group is displayed on (Fig. 1) and (Fig. 2).

Due to this, the non-parametric Friedman test was carried out over the users' performance data, obtaining the following results. For the affected side $\chi^2(2, 17) = 2.47$, pvalue = 0.291, and effect size Kendall W = 0.0727. For the unaffected side $\chi^2(2, 17) = 0.471$, pvalue = 0.79, and effect size Kendall W = 0.0138. From these results, it is shown that, as both pvalues are less than the significance level of 0.05, the null hypothesis that states that all the

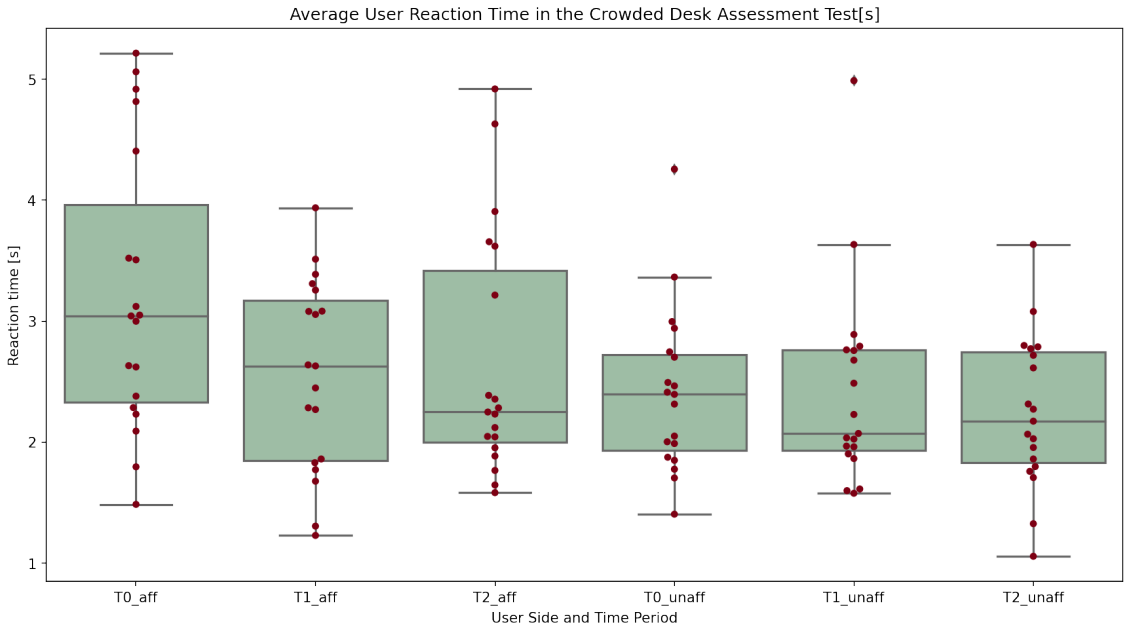

Figure 1

Visualisation of the distribution of users average reaction speed per side on the Crowded desk search test.

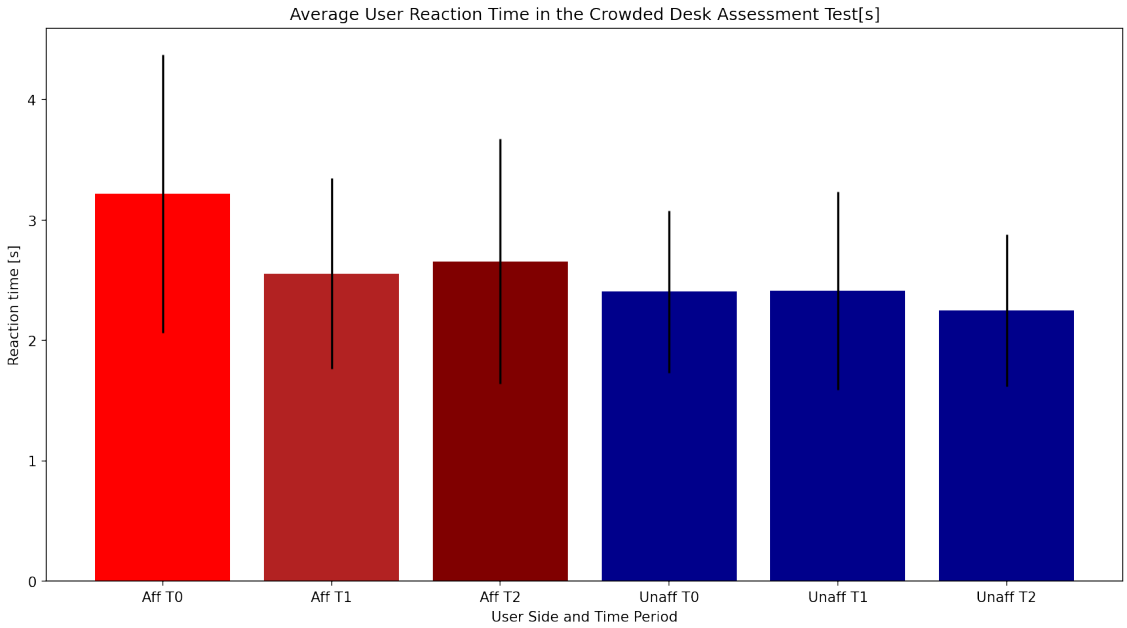

Figure 2

Visualisation of users average reaction speed per side on the Crowded desk search test.

related variables come from the same population cannot be rejected. Lastly, upon analysing the effect sizes for each group, we observe that the effect size of the magnitude is small. In conclusion, despite having two months of more data, it is still not enough for conclusive results.

For the results of the Activities of daily living questionnaire, these are depicted on figure (Fig. 3).

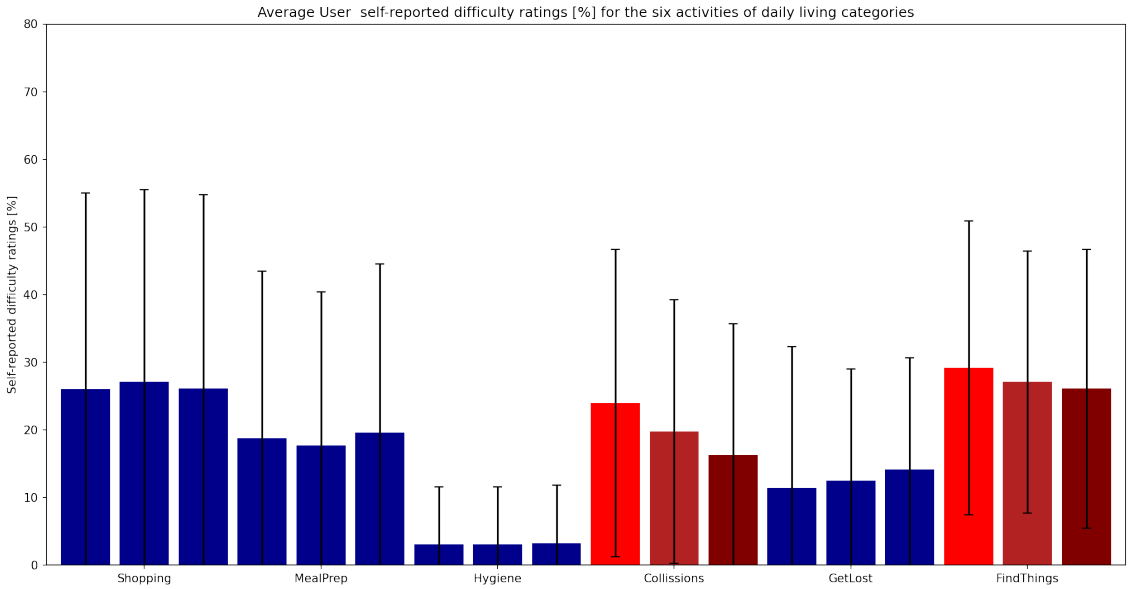

Figure 3
Visualisation of users self reported difficulty on the Activities of daily living questionnaire.

Considering all of this, the results of the two-way ANOVA, with Greenhouse-Geisser measures were the following: For collisions, F(2, 17) = 4.646, pvalue = 0.021, $\eta^2 = 0.147$ and $\varepsilon = 0.73$. For finding things F(2, 17) = 0.325, pvalue = 0.66, $\eta^2 = 0.012$ and $\varepsilon = 0.658$. From these results, a significant time and activity interaction is shown on the collisions activity. As its pvalue is lower than the significance level of 0.05, this is not the case for the *finding things* activity.

Lastly, regarding studies associated to users' performance on the Visual Search therapeutic activity, as observed on (Fig. 4), users' performance improvement is still a factor that is present on the application. When analysing the number of rounds played, shown on (Fig. 5), the same pattern is observed, where users over time tend to play the recommended amount of rounds. And lastly, when analysing users play time in hours, depicted on (Fig. 6), an interesting phenomenon happens between days 13 and 14 of the therapy, which will be further studied.

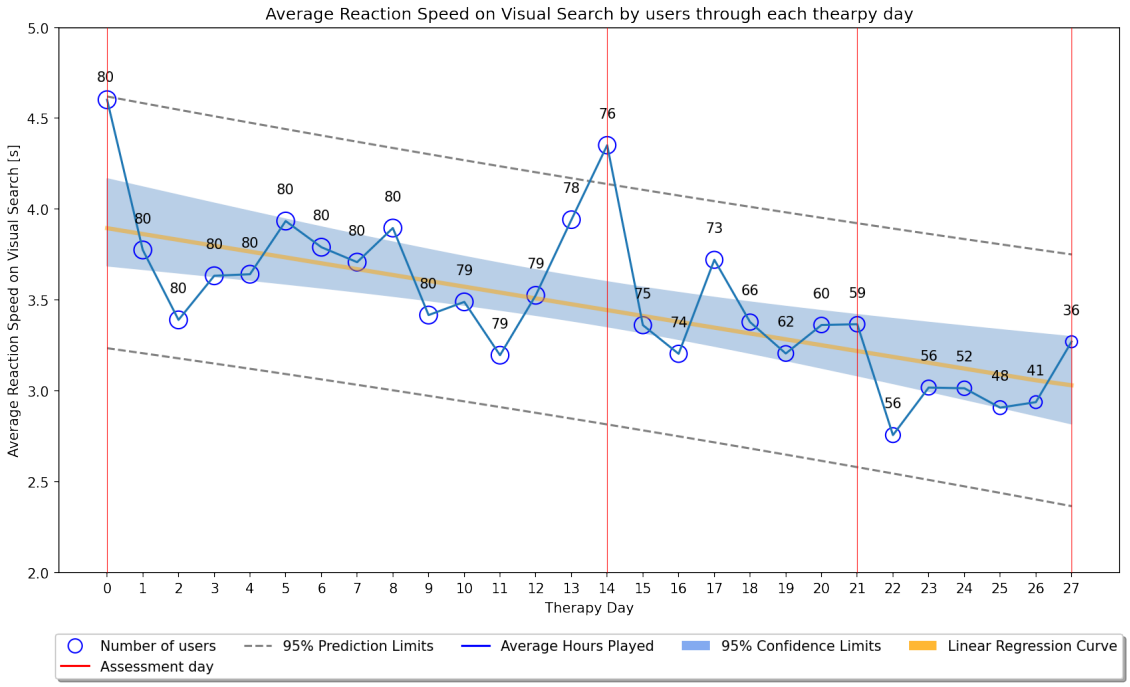

Figure 4
Visualisation of users average reaction speed on the Visual Search therapeutic activity, per day of therapy.

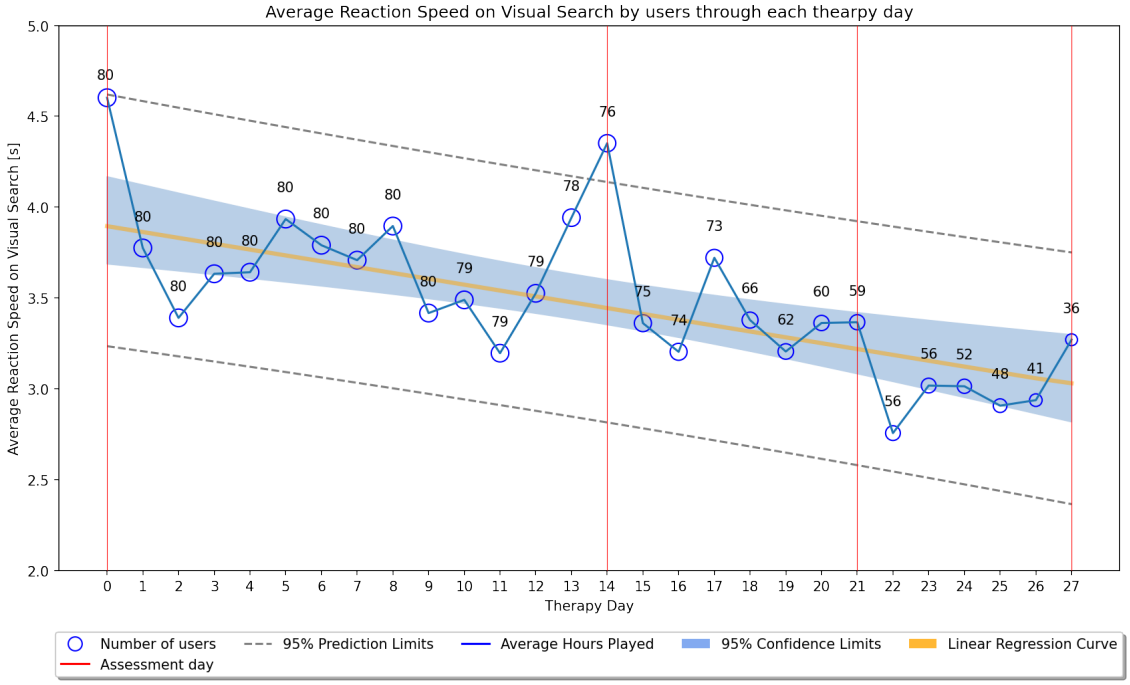

Figure 5
Visualisation of users average number of rounds played on the Visual Search therapeutic activity, per day of therapy.

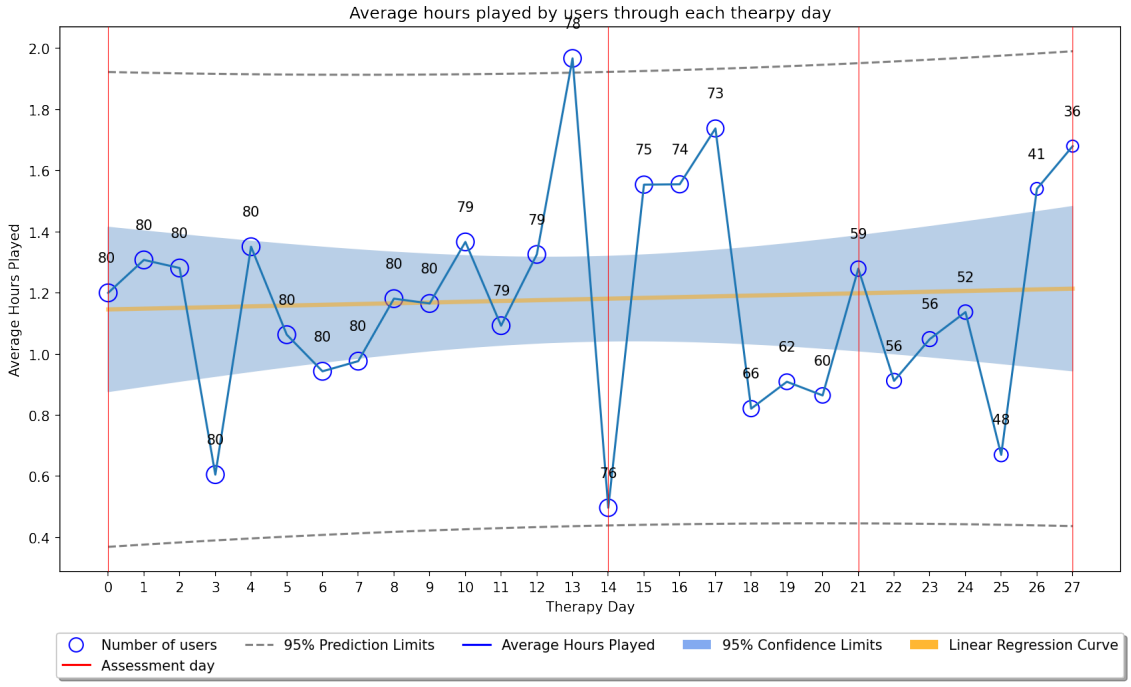

Figure 6
Visualisation of users average number of hours of interaction with the Eye-Search application, per day of therapy.