Eyescape: The Lazy Eye Odyssey
Desenvolvimento e avaliação de um jogo para tratamento de Ambliopia em crianças na primeira infância
Versão final após defesa

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(2º ciclo de estudos)

Orientador: Prof. Doutor Bruno Miguel Correia da Silva

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Declaração de Integridade

Eu, Alexandre Baía Janeiro, que abaixo assino, estudante com o número de inscrição M13045 do Mestrado de Design e Desenvolvimento de Jogos Digitais da Faculdade de Engenharia, declaro ter desenvolvido o presente trabalho e elaborado o presente texto em total consonância com o **Código de Integridade da Universidade da Beira Interior**.

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CHAVE MÓVEL

Dedication

To my dear family,

Without the love, support, and encouragement you have shown me on this journey, none of this would have been possible. I am sincerely grateful to you, my parents, for never losing faith in me and for encouraging me to pursue my goals. Every achievement I have reached is a reflection of the love and dedication I have received from you.

To Professor Bruno Silva, my supervisor,

The success of this dissertation was largely dependent on your guidance and expertise. I am infinitely grateful for your patience, wisdom, and unwavering support, which have guided me every step of the way, from my undergraduate studies to the completion of my master's degree. This research was shaped and accomplished thanks to your invaluable contributions.

To Dr. Miguel Leitão and Dr. Júlio Brissos,

I sincerely thank you for your collaboration, knowledge, and insight throughout this study. Your suggestions and advice truly enriched my research and added a valuable dimension to my work.

This master's dissertation is dedicated to all of you who made the realization of this game possible and encouraged me to keep seeking new ways to improve the quality of life for people with amblyopia.

My heartfelt thanks, Alexandre Janeiro

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Summary

Amblyopia, commonly known as ”lazy eye,” is an eye condition that affects millions of children worldwide. It is characterized by reduced vision in one eye due to insufficient visual stimulation during the early years of life. Early and effective treatment is crucial to prevent long-term complications.

In this challenging context, an innovative and exciting solution has emerged: a game for the treatment of amblyopia, developed using Unity technology and aimed at young children. This game represents not only a novel approach to amblyopia treatment but also incorporates a playful element that captures children's attention while promoting healthy visual development.

The journey that brought us here is the result of dedicated collaboration between ophthalmology experts, game developers, and healthcare institutions in Portugal, such as the Dr. Gama Pinto Ophthalmology Institute.

We firmly believe that the combination of medical expertise, technology, and the magic of games can create a groundbreaking approach to treating amblyopia. By engaging children in an immersive and playful environment and utilizing 3D glasses to optimize visual stimulation, we hope to open new horizons in the field of ocular therapy for children.

This summary is an invitation to embark on this exciting journey. In this work, you will discover the details of the game, the results of clinical trials with real patients, and prospects for continuous improvement. Above all, we are thrilled by the hope that this initiative can have a significant impact on the lives of children with amblyopia and ultimately provide them with a brighter visual future.

We extend our gratitude to everyone who contributed to making this dissertation a reality and hope this is just the beginning of a new era in amblyopia treatment.

Key-Words

Amblyopia, treatment, game, Unity, 3D glasses, visual therapy, childhood, medicine, science

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Acronyms

AVOD Acuidade Visual Olho Direito

AVOE Acuidade Visual Olho Esquerdo

OD Olho Direito

OE Olho Esquerdo

SD Standard Deviation

Chapter 1

Introduction

The advancement of digital technologies has opened up new possibilities for areas as diverse as medicine and game development. This dissertation explores a promising intersection between these two fields, proposing an innovative solution for the treatment of amblyopia, a vision condition that affects millions of children. By combining medical knowledge with technological creativity, this work aims not only to propose an effective treatment but also to demonstrate how digital games can have a positive impact on eye health.

This chapter presents the general framework of the dissertation, the motivation behind this work, the objectives set, and finally the organization of the document, which reflects the steps taken to achieve the expected results.

1.1 Framework

This work represents the research and development that led to the creation of a solid foundation for the innovative approach presented here. The enthusiasm generated by the topic encouraged research to understand the potential of combining medicine and technology, particularly in the screen-based domain. The experience and knowledge gained are crucial for the design and implementation of this work, which aims to make a significant contribution to the application of digital games in the treatment of ocular diseases.

The use of current technological resources is increasingly effective not for short-term progress but for demonstrating positive effects. In the medical field, many treatment areas incorporate digital games, such as physical and psychological therapy. In this context, the application of games emerged as an effective way to treat conditions such as attention deficit disorder and improve patient adherence.

Due to the nature of this work, methods are needed to demonstrate positive results through the integration of medicine and technology, especially in the treatment of vision-related problems. The scope of the work includes a complete description of the developed game, but also its application in the treatment of amblyopia (lazy eye). This dissertation, in collaboration with Dr. Miguel Leito and Dr. Júlio Brissos, is not only a guide on the topic of digital game treatments for amblyopia, but also extends to support all phases of development.

The game was tested in children with amblyopia as part of this dissertation, under the supervision and guidance of healthcare professionals. The Instituto de Oftalmologia Dr. Gama Pinto was the location where exams were conducted on real patients, providing crucial clinical data on the effectiveness of the game in treating amblyopia and the possibility of modifying the gaming experience according to the therapeutic needs of the children.

The chapter is organized into four sections that cover the context of the dissertation, the motivation for its selection, the outlined objectives, the overall plan of the work, and finally, the main organization of the document.

1.2 Motivation

The topic of this dissertation is based on two pillars that have always sparked my interest and my desire to deepen my knowledge: game development and its relationship with the medical field. With this clear vision, we sought the advice of Dr. Miguel Leitão and Dr. Júlio Brissos, who quickly presented a program that precisely combined these aspects.

After a detailed analysis by health professionals, it was agreed that the implementation would be carried out in *Unity* using the *C#* programming language. This choice not only provided a solid technical foundation but also introduced additional challenges to the game development in a new environment, increasing the complexity and demands of the challenge. Using a language and game engine where the experience is limited is more exciting and requires more learning. Without major obstacles, this challenge became an enriching opportunity to expand my skills and access new areas of knowledge.

It is truly astonishing how the creation and application of games can coexist in the medical space. Playing games can be a fun way to treat diseases like amblyopia, a condition that affects children's vision. Games can also be used as therapeutic tools. This imaginative and inventive use of game technology offers patients a real opportunity to improve their quality of life, beyond a technical and creative challenge. Developing a specialized game for treating amblyopia represents an opportunity to create a tool that can be used both at home and in clinical settings, increasing accessibility and engagement in treatment.

Throughout this process, learning and development resulted from the challenge of overcoming technical and design limitations. A proactive attitude in problem-solving and developing creative solutions was encouraged by the constant need to innovate and apply the knowledge acquired. Due to the complexity of this dissertation, technical knowledge alone is not enough. A deep understanding of the end users' requirements and the healthcare professionals' needs is also essential. Thus, completing this master's dissertation offers a rare opportunity to explore the intersection of technology and medicine, broadening the field of study and increasing the potential for impact on society.

1.3 Objectives

The main objective of this dissertation was the research, development, and evaluation of a digital game that helps eliminate interocular suppression and consequently improve the vision of the lazy eye through the use of anaglyph glasses in young children.

To achieve this main objective, the following partial objectives were defined:

1. Contextualization with the proposed objectives and completion of the state of the art;
2. Requirements analysis and architecture;
3. Game modeling and development;
4. Real-world testing and validation;
5. Writing of the Master's thesis;

1.4 Document Organization

The present article is organized as follows to reflect the work carried out:

1. The first chapter – **Introduction** – describes the dissertation, the justification for its selection, its objectives, the structure of the document, and its context.
2. The second chapter – **State of the Art** and **Technologies and Tools Used**: This section describes the key ideas covered in the dissertation and provides an overview of the technologies used in the creation and execution of the game, respectively.
3. The third chapter – **Game Design** – presents the full description of the program through its requirements and diagrams.
4. The fourth chapter – **Implementation and Game Objects** – provides a detailed explanation of the implementation, operation, and testing of the main features of the game.
5. The fifth chapter – **Testing and Results** – This section discusses the results and tests conducted with real patients.

Chapter 2

State of the Art

In recent years, games used in the healthcare sector [1] have proven to be very promising, especially those aimed at treating medical conditions. By involving patients in such therapies, it can facilitate a lighter approach to treatment, which often improves adherence and effectiveness. Health-related games are increasingly being explored and have been applied to mental health, physical rehabilitation such as physiotherapy, where movement-based games help to recover motor functions [2], and more recently, to the treatment of ocular diseases such as amblyopia [3].
They have not only shown positive results in treatment but are also often used for diagnostic purposes [4].
Due to their adaptability, digital games can be used as supplementary tools in a variety of medical treatments, allowing continuous monitoring and personalized changes based on each individual's progress.
This chapter is organized into two sections: **State of the Art**, which covers the theoretical elements necessary for understanding the work carried out, including an explanation of the medical condition and a description of the anaglyph glasses, followed by the second section: **Related Work**, which covers works carried out in the same context that I used as references throughout the development of this dissertation.

2.1 State of the Art

In this section, a thorough analysis of the theoretical foundations [5] necessary for understanding the work at hand is made. As a result, the two subsections that follow address in detail the topics of amblyopia (2.1.1) and anaglyph glasses (2.1.2), providing a complete synopsis of their meanings, applications, and importance for this research.
Moreover, the third section (2.3) presents a detailed analysis of the literature related to this specific eye condition. This section examines previous studies, accepted therapies, and the technologies used, which allows for a more comprehensive and well-founded contextualization of the work carried out.

2.1.1 Amblyopia

Amblyopia [6] [7], also known as "lazy eye," affects about 3% of children and adolescents in the United States and is the leading cause of monocular visual impairment in children.

This disorder, defined by a reduction in vision in one eye, usually occurs in early childhood (up to six years of age). When detected early, it is believed that treating this condition is relatively simple. However, if left untreated, amblyopia can cause irreversible changes in the occipital cortex of the brain, potentially leading to permanent blindness in the affected eye.

The lazy eye results from other conditions that affect vision:

1. **Strabismus** - It consists of the misalignment of the eyes;
2. **Myopia or Hyperopia (nearsightedness or farsightedness)** - The inability of one or both eyes to see objects clearly at near or far distances, typically causing extra effort to see or bringing the object too close;
3. **Congenital Cataracts** - Usually present from birth, congenital cataracts in one eye can cause the child's vision in that eye to appear cloudy, forcing the other eye to work harder;

Traditionally, amblyopia has been treated as a monocular impairment, often requiring the dominant eye to be patched in order to force the amblyopic eye to function. With success rates ranging from 73% to 90%, this therapeutic method has been effective in improving visual acuity [8] in a large proportion of affected youth. It is important to note that, even after extensive treatment, 15% to 50% of individuals may not achieve what is considered normal visual acuity.
The complexity and potential drawbacks of standard therapeutic treatments make it necessary to investigate new methods and technologies that can improve or complement current amblyopia treatment techniques. By identifying more tailored and efficient treatments for this ocular disease in children, our research aims to deepen the understanding in this area. Part of this master's thesis includes a critical evaluation of the current body of literature, along with the proposal of new therapeutic approaches supported by credible scientific data.

2.1.2 Anaglyph glasses

Anaglyph is an image (or a video) that is specially formatted to provide a stereoscopic three-dimensional effect when viewed with glasses [9] of two different colors (each lens with a different color, usually *Blue* or *Red*).
When viewed through the red filter/lens, the red image disappears, and only blue objects are seen, and vice versa for the blue filter, which only "sees" colors that are not blue.

An anaglyph is a visual representation, static or moving, specifically formatted to appear stereoscopic and three-dimensional when viewed through specialized glasses known as

anaglyph glasses. These glasses have lenses of different colors [10], usually *red* and *blue*, and each filters a specific region of the color spectrum.
Only elements of the image with red color components can be seen when the anaglyph is not viewed through the red lens. Similarly, only the elements of the image without blue color components can be seen when the blue filter is used. The human brain can perceive the depth and dimension of the things presented in the anaglyph image or video due to the unique three-dimensional experience created by the separation of hues.

2.2 Digital Games and Therapy

Digital games have proven to be a promising tool in various therapeutic areas due to their ability to engage and motivate users, offering a controlled and interactive environment. They are effective in creating personalized experiences by adjusting difficulty and stimuli according to the patient's individual needs. When it comes to therapies like amblyopia treatment, digital games are particularly advantageous because they can be designed to work directly with the patient's visual difficulties. Games that use specific visual stimuli, such as contrasting colors or adjustments in opacity and brightness, can encourage the brain to improve depth perception and the ability to perceive fine details, which are essential for amblyopia treatment. Moreover, games based on gradual challenges and visual rewards keep the patient motivated and engaged, which is crucial for long-term treatments. The playful aspect also reduces the perception of effort during the treatment, making it more enjoyable, facilitating adherence to daily therapy sessions. For these reasons, games like the one developed for amblyopia treatment, which combine fun and therapeutic benefits, are an ideal choice. They not only stimulate the brain's visual areas but can also be adjusted to suit the patient's pace and needs, ensuring a continuous and effective learning experience.

2.3 Related work

This section highlights the current state of knowledge in the field, identifies gaps, and provides context for the new research. By examining previous work, we can demonstrate how their project contributes to the existing body of knowledge, what distinguishes it from earlier efforts, and how it builds on or diverges from existing methodologies and findings.

2.3.1 Dig Rush

Dig Rush [11] [12], developed by *Ubisoft* in partnership with *Amblyotech*, is a therapeutic game with a simple design aimed at treating amblyopia, also known as ”lazy eye”. The methods created by renowned experts in the field, such as doctors **Jeff Blum**, **Behzad**

Mansouri, **Jeremy Cooperstock**, **Robert Hess**, and **Long To** from *McGill University*, served as the foundation for the creation of this game.
Dig Rush is a tablet application that works best when used in conjunction with anaglyph glasses, and has shown remarkable efficacy, improving vision in 90% of amblyopia cases. The goal of this game is to train the brain to use both eyes in unison, which greatly aids in the rehabilitation process for those suffering from this condition. In Figure 2.1, we can see an example of a level from the game.
Clinical trials conducted after the prescription of Dig Rush for children with amblyopia showed that this treatment was more effective than the conventional method of occluding the unaffected eye for two weeks. The results obtained, despite the fact that the study lasted only two to four weeks and involved a relatively small sample, suggest binocular games like Dig Rush, which aim to overcome ocular suppression through contrast rebalancing, as a potentially effective and complementary treatment option for amblyopia.

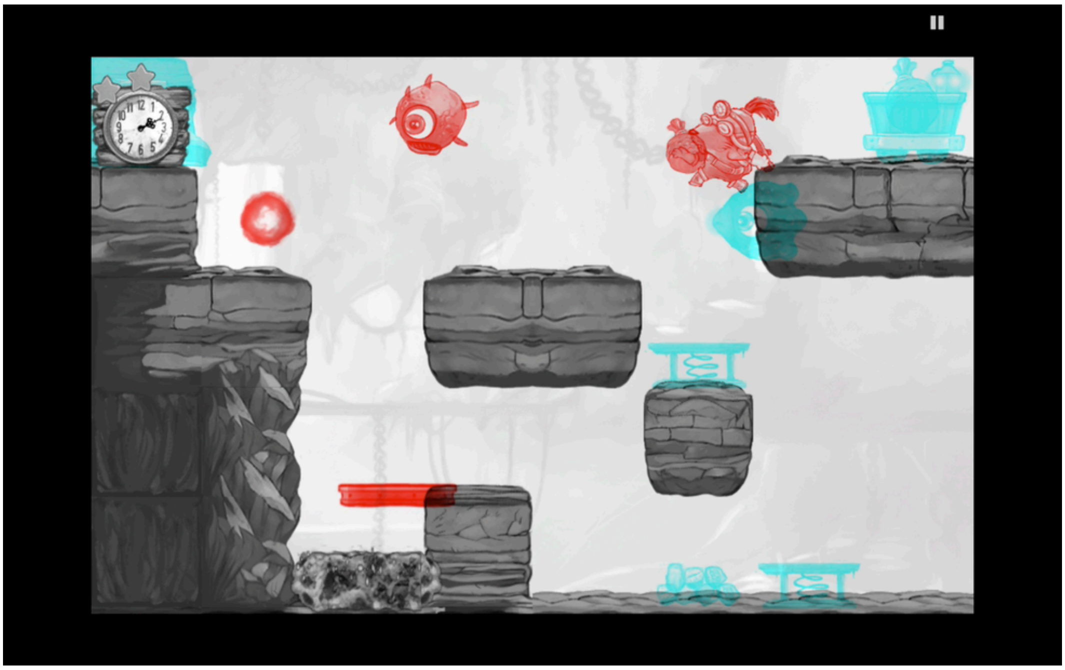

Figure 2.1: *Dig Rush - Game*

2.3.2 Pan's Remarkable Adventure

In the game *Pan's Remarkable Adventure* [13], designed to train the vision of children with amblyopia, also focused on binocular stimuli, the main character, *Pan*, travels through various locations in Ancient Greece in an effort to collect as many coins as possible while avoiding enemies and finding rewards.
The way the game was designed forces the player to use both eyes simultaneously. This is essential to strengthen the amblyopic eye and improve the visual connection between the brain hemispheres. As the player progresses through the levels, the difficulty of the activ-

ities gradually increases and involves identifying objects, colors, or shapes, which helps improve the visual acuity of the damaged eye. In the first training phase, participants follow a pre-established path through the map levels. Each session ends with a test level that evaluates the player's performance in the three training phases. The game can also provide personalized modifications to tailor the therapy to the needs of each patient. To ensure that the treatment is effective and adapted to the unique development of the player, these adjustments can involve changing the size, contrast, or brightness of objects.
In Figure 2.2, a stage of the game is depicted.

Figure 2.2: *Pan's Remarkable Adventure - Game*

2.3.3 Lazy Eyes Blocks

A game called *Lazy Eye Blocks*, Figure 2.3, was created specifically to treat amblyopia, or ”lazy eye”. The game is based on a therapeutic method that promotes the use of both eyes through visual cues. Players of *Lazy Eye Blocks* are given a set of colored blocks that must be placed in predetermined patterns. Players must recognize and correctly fit the blocks using their binocular vision to complete the task.

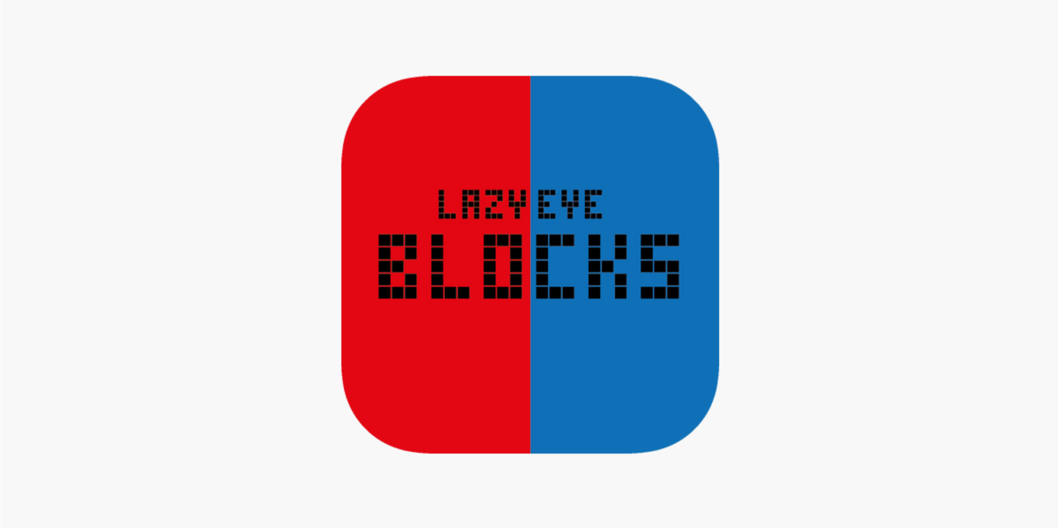

Figure 2.3: *Lazy Eyes Blocks - Game*

2.3.4 Vivid Vision

A virtual reality platform called *Vivid Vision* [14] was created to treat visual problems such as amblyopia, strabismus, and stereopsis deficiency. This system creates a dynamic visual treatment in which the patient interacts with three-dimensional scenarios through the use of a virtual reality environment. The main advantage of this platform is that it allows the adjustment of factors such as contrast, opacity, and sharpness between the eyes.
The basis of *Vivid Vision*'s technology is also binocular stimulation, which involves stimulating both eyes differently, so that the dominant eye sees less contrast or opacity in its vision, and the amblyopic eye sees a clearer image. By making both eyes work together, visual function gradually improves. *Vivid Vision* also allows caregivers to monitor the patient's progress, facilitating treatment adjustments, an important aspect in long-term therapies like the treatment of amblyopia. In Figure 2.4, we can see how vision appears through this platform.

Figure 2.4: *Vivid Vision*

2.3.5 Experimental Games

The young participants in the experiment received instructions and contextual limitations in the early stages to help them develop their motor skills, collect objects, and use the aiming tools. The instructions related to how to aim at one or more enemy robots, collect health items, and explore the entire virtual world. The aiming tool had to be activated by clicking with the mouse when the reticle was positioned to point at the center of the robot. This game mechanic was similar to first-person shooter games, but the aiming instruments were magic wands and juicer machines instead of traditional weapons.

The dichoptic lines were aligned horizontally and vertically before the stereoscope mirrors were adjusted for each training session. Regarding the image arrangement, one eye was shown the upper and left side of the cross, while the other eye was shown the lower and right side.

Figure 2.5, which shows the eyes being adjusted according to the presented cross, provides a clear image of the alignment technique and highlights its significance for the outcome of the experiment. The children who participated were able to engage in the suggested training activities due to the methodical technique that ensured a precise and consistent visual experience. This, in turn, promoted an environment conducive to the development of the necessary skills.

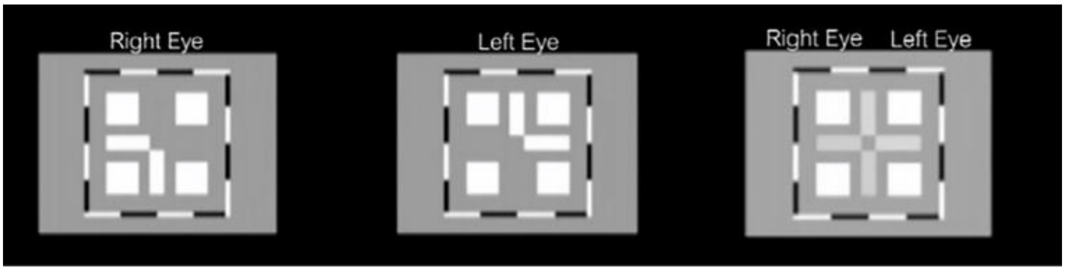

Figure 2.5: *Experimental game*

After the correct alignment, both eyes were able to distinguish the high-contrast image, which displayed a cross with a square cut-out in the center, surrounded by four more squares. The effectiveness of the proposed exercises depended largely on the exact and consistent visual experience that this visual arrangement provided.

The examiner ensured that both halves of the fixation field were visible to the young participants after the game had been launched. To ensure that the children were not obscuring any of the visual elements, the examiner also carefully observed the children's performance on the perceptual learning task.

The visual features and game dynamics of the game are illustrated in detail in Figure 2.6, which presents images of the game [15], developed by *Christina Gambacorta*, *Mor Nahum*, *Indu Vedamurthy*, *Jessica Bayliss*, *Josh Jordan*, *Daphne Bavelier* and *Dennis M. Levi*. These images provide important information for understanding the approach and results of the experiment, by graphically illuminating the context and features of the game.

Figure 2.6: *Experimental game*

2.3.6 Dichoptic films

Dichoptic films are films designed to be watched with 3D glasses, using two distinct images (one for each eye) to create the illusion of depth and a three-dimensional perception. These images are either overlaid or split, with the glasses allowing each eye to see only the corresponding image, resulting in a visual effect of depth and spatiality. Dichoptic films can be displayed in specific formats, such as anaglyphic (with colored lenses). This type of film is commonly used in cinemas and, more recently, in virtual reality devices. According to several authors, the young participants in the study watched a variety of dichoptic films [16] on a passive 3D screen while wearing anaglyph glasses for two weeks. These films were carefully modified dichoptic versions of eighteen animated movies.
During the process, one amblyopic eye received a low-contrast image, and the other a high-contrast image. A uniform image mask, consisting of irregular shapes (bubbles), was placed over the images observed by each eye in order to provide an effective dichoptic effect. Throughout the film, the distribution of the bubbles changed dynamically every ten seconds.
This technique ensured that some parts of the image could only be seen with one eye, while other parts could only be seen with the other eye, and some parts required the fusion of images from both eyes to be fully visible. In Figure 2.7, we can see an example of how

these films appear.
This methodical and controlled experimental technique allowed for an in-depth examination of the therapeutic effects of dichoptic films on amblyopic vision in children, providing valuable insights for the creation of effective treatments for this visual disorder.

Figure 2.7: *Dichoptic films*

2.3.6.1 Eyescape's positive features

In Table 2.1, a comparison of the related works reviewed above can be observed. Games such as *Eyescape*, *Dig Rush*, *Lazy Eyes Blocks*, and *Vivid Vision* stand out. The second, for example, is known for employing visual filters and challenging levels to enhance users' vision. Conversely, the game developed in this dissertation, *Eyescape*, allows for flexibility by dynamically altering opacity over a defined period, set by the patient's supervisor, thus providing personalized monitoring of treatment progress.
The game dynamics are designed to keep the player engaged, which is crucial for ensuring adherence to the treatment plan. Children find it interactive due to its intuitive design and user-friendly interface, making the therapeutic process less burdensome and more enjoyable. The game is easily accessible to a broad audience, as it runs on standard computer platforms without requiring additional equipment beyond a computer.
The feature of continuous treatment is another critical advantage. This is something many traditional approaches and therapeutic games struggle to match in terms of adaptability. By meeting the specific needs of each patient, this ensures that every gaming session significantly improves vision under the supervision of the attending physician.
In summary, *Eyescape* is an effective and engaging alternative compared to other games. Its 2D gameplay style, short session duration, computer accessibility, and use of anaglyph glasses make it an efficient choice. Furthermore, the ability to adjust difficulty levels according to the patient's needs ensures ongoing enjoyment while delivering the most effective treatment.

Table 2.1: Comparison Table of Therapeutic Games

Game	**Primary Objective**	**Treatment Duration**	**Game Format**	**Supported Platform**
Eyescape	Amblyopia	20 min daily for 15 consecutive days (5h total)	2D Platformer	PC
Dig Rush	Amblyopia	30 min/day for 4 weeks	Puzzle	Tablets
Lazy Eyes Blocks	Amblyopia	Unknown	Puzzle	Tablets, Smartphones
Vivid Vision	Various visual conditions	Recommended 30–60 min/day	Virtual Reality (VR)	PC, VR (Oculus, HTC Vive)
	Technology Used	**Interaction Type**	**Adjustable Difficulty**	**Target Audience**
Eyescape	Anaglyph Glasses	Keyboard	Yes, opacity and progressive	Children
Dig Rush	Anaglyph Glasses	Touchscreen	Yes, progressive	Children
Lazy Eyes Blocks	Anaglyph Glasses	Touchscreen	Unknown	Children
Vivid Vision	Virtual Reality (VR)	VR Controllers	Yes (adaptable to patient)	All ages
	Clinical Trials	**Number of Levels or Stages**	**Graphical Environment**	**Medical Collaboration**
Eyescape	Yes	15	2D (bitmap)	Yes
Dig Rush	Yes	Unknown, patient-dependent	2D	Yes (Ubisoft and doctors)
Lazy Eyes Blocks	Yes	Unknown	2D	Yes
Vivid Vision	Yes	Unknown, patient-dependent	3D	Yes

2.4 Conclusions

A research effort was undertaken to deepen the understanding of amblyopia and refine the game to serve as an effective therapeutic aid, considering all relevant factors. It was essential to conduct a thorough investigation into how these devices function with different colors to effectively integrate the glasses into the treatment.

After analyzing the available therapeutic options, the focus of this work was defined. Among the reviewed solutions, the game *Dig Rush* stands out as the closest approach, as it incorporates color and anaglyph glasses into gameplay. However, considering that dichoptic films use specific patterns and that several alternatives for amblyopia treatment exist beyond the traditional patching method, it was possible to study and draw conclusions that guided the development of Eyescape.

In conclusion, careful consideration of these factors was necessary to carry out this dissertation and ensure the feasibility and effectiveness of the proposed treatment.

Chapter 3

Eyescape's Game Design and Mechanics

3.1 Introduction

This chapter, which is divided into several sections, provides a comprehensive introduction to Game Design.
The complete analysis of system requirements, outlining the crucial components necessary to advance this dissertation, is addressed in Section 3.3.
An in-depth understanding of the interactions between the system and its users is provided in Section 3.4, which focuses on the identification and definition of use cases.
The diagram explaining the game's operation is presented in Section 3.5, offering a visual representation of the various components and their relationships.
In conclusion, Sections 3.6.2, 3.7, and 3.8 discuss the identity of the game, its mechanics, and all the technologies used in the development of this dissertation. These sections highlight the structures, tools, and programming languages employed to successfully build the game. Understanding the technological environment in which the game was created and developed requires a thorough comprehension of this technical study.

3.2 Inspirations

The inspiration for creating this specific type of game is presented in this section. The strategy prioritized simplicity and the reduction of game mechanics to create an experience accessible to young players. This approach also eliminated the need for significant coordination and skill, as the game requires only the use of one hand.
With this idea in mind, it was determined that the best format to meet these requirements would be a platform game. Thus, four distinct games were the main sources of inspiration for the creation of this dissertation: *Donkey Kong* [17], which served as an inspiration for being a 2D game; *Super Mario* [18], which inspired the development of a game with similar obstacles; *Dig Rush* [19], due to its shared goal of addressing amblyopia; *Manic Miner* [20], as a historical platform game; and *Adventure Time Game Wizard* [21], for its design and gameplay. Three of these games have roots in a past era marked by the introduction of electronic game consoles and generally easy-to-understand game mechanics. The third game, *Dig Rush*, was created more recently and shares the same goal as this work: correcting amblyopia. The visual representations of the four games are presented in Figure 3.1, providing a visual summary of the factors that influenced the design and develop-

ment of the respective game. These images are a crucial visual aid for understanding the characteristics and key components of the video games that inspired this dissertation.

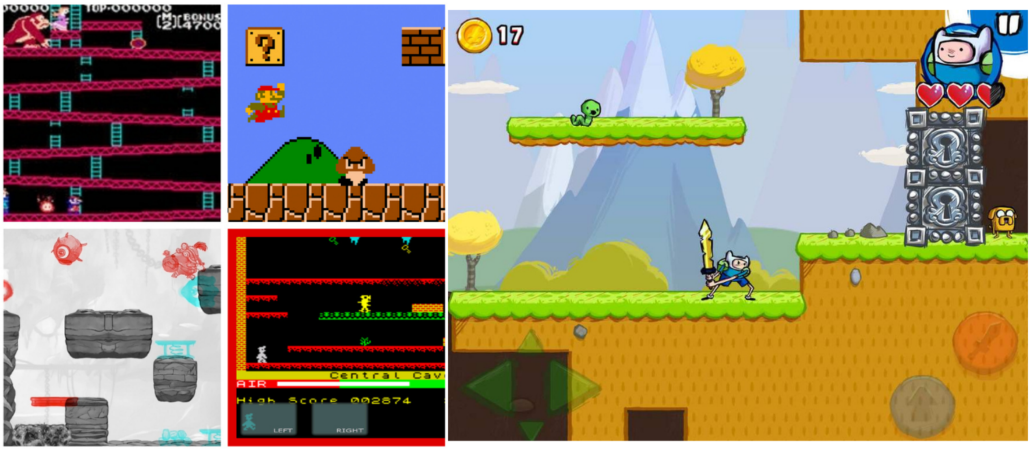

Figure 3.1: *Inspiration Games|| 1-Donkey Kong; 2-DigRush; 3-Super Mario; 4-Manic Miner; 5-Adventure Time Game Wizard*

3.3 Requirements Analysis

The purpose of this section is to perform a comprehensive analysis of the functional and non-functional requirements of the system under study. Its goal, divided into two distinct subsections (3.3.1 and 3.3.2, respectively), is to enumerate and characterize all the requirements necessary for an in-depth understanding of the system, in order to accurately and successfully guide its development.

3.3.1 Functional requirements

The purpose of functional requirements is to determine the expected operation and behavior of the system in response to each user input. These describe what should happen when a user interacts with the system. Tables 3.1 and 3.2 present the functional requirements defined for the game, such as the operation of the mechanics, visual feedback, as well as possible actions in the main menu. These requirements ensure that the game adheres to specific rules that determine its proper functionality.

Table 3.1: Functional Requirements

No.	Description of Functional Requirements
1	The system must start the timer after the user completes the introductory level.
2	If all apples are not collected, the player cannot advance to the next level.
3	The character must touch the goal to advance to the next level.
4	By pressing the keys ”W”, ”D”, ”A” or the arrow keys, the user can move the character.
5	Once the character touches the goal, the system must record the keys used.
6	For each apple collected, the system must add 10 points to the counter.
7	If the character touches the spikes, it dies and the level restarts.
8	If the character touches the flying platforms, they fall after X seconds, depending on the level.
9	If the character jumps over the fans, it glides and only falls when not above them.
10	The enemy character starts moving as soon as a level containing it begins.
11	The enemy character kills the main character if the latter touches it from the sides.
12	If the enemy character kills the main character, the level restarts.
13	The enemy character dies if the main character jumps on it.
14	In all levels, there is a ”Menu” button that redirects the user to the main menu.
15	In the main menu, the user can choose the options **Play**, **How to Play**, and **Exit**.
16	In the main menu, the **Play** button redirects the user to the game’s introductory level.
17	In the main menu, the **How to Play** button redirects the user to an informative page explaining the controls and objectives of the game.
18	In the main menu, the **Exit** button closes the game.
19	The system must provide visual feedback when the main character collides with spikes or the enemy.
20	The system must allow the player to pause the game at any moment, resuming from the current state when desired.
21	The system must ensure a smooth and responsive gaming experience, minimizing delays or technical glitches during gameplay.

Table 3.2: Functional Requirements

No.	Description of Functional Requirements
22	The system must be compatible with different operating systems, ensuring accessibility and usability across a variety of devices.
23	If the character is hit by a meteor, it dies, and the level restarts.
24	After the player clicks on **Play**, they must choose the period in weeks during which they are playing.

3.3.2 Non-functional requirements

The non-functional requirements cover aspects such as performance, security, availability, and ease of use, which are not directly related to the application's functionality. To ensure the overall success of the application, they set standards and general characteristics of the system that complement the functional needs previously described. These specifications are organized and presented in detail in table 3.3.

Table 3.3: Non-Functional Requirements

Nº	Description of Non-Functional Requirements
1	The game should work in any environment
2	The game should maintain the highest level of simplicity possible, aimed at a child audience
3	At the end of each level, the system should save the record of keys used in that level
4	The user cannot choose which level to play. There are eleven consecutive levels
5	The system should not take more than 2 seconds to change levels
6	The user should not have access to the record of keys pressed in the different levels

3.4 Use Cases

For illustrating how a system behaves through the interactions of its actors, use cases are formal narratives that explain processes through structured prose. They also describe the sequence of activities that define a main scenario and alternative scenarios. This method highlights the various ways users interact with the system, offering a comprehensive and in-depth perspective of its features. This description provides a solid foundation for the design, implementation, and testing of the system. It also helps to understand how the system should respond in different scenarios and acts as a crucial guide during the software development process.
Use cases also help stakeholders communicate with each other and develop a shared understanding of the goals and requirements of the game, which is essential for its success.

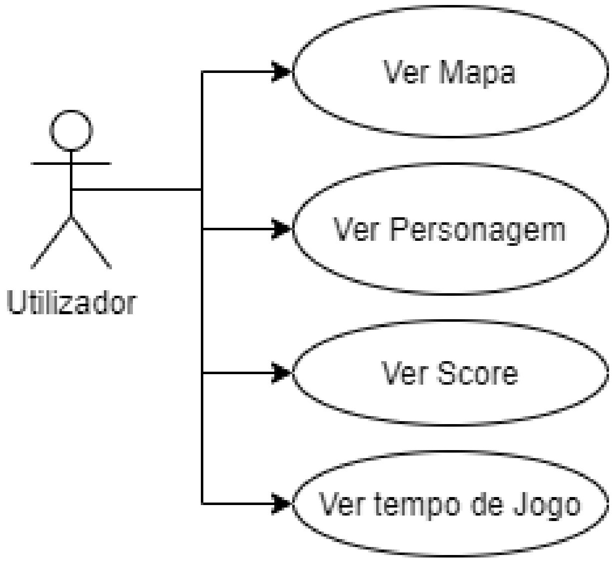

Figure 3.2: *Use Case - Actions*

The use case diagram, which describes the different possible activities within the game environment, is presented in Figure 3.2 and covers all user actions with the system. The functionalities offered to users, as well as the main panels and components included in the game interface, are represented succinctly and simply in this figure. This graphical representation, which highlights the available interaction and navigation options for users during their experience, is crucial for a deep understanding of the system.

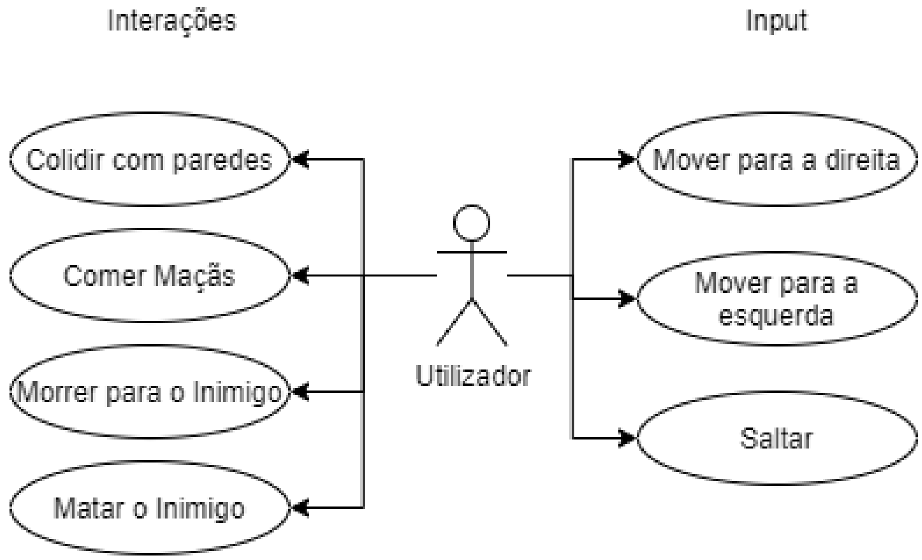

Figure 3.3: *Use Case - Input and Interactions*

The use case diagram for the *User Input* and the player-game interactions is presented in Figure 3.3. It provides a detailed representation of the many inputs the user can provide and how these interactions affect the functionality of the system. This diagram offers a comprehensive view of the various ways the player interacts with the game. It highlights the available actions and how they impact the behavior of the character controlled by the user and, ultimately, the evolution of the overall game experience.

3.5 Activity Diagram

As the activity diagram outlines the exact steps required to perform a specific task within the system - whether through *software* or human interaction - it is essential for decoding and understanding the behavior of the programs. This section presents Figure 3.4, which shows the activity diagram of the application.
The user is first taken to the Main Menu, where three options are displayed, each with a distinct function: 1) Play; 2) How to Play; and 3) Exit.

Choosing **Play**, the user must select the **lazy eye**, either right or left, and is then redirected to the next screen, the **interval in days that the player is playing**, eventually starting the levels, passing automatically from one to the next after meeting the game's rules.
If the user presses **How to Play**, they are directed to an informational page.
If the third option, **Exit**, is chosen, the user closes the application.

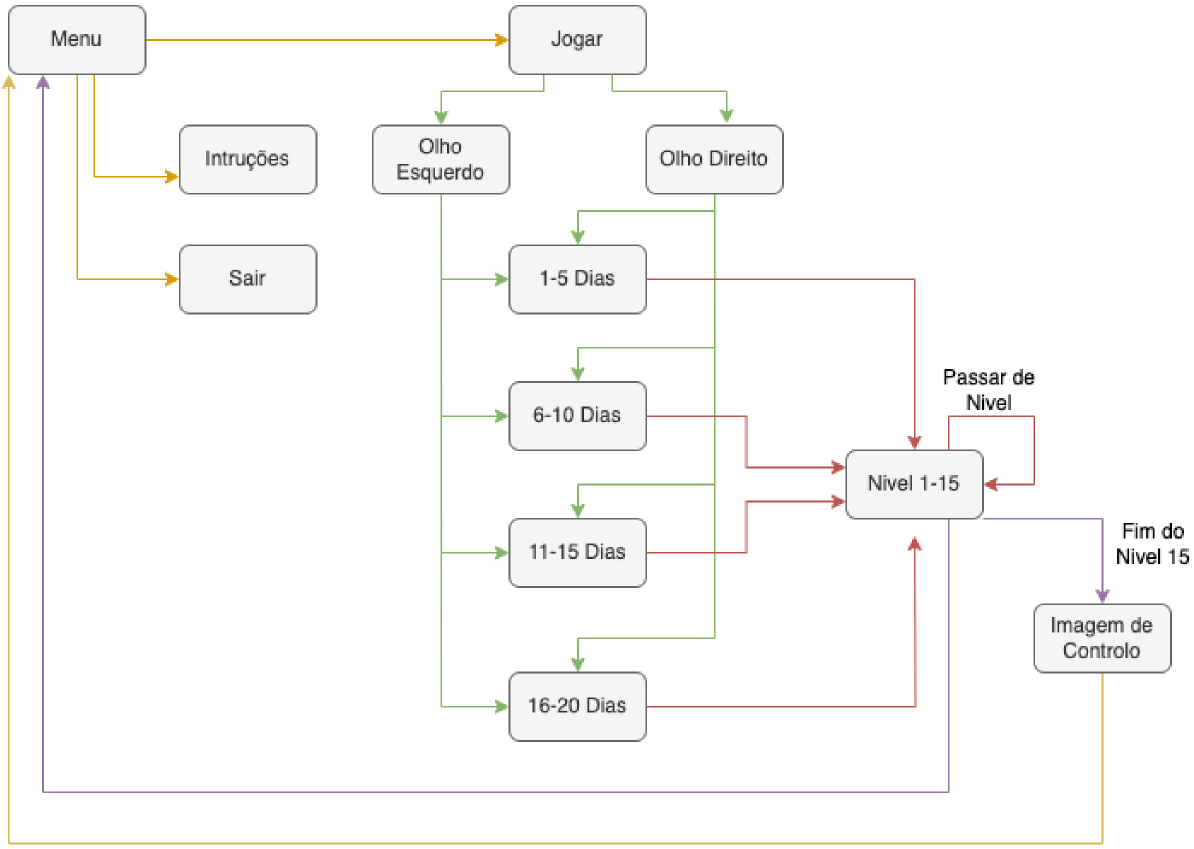

Figure 3.4: *Activity Diagram*

3.6 Game mechanics

3.6.1 Movement Controls

Due to the simplicity of the game, even players with little experience can easily adapt to its features. Below is an overview of the main mobility and interaction elements of the game. With two distinct control types available, the user can customize their experience according to their preferences. They can use the arrow keys as well as the ”A”, ”W”, ”D”, and ”Space” keys. The following mechanics [22] are part of the system design:

- Key A or Left Arrow: Moves the character to the left.
- Key D or Right Arrow: Moves the character to the right.
- Key W or Up Arrow: Performs the jump.
- Space Key: Also performs the jump.

This simple mechanic is not only better for children with limited dexterity, but also allows for quicker reactions from players, which is essential in a game where response speed is critical for level progression.

3.6.2 Jumping Mechanics and Double Jump

A *Double Jump* [23] mechanic allows the player to reach higher platforms and overcome difficult barriers. The player must press the jump key "W" or "Space" twice in quick succession to perform a double jump. The character can jump normally with the first press, and can jump even higher in the air with the second press, giving more control over vertical movement. We can conclude that this component is sometimes key to solving certain challenges in the game, as it is necessary to advance in some levels and reach places that are unreachable with a single jump. In Figure 3.5, we can see the difference in height between the two jumps.

Figure 3.5: *Height - Jump vs Double Jump*

3.6.3 Interaction with the Environment

A key component in the development of the game is interaction with the environment. Beyond movement and normal jumps, the player will need to jump over platforms to progress, with some platforms being movable, while others need to be reached with precision. Avoiding obstacles is another feature where the player faces a series of challenges with varying levels of difficulty. Finally, collecting items to progress in the game is essential, as simply evading or defeating enemies is not enough. The player is required to collect items scattered throughout the level. The combination of these mechanics ensures a dynamic and engaging gameplay experience, maintaining the game's objective in a way that is appealing to children.

3.7 Aesthetics and Visual Identity

The 2D visual style, based on bitmaps [24], evokes the simplicity of classic platform games while providing a timeless and nostalgic vibe. The selection of the visual style was carefully considered in relation to the therapeutic objective, as the use of anaglyph glasses requires a specific color scheme.

The primary colors, red and blue, are used to gradually improve binocular vision and are essential for the amblyopia treatment mechanics. Both the main character and the enemy are assigned distinct tones, which enhances the player's immersion in the visual treatment experience during gameplay. Other elements of the environment, such as platforms, spikes, saw blades, and other obstacles, use a natural and varied color palette to ensure a balanced visual experience without compromising the treatment, avoiding monotony in the design.

The boundaries of the map and certain parts of the terrain follow the same style, using natural real-life tones that provide enough contrast without tiring the players. This approach offers a familiar aesthetic that enhances the game while optimizing therapeutic effectiveness through a progressive visual adaptation. Figures 3.6, 3.7, 3.8, and 3.10 provide examples of the colors used in the game.

Figure 3.6: *Color Palette - Menu*

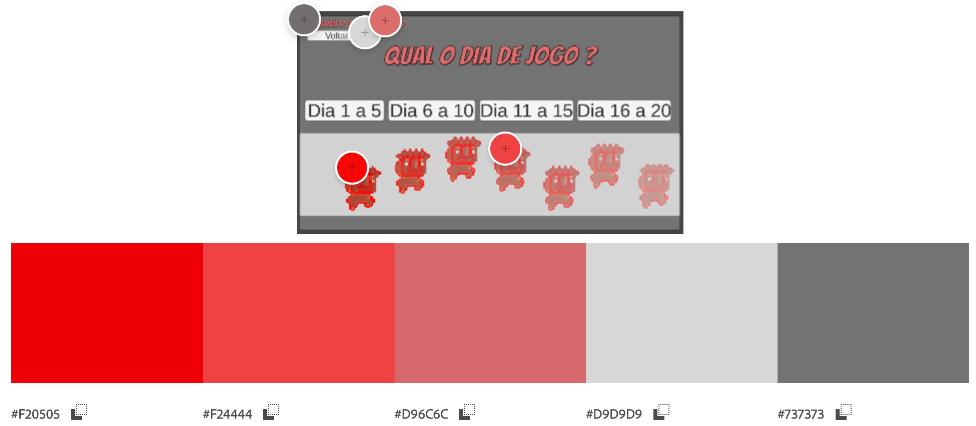

Figure 3.7: *Color Palette - Playing Period*

Figure 3.8: *Color Palette - Introductory Level*

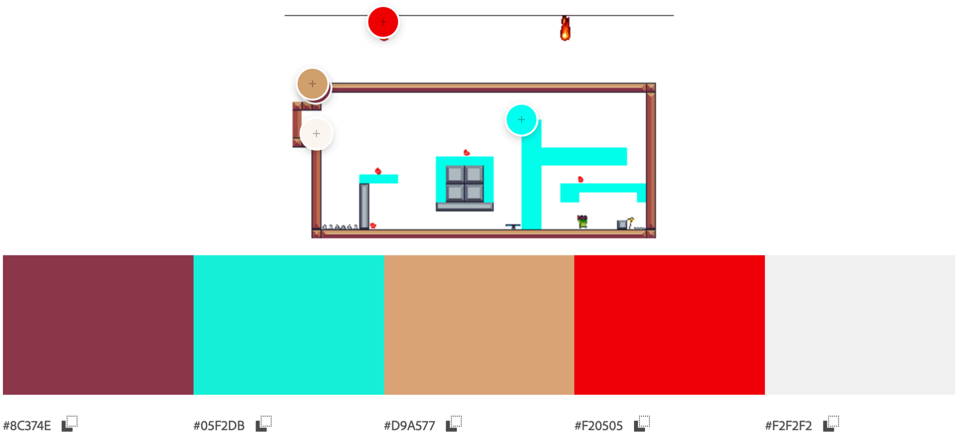

Figure 3.9: *Color Palette - Level 15*

The control image at the end of each level serves as an evaluation tool to assess the player's visual progress in the context of amblyopia treatment. This image features specific elements, such as apples, that challenge binocular vision and help the medical professional understand the game's impact on the treatment. Each control image has an opacity level corresponding to the period the patient has been playing.

Figure 3.10: *Control Image*

3.8 Technologies and Tools Used

3.8.1 Unity

Unity [25] [26] is a well-known and widely used game engine in the digital game development sector. This engine is notable for its adaptability, ease of use, and support for a wide range of platforms, including virtual reality environments, consoles, and mobile devices. Without the need for additional tools, Unity provides an integrated development environment that allows the creation of everything from simple 2D games to complex 3D experiences.

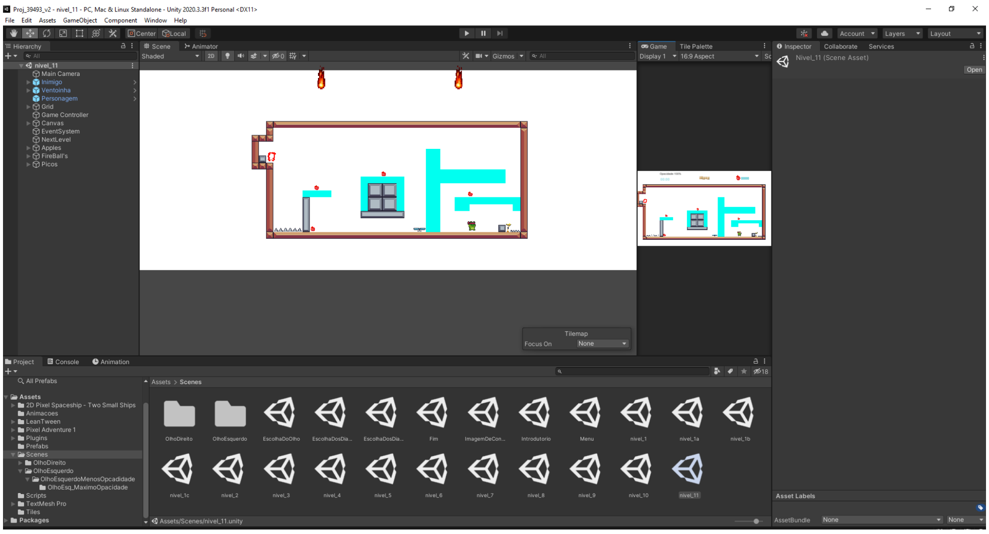

Figure 3.11: *Unity Platform*

Unity, shown in Figure 3.11, was the primary tool used in this work. Its features, such as the resource library, animation systems, and integrated physics, were essential for accelerating development and ensuring the quality of this dissertation. Moreover, the vibrant community and the abundance of resources, including tutorials and available documentation, simplified the problem-solving process and the integration of features.

3.8.2 C Sharp

C Sharp [27][28] or *C#* is an object-oriented programming language created by Microsoft for its .NET platform. This language combines the robustness required to create large-scale applications with a simple syntax. *C#*, which draws inspiration from languages like Java, C++, and Object Pascal, provides programmers with a familiar environment if they are accustomed to working with object-oriented languages. The primary language used in the development of this dissertation to build the Unity game logic was *C#*. Effective development was made possible by the natural integration of *C#* with Unity, which allowed for the development and testing of game functionalities within the Unity environment.

Additionally, the use of scripts that regulate everything, from character movements to the intricate relationships between the many pieces of the game, was key to its success.

3.8.3 Json

Json [29] or *JavaScript Object Notation* is a popular data interchange format used for communication between systems. JSON is a programming language compatible with almost all environments, despite its name suggesting a clear connection to JavaScript. JSON is the recommended format for modern web applications and data exchange in APIs because it is more efficient and easier to read and write than alternative formats such as XML. In this dissertation, JSON was used to store game data, including player movements and customization details. Due to its simplicity, data in *C#* can be easily manipulated using freely available libraries, ensuring that information is stored and retrieved efficiently.

3.8.4 Photoshop

Developed by Adobe Systems, Adobe Photoshop [30] is a graphic editing program created by Adobe Systems. Photoshop is widely used by both professionals and beginners due to its vast set of features, ranging from simple image editing to the creation of complex compositions. Almost all of the game's visual resources, such as textures, interfaces, and graphic components, were created or modified using Photoshop. Photoshop's sophisticated features for managing layers and effects, combined with its versatility in handling various image formats, were essential in ensuring the game's visual quality.

3.9 Conclusions

This chapter began with an in-depth analysis of the requirements, followed by a detailed discussion of the main functions of the dissertation. The use case diagrams were then presented, illustrating how the actors interact with the system. Finally, the activity diagram highlighted the flow of the game, providing a deeper understanding of the system's internal operations. The evaluation of the technologies and tools used, along with a concise explanation of their main features and functionalities, provides a solid foundation for the development and understanding of this work.

Chapter 4

Implementation and Game Objects

This section provides a comprehensive explanation of the implementation carried out throughout this dissertation, along with the associated graphical component. The goal of this dissertation is to develop a 2D platform game in the *Arcade* genre, using a *BitMap* style. The primary objective for the player is to complete each level, overcoming a series of obstacles that have been carefully crafted to test their abilities. These will be discussed in more detail in the following sections. The player's ability to overcome obstacles throughout the levels and the requirement to collect all the objects found in each stage are the fundamental features of the game. The player cannot progress to the next phase of the game without collecting all these objects, represented by apples in this case, even after completing a level. This rule emphasizes the exploratory aspects of the game, requiring the player to return and finish collecting the collectible items. The game was designed to offer fifteen distinct levels, each culminating in a control image that allows supervision to review progress up to that point. In addition to maintaining conventional gameplay, the game was also modified to function with anaglyph glasses. Depending on the lens used, this functionality allows players to experience different visual aspects. This method adds another layer of complexity and immersion, requiring the player to switch between lenses to examine all necessary elements to advance in the game. For the main character, a variable opacity mechanic was also incorporated. The character's opacity value is lower at the beginning of the game, requiring more effort from the player to see them. The character's opacity gradually increases as the player progresses through control images, and supervision decides to enhance its visibility in the later stages of the game. This particular aspect aims to make the first challenge of the game more difficult, while also offering a learning and adaptation curve throughout the game.

4.1 Features for Amblyopia

This section describes the features designed to be used in conjunction with anaglyph glasses as a treatment for amblyopia. The way a player interacts with the game changes depending on the lens (**blue** or **red**) when wearing these glasses. Depending on the dominant color in the environment, each lens either highlights or obscures specific features of the game, providing a distinct experience.

4.1.1 Blue Lens and Red Lens

All elements of the game that are not blue are presented through the blue lens. This means that when the player uses this lens, any blue object, such as the floor, will be hidden from view. However, collectible items and characters, such as the apples, which come in a red hue, remain visible. By requiring the player to switch between lenses to see the entire game environment, this feature aims to promote the use of both eyes. The red lens, like the blue lens, displays all game elements except for the red ones. Consequently, important components such as the red apples and the character will not be visible through this lens. To observe everything and progress in the game, the player must alternate between the lenses. Since it requires the player to use various visual fields to complete the proposed objectives, this mechanic is crucial for the treatment of amblyopia. A screenshot of the game through both the Blue and Red lenses can be found in Figure 4.1.

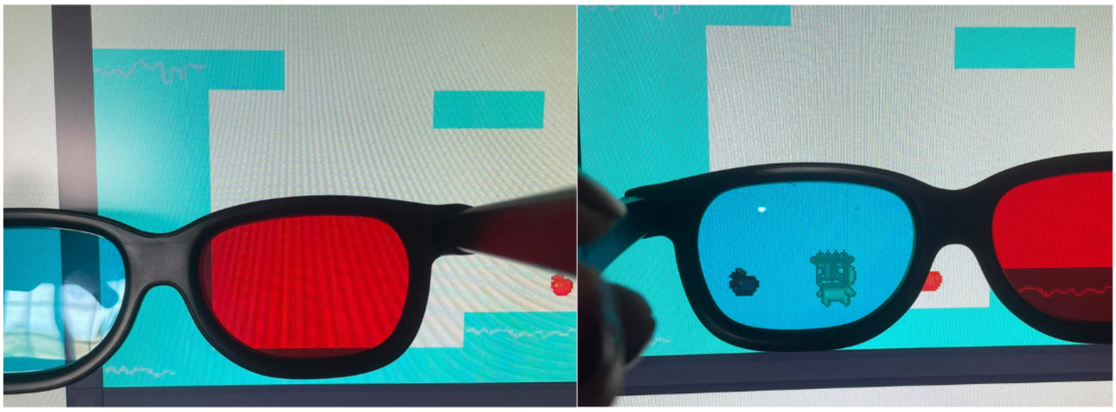

Figure 4.1: *Vision through the Red Lens and Blue Lens*

4.2 Game Characters

4.2.1 Main Character

The implementation of the character's physics in the game is presented in this section. To ensure an authentic and reactive interaction with the environment, the character was meticulously created using the basic principles of physics found in game engines.

First, we must understand that the character has *RigidBodies* [31], which essentially tells the program that this object is solid, has gravity, its own weight, friction, and defines the axis on which it can move. In this case, it is defined along the X and Y axes, not the Z axis, as the game is two-dimensional.

The character also has *Colliders*[32], which are transparent wrappers around it that define its boundaries. These detect collisions with walls and the floor, preventing the character from passing through them.

The character's opacity levels change throughout the game, starting at a lower value and gradually increasing to ensure effective treatment throughout the gameplay period. Figure 4.2 shows the main character and the enemy, respectively. The character's behavior is also defined by *Scripts* [33], in addition to the previously mentioned elements integrated into the *Unity* engine.
The *Double Jump* feature allows the character to jump higher. The character cannot jump unless it is touching the ground.

4.2.2 Enemy

The enemy is a secondary character designed to move in a back-and-forth motion similar to the saw (Sub-section 4.4.3).
However, unlike the saw, the enemy changes direction when it hits a wall, not after a set period of time. It was necessary to use *Colliders*, *RigidBodies*, and a *Script* to define this behavior.
Three colliders are present on the enemy: one on the head, one on the right, and one on the left. The head collider is the only way to defeat the enemy, which can only be eliminated if the main character jumps on top of it. The right and left colliders are designed to eliminate the main character with the slightest touch.
The enemy was added to increase the difficulty, as every time it touches the main character, the player has to restart the level. However, defeating the enemy is not necessary to advance in the game. Figure 4.2 shows the characters.

Figure 4.2: *Main character and Enemy*

4.3 Collectible Objects

4.3.1 Apples

The apples use the same element as the character, *Colliders*, so that the program always knows when the character has touched them. Figure 4.3 shows the image of the apple.

Figure 4.3: *Apple Item*

When these are touched by the character, through a *Script*, it was defined that they should be destroyed to prevent the player from collecting the same apple multiple times.
A value of ten points was also assigned to each apple, so the player can only progress to the next level after collecting all the apples. To prevent players from memorizing the locations in advance if they need to repeat a level, thereby bypassing the true objective of the game, the treatment of amblyopia, the apples were designed to appear randomly at the beginning of each level.

4.4 Obstacles

4.4.1 Flying Platform

The flying platform (Figure 4.4, image 1) is an element on which the character can jump, but it falls after a predefined time interval, adjusted according to the difficulty of the level. It was programmed to be destroyed as soon as it touches the ground.
To implement this functionality, *RigidBody's*, *Collider's*, and *Target Joint's* were used. The latter, not previously mentioned, is used to keep the platform stationary in the air until the character makes contact with it.

4.4.2 Trampoline

The trampoline (Figure 4.4, image 2) is a game element that is manipulated only through a *Collider* and a *script*.
The impulse force is the main factor in determining the trampoline's behavior in the game. An ideal value for this force can be obtained through a series of trials and errors, taking into account the character's weight and the force of gravity.

4.4.3 Saw

The saw (Figure 4.4, image 3) is a deadly weapon that instantly kills the character if it comes into contact with it. The saw is activated by a *Script* and uses a single *Collider*. The main variables in its programming, designed to perform a horizontal oscillatory movement, are speed and travel time in each direction.

4.4.4 Spikes

One of the aspects of the game that kills the character instantly with the slightest touch are the spikes (Figure 4.4, image 4). All that is needed to implement this mechanic are *Collider's*, with no other resources required. To identify when a character collides with the spikes in the game, a special *tag* called ("Spikes") was created and associated with each of these items. Instead of generating a distinct *Script* for each spike, the character was programmed to automatically trigger a *Game Over* when a collision with the *tag* "Spikes" is detected, forcing the player to restart the level.

4.4.5 Fans

The fans (Figure 4.4, image 5) are objects composed of a *Collider* and an additional component called *Area Effector*, whose main function is to generate an upward force that 'pushes' the character upward. Using the *Area Effector*, it is possible to adjust both the angle and intensity of the force applied to the character, allowing precise control over the direction and strength of the thrust. In Figure 4.4, image 6, we can see through particles the direction in which this object will repel the character.

4.4.6 Fireball

A dynamic feature added to the game to create a sense of difficulty and unpredictability is the fireball (Figure 4.4, image 7). It consists of three elements: a *script*, a *Collider*, and a *RigidBody*. The fireball falls from the sky realistically due to the *RigidBody*, which gives it physical attributes such as mass and gravity. The physical boundaries of the fireball are defined by the *Collider*, an invisible element that ensures the fireball can interact with other game elements, such as the character and the ground. The *Collider* detects a collision when the fireball comes into contact with the player. The behavior of the fireball is controlled by the *script* attached to it. While the fireball is not triggered by a programmable timer, it remains suspended in the air out of the player's view. The script allows the *RigidBody* to act after a predetermined amount of time, causing the fireball to fall from the sky. The script is activated if the fireball hits the player, instantly killing them and forcing them to restart the level.

The player faces an additional obstacle due to this mechanism: they must stay alert and act quickly to avoid being hit by the fireball, thus increasing the difficulty level as the game progresses.

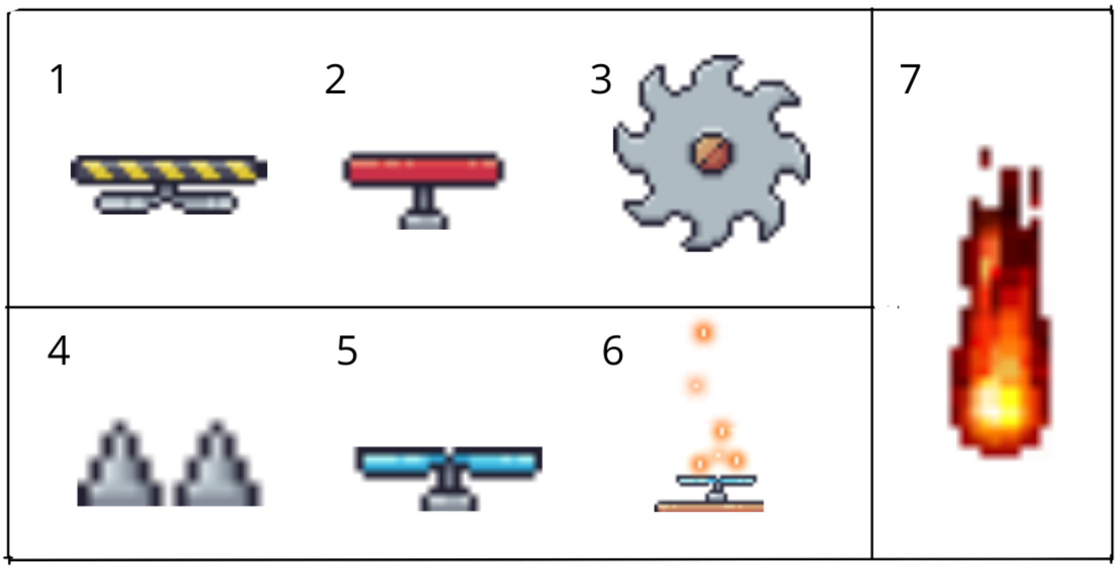

Figure 4.4: *1:Flying Platform; 2:Trampoline; 3:Saw; 4:Spikes; 5:Fan; 6:Wind Particles; 7:Fireball*

4.5 Finish Line

Each level has a small flag that the player must touch to proceed to the next level. However, advancement is only possible when the player collects all the apples scattered throughout the level. The completion mechanism focuses on more than just reaching the flag. These apples serve as an additional objective that tests the player's ability to traverse the environment and overcome obstacles. This adds an extra layer of difficulty and interest to the game, while also promoting careful exploration of the environment and the development of the player's skills. The goal is an object with only a *Collider* and a *script* so that when the character touches it, and if they have collected all the apples in the current level, they can progress to the next *Scene*. The finish line is represented in Figure 4.5.

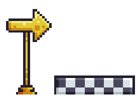

Figure 4.5: Finish Line

4.6 Keys Used

One of the features of the game is to record the keys that the player presses most frequently to determine whether the child has managed to see a particular object. It is possible that the child may use an unusual combination of keys if they are unable to see the object. This information can help the supervisor better understand the situation.
To achieve this, the *JSON* format [29] was used to store the data. A file named **PlayerData.json** contains the information that is recorded each time a key is pressed by the player, allowing for a detailed analysis of their interaction patterns.

```
public void guarda(){
    playerJson = JsonMapper.ToJson(Player);
    Debug.Log(playerJson);
    using (StreamWriter sw = File.AppendText(Application.dataPath + "/
        PlayerData.json")){
    sw.WriteLine(playerJson);
    }
}
```

Listing 4.1: Function to Save Information in the *PlayerData.json* File

4.7 Graphical Component

The illustrations of the game are presented in this section. Figure 4.6 shows the initial menu when the player interacts with the game for the first time. Then, Figure 4.7 displays the eye selection menu, Figure 4.8 represents the play period selection menu, and Figure 4.9 shows the introductory level. Last but not least, Figure 4.10 presents a more difficult level (level fifteen), where it is assumed that the player is already familiar with the game's objectives and mechanics. In this level, several obstacles are added, such as spikes, an enemy, and fireballs that may fall at any moment.

4.7.1 Menu

The initial menu consists of only three buttons.
Figure 4.6 shows it represented.

4.7.2 Choice of Affected Eye

When the player clicks the 'Play' button in the Menu, they are redirected to a new page where two buttons are presented: 'Left Eye' and 'Right Eye'. The player must choose which

Figure 4.6: *Start menu*

eye is not affected, as the levels will vary depending on the selection. Figure 4.7 shows this screen.

Figure 4.7: *Eye choice*

4.7.3 Choice of Game Period

After selecting the unaffected eye, the player will see a new screen with four buttons. Considering that the treatment lasts about four weeks, these buttons allow the player to select the current week. Since the opacities differ and an improper choice may compromise the effectiveness of the therapy, it is crucial to consider the supervisor's perspective when selecting the period. This screen is represented in Figure 4.8.

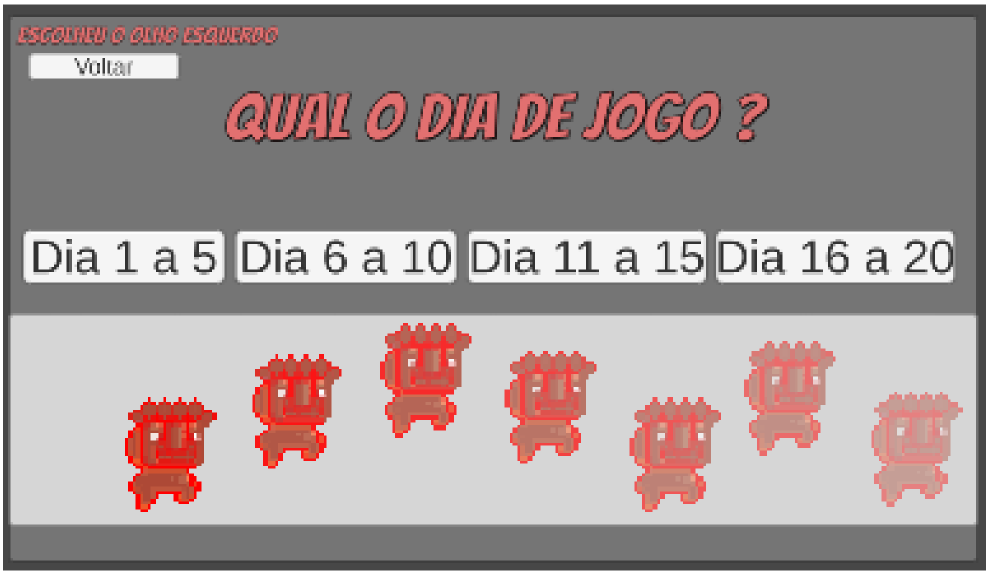

Figure 4.8: *Choice of game period*

4.7.4 Introductory Level

The game's introductory level presents the user with fundamental concepts in an easy-to-understand manner. This level teaches the player to use the directional keys to maneuver the character and jump, including the "double jump," which is achieved by pressing the jump key twice. There are not many difficulties, making the introduction easy and progressive. The objective is to collect two apples, each worth ten points, to achieve twenty points and reach the final flag. The player is prepared for the more challenging tasks in the subsequent levels thanks to the easy and intuitive design of this level, which also creates a smooth learning curve.
The illustration of this introductory level is shown in Figure 4.9.

4.7.5 Level Fifteen

Level fifteen is a more advanced level, featuring several difficulties that require the player to have a bit more patience and agility to overcome all the obstacles. Figure 4.10 shows the representation of level fifteen.

Figure 4.9: *First level - Introductory level*

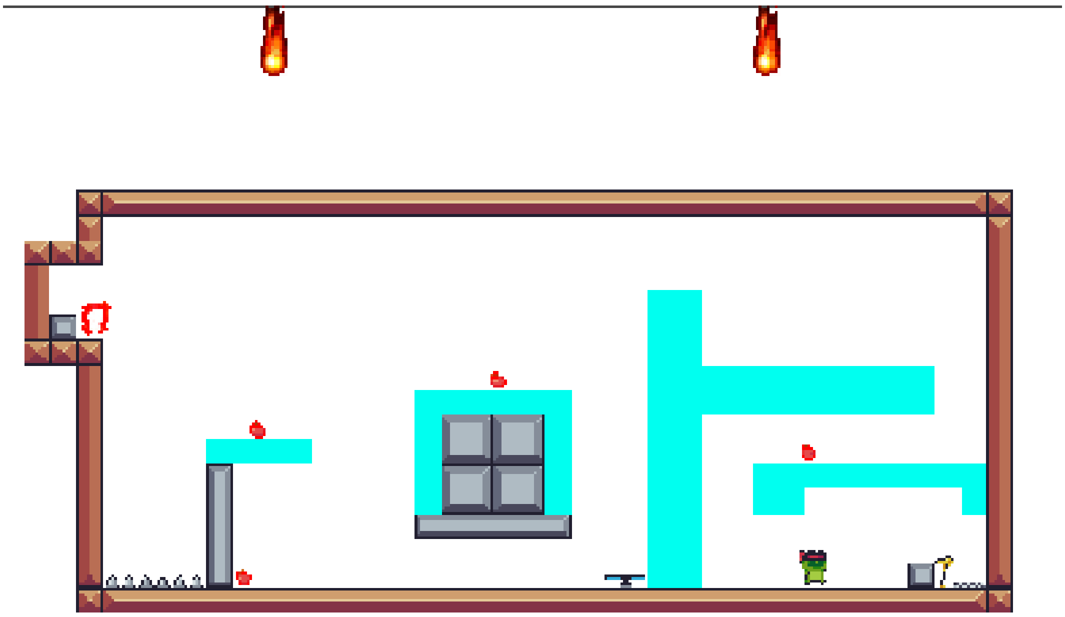

Figure 4.10: *Level fifteen*

4.8 Animations

This section describes the animation process [34], which includes all the components of the game, as well as the movement of the characters. To create the movement effect, short looping videos are used, consisting of a sequence of images [35] with about 24 samples (the speed of transition between each image). An illustration of the character in motion is shown in Figure 4.11.

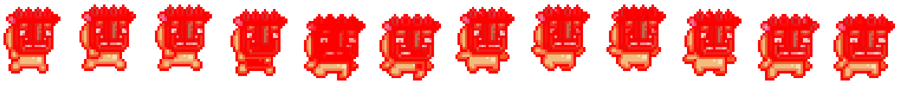

Figure 4.11: *Main Character running*

In Figure 4.12, the movement of the trampoline is depicted when the character jumps on it, resulting in an upward motion.

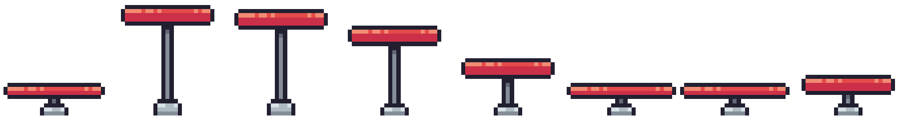

Figure 4.12: *Impulse movement of the trampoline*

In Figure 4.13, the animation of the goal is shown, where the only movement present is that of the arrow pointing towards the checkered goal, giving the impression that it is moving with the wind.

Figure 4.13: *Finish line movement*

4.8.1 Game Executable

The game is currently available for testing on the *Itch.io* platform, a website dedicated to the release of games. *Itch.io* allows users to host, sell, and download electronic games. The game presented in this dissertation is accessible through the ***link:***
`https://xano-j.itch.io/amblyopia-treatment-game-v5`

4.9 Conclusions

This chapter began with a comprehensive explanation of each component used in the game, along with a list of related resources and an explanation of how they are utilized. We then described how the game logs the player's keystrokes in a *JSON* file and the reasoning behind implementing this functionality. In the graphical component section, we provided a brief synopsis of the game using figures, supported by brief explanations that help contextualize each visual feature, including the main menus, the introductory level, and the final level. Next, we analyzed the animations in more detail, including how they were created and put into action. Finally, there is a *link* that allows testing and interacting with the features and functionalities explained, playing the game in real-time.

Chapter 5

Tests and Results

The development and analysis of tests using a game specifically created to treat childhood amblyopia will be discussed in this chapter. Amblyopia, also known as ”lazy eye,” is a disorder that affects vision. Early detection and treatment are essential to prevent irreversible damage. Through the use of creative methods and playful approaches, this dissertation aims to spark children's curiosity and encourage visual rehabilitation in a fun and engaging way.
Verifying the effectiveness of the game requires conducting experiments with real cases, which is essential. These tests provide factual information about the game's usability, the system's effectiveness, and the children's reactions to the therapy. They also help identify areas that need further development, ensuring that the game is tailored to meet the individual needs of the players.
The analysis of test results is particularly important, as it allows for both quantitative and qualitative evaluation of the game's effects on amblyopia treatment. Data collection and analysis enable the assessment of treatment effectiveness, the tracking of children's visual development, and the evaluation of the game's reception as a therapeutic aid.
Thus, this chapter will cover the methodology, participant selection criteria, testing environment, and results.

5.1 Limitation of the Number of Tests

After the first phase of recruitment, intervention, and the dissemination of initial results in December 2023, a second round of recruitment was launched with expanded inclusion criteria for individuals aged between 5 and 18 years. However, the pediatric care activity directed at users aged 0-18 at this institution (Instituto Dr. Gama Pinto) was closed due to the restructuring of the National Health Service, which began in January 2024, and the subsequent inclusion of the Instituto de Oftalmologia Dr. Gama Pinto into the Unidade Local de Saúde de São José. Due to the redistribution of resources and the redefinition of care priorities resulting from the new organization of health units, this restructuring had a substantial impact on the study's ability to continue.
Since the service no longer provided pediatric care, it was not possible to accept new candidates within the established age range. The inability to expand the study to a more diverse and representative sample, due to the scarcity of new admissions, reduced the overall robustness of the study.

5.2 Methodology

5.2.1 Inclusion Criteria

The inclusion criteria are a set of factors that determine which subjects can be included in this study. These criteria are also pre-defined to ensure consistency and quality in the results, aligning them with the objectives of this work.

Thus, only two criteria were required:

1. Unilateral amblyopia (interocular difference of 0.2);

2. Age 5-10 years.

5.2.2 Exclusion Criteria

Exclusion criteria are parameters that, as the name suggests, exclude certain subjects who do not possess the necessary characteristics for the development of this study or who, for some reason, do not meet the inclusion criteria. Thus, the exclusion criteria are as follows:

1. Near tropia >4DP;

   The expression ”near tropia >4DP” refers to a condition where the misalignment of the eyes is more pronounced when focusing on near objects, and the deviation is greater than 4 prism diopters (DP). Prism diopters are units of measure that quantify the degree of ocular deviation. A value greater than 4DP indicates a significant misalignment that can interfere with normal binocular vision, causing issues such as double vision (diplopia) or difficulty in depth perception.

2. Developmental delay;

3. Structural lesions of the visual cortex;

4. Photosensitive epilepsy.

   Photosensitive epilepsy is a neurological condition in which exposure to specific visual stimuli, such as flashing lights or repetitive visual patterns, triggers epileptic seizures. This type of epilepsy is a form of reflex epilepsy, where the seizures are provoked by external sensory stimuli.

5.3 Pre- and Post-Intervention Evaluation

5.3.1 Study of Visual Acuity

The ability of the visual system to detect details and differentiate distinct objects or shapes within the field of view is known as visual acuity, studied using the test shown in figure 5.1. It is a key factor in determining the degree of clarity and precision with which the eye can see. This examination is essential for the diagnosis and monitoring of ocular disorders such as myopia, amblyopia, and others, which can affect the quality of vision.

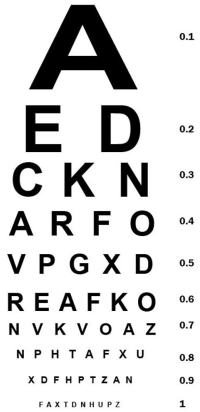

Figure 5.1: *Visual acuity test*

The following tables, (5.1) and (5.2), present the results of this evaluation accompanied by two graphs for easier reading (Visual Acuity Graph and Stereopsis Graph), referencing the right eye (Acuidade Visual Olho Direito (AVOD)) and left eye (Acuidade Visual Olho Esquerdo (AVOE)), both before the intervention (indicated by number 1) and after the intervention (indicated by number 2), as well as the study of stereopsis, pre (Stereopsis 1) and post (Stereopsis 2) treatment.

Table 5.1: Assessment of Patients' Visual Acuity Before and After Treatment

Patient	**AVOD1**	**AVOD2**	**AVOE1**	**AVOE2**
Patient 1	1.0	1.0	0.5	0.6
Patient 2	0.7	0.8	0.9	0.9
Patient 3	0.8	0.9	0.6	0.7
Patient 4	0.8	0.8	1.0	1.0
Patient 5	0.6	0.7	0.8	0.9
Patient 6	0.1	0.1	0.9	0.9
Patient 7	0.9	0.9	0.7	0.7
Patient 8	0.7	0.8	1.0	1.0

1. **AVOD1**: Visual Acuity Right Eye 1
2. **AVOD2**: Visual Acuity Right Eye 2
3. **AVOE1**: Visual Acuity Left Eye 1
4. **AVOE2**: Visual Acuity Left Eye 2

Analyzing table 5.1 and the graph in figure 5.2 below, several conclusions can be drawn. Regarding the **right eye**, most patients showed an increase in visual acuity values after treatment. Although this increase was small, it indicates an improvement. Other patients, such as **1** and **7**, maintained the same visual acuity, which suggests that the game had a maintenance effect rather than deterioration. Lastly, patient **6** shows a very low visual acuity value, around 0.1, both before and after the treatment, which suggests that the game may not have been effective in more complex cases. Regarding the **left eye**, patients **1**, **3**, and **5** show very positive results, indicating that the treatment was effective for them. Patients **4**, **6**, and **8**, who already had high visual acuity before the treatment, were able to maintain that level, suggesting that the game was effective in maintaining visual acuity. On the other hand, patient **7** did not show any changes in the left eye after the treatment, and their visual acuity remained low, around 0.7, with no significant alterations. Comparing the two eyes, right and left, the test shows different responses. If we look at patient **1**, who had a very high visual acuity in the right eye (1.0) but much lower in the left eye (0.5), there was an asymmetry between the two eyes. After treatment, this asymmetry decreased (1.0 and 0.6, respectively), indicating an improvement in visual balance.

Observing other curious facts, we can affirm that the game resulted in small but significant

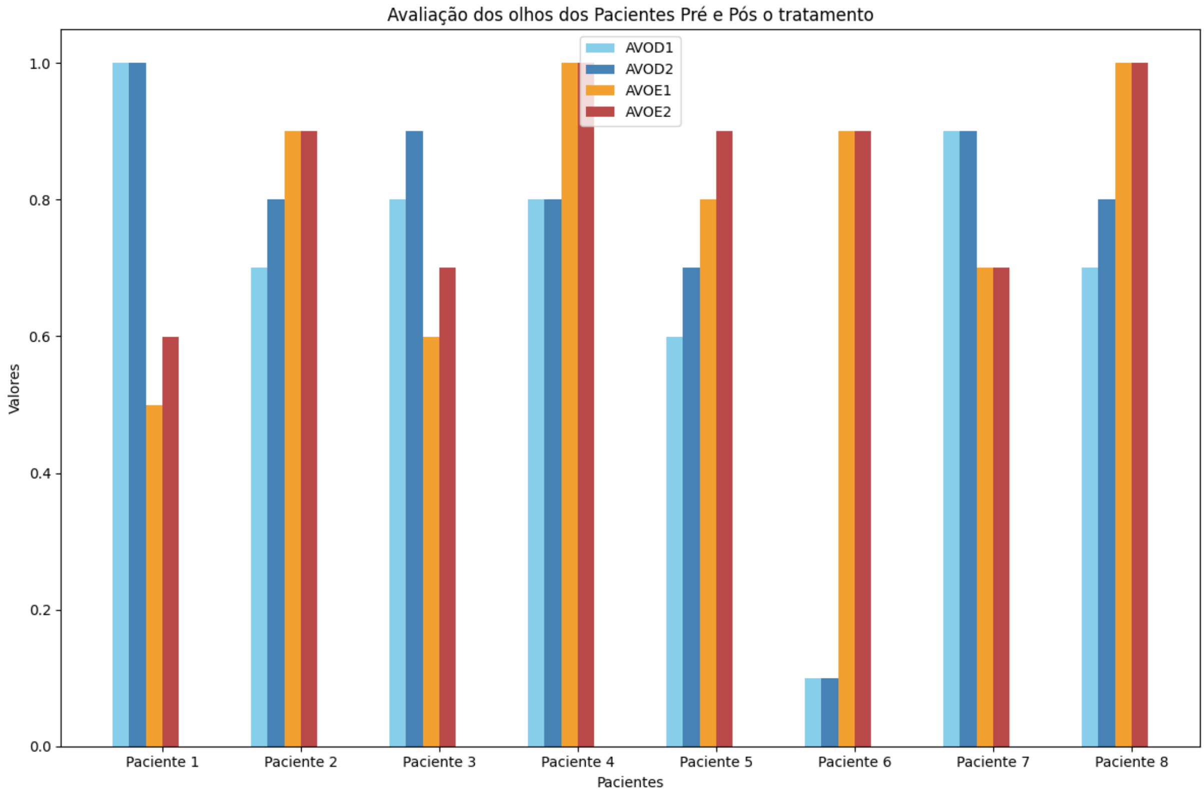

Figure 5.2: *Visual acuity of both eyes - Pre and Post Treatment*

improvements. In patients with initial values of 1.0, maintaining visual acuity indicates that the treatment is not harmful. Finally, in patients with very low visual acuity, no significant improvements were observed, suggesting that the game may have limitations in very severe cases.

5.3.2 Study of Stereopsis

Stereopsis, also known as stereoscopic vision[36], is the ability to perceive depth and distances between objects in the visual field, resulting from the integration of two slightly different images captured by the eyes. This ability allows the brain to create a three-dimensional perception of the environment. To quantify stereopsis, the ”Titmus Stereopsis - Circles” test [37] was conducted. In the Titmus Circle Test, Figure 5.3, a sequence of grouped circles is presented to the patient, with two circles drawn in each group, slightly offset from the two-dimensional plane of the page. The patient, wearing polarized glasses, must determine which circle ”pops” out of the page, indicating that they can perceive in three dimensions.

The test produces a numerical value for binocular disparity, measured in arc seconds. This

Figure 5.3: *Titmus circle test*

value indicates the minimum angle difference that both eyes can discern to combine two different images into a single depth perception. A person's stereoscopic ability increases with the reduction in arc seconds. This ability is often affected in cases of amblyopia, and the Titmus test is crucial for assessing the level of stereopsis.

The graph in figure 5.4 refers to Stereopsis, the ability to perceive depth, before (Stereopsis1) and after (Stereopsis2) treatment. Stereopsis is measured in arc seconds, meaning that a smaller number of arc seconds indicates better depth perception, and lower values represent better stereoscopic ability.

Table 5.2: Evaluation of Patients' Stereopsis Before and After Treatment

Patient	**Stereopsis 1**	**Stereopsis 2**
Patient 1	40	40
Patient 2	80	40
Patient 3	200	200
Patient 4	40	40
Patient 5	100	100
Patient 6	200	200
Patient 7	200	200
Patient 8	140	100

1. **Stereopsis 1**: The ability of the brain to combine the images received by both eyes into a single three-dimensional image **Pre-treatment**

2. **Stereopsis 2**: The ability of the brain to combine the images received by both eyes into a single three-dimensional image **Post-treatment**

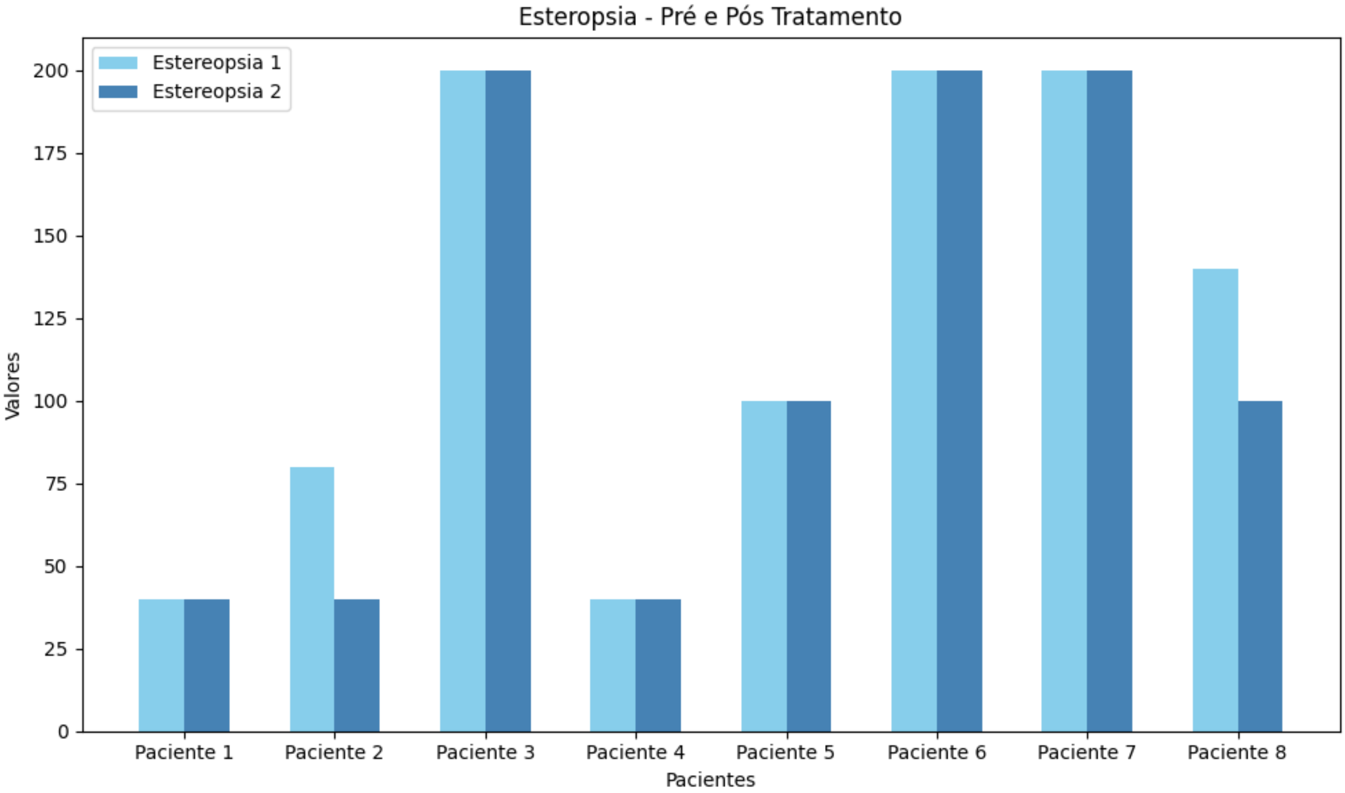

Figure 5.4: *Stereopsis - Pre and Post Treatment*

Analyzing table 5.2 and the graph in figure 5.4, it can be concluded that the stereopsis of patients generally improved after treatment, as the values decreased in several cases, indicating that the game had a positive impact on improving perception skills. Patient **2**, who improved from 80 arc seconds to 40 arc seconds, shows a significant improvement, as does patient **8**, who started with 140 arc seconds and after treatment achieved 100 arc seconds. Although the improvement was not as great, it still indicates significant progress. Patients **1**, **3**, **4**, **5**, **6**, and **7** showed similar results before and after treatment, which suggests stability. For patients **1** and **4**, who started with values of 40 arc seconds and ended with the same values, this indicates maintenance, which is positive as it means the treatment preserved their stereopsis ability rather than causing deterioration. Patients with initially very high values showed no changes, indicating that this treatment may be limited in extreme cases. Once again, the study of stereopsis, similar to the study of visual acuity, indicates that the treatment is effective, resulting in small but relevant improvements. However, for patients with very high initial values, this may not be an appropriate treatment.

5.3.3 Contrast Sensitivity Study

One of the most important factors in evaluating a patient's visual function is contrast sensitivity, particularly in cases where diseases like amblyopia have a less evident impact on visual acuity. In the present study, an evaluation of the patients' contrast sensitivity was performed in both eyes, before and after the therapeutic intervention. The results of this test are presented in table **??** for the right eye (Olho Direito (OD)) and the left eye (Olho Esquerdo (OE)), before (indicated by number 1) and after (indicated by number 2) the intervention. To assess contrast sensitivity, the Pelli-Robson test (Figure 5.5) was used, a tool commonly employed in both clinical and research settings. This test evaluates the ability of a person to detect small variations in contrast, a visual function that extends beyond acuity. The ability to perceive objects in low-light or low-contrast environments is facilitated by contrast sensitivity. The Pelli-Robson test [38] consists of three lines of letters of uniform size, each line having progressively weaker contrasts. The patient is asked to recognize the letters until the contrast reduction prevents them from doing so. A quantitative assessment of the patient's contrast sensitivity is provided by the final score, which indicates the lowest level of contrast the patient can recognize. For consistent results in the Pelli-Robson test, the card should be placed one meter away from the patient and the room should have consistent lighting. The test is administered monocularly, meaning one eye is evaluated at a time. Two separate cards are used, one for each eye, so the patient cannot memorize the letters.

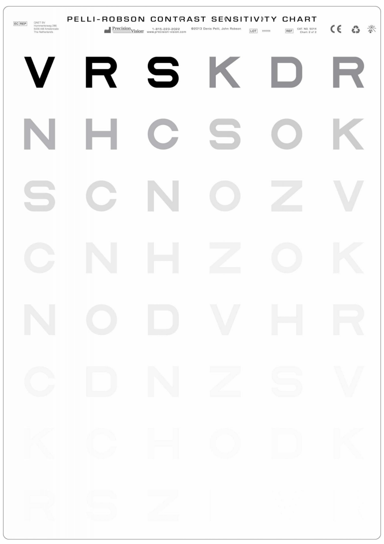

Figure 5.5: *Pelli-Robson Test*

Table 5.3: Contrast Before and After Treatment

Patient	Contrast OD1	Contrast OD2	Contrast OE1	Contrast OE2
Patient 1	1.55	1.55	1.70	1.70
Patient 2	1.40	1.55	1.40	1.55
Patient 3	1.55	1.55	1.25	1.55
Patient 4	1.55	1.70	1.70	1.70
Patient 5	1.40	1.55	1.55	1.70
Patient 6	1.40	1.55	1.40	1.70
Patient 7	1.55	1.55	1.40	1.55
Patient 8	1.40	1.55	1.70	1.70

1. **Contrast OD1**: Right Eye Contrast 1
2. **Contrast OD2**: Right Eye Contrast 2
3. **Contrast OE1**: Left Eye Contrast 1
4. **Contrast OE2**: Left Eye Contrast 2

Analyzing table 5.3 and the graph in figure 5.6 below, and knowing that higher contrast values suggest a better ability to distinguish between different shades of light and darkness, we can conclude that most patients showed improvements or maintenance in both the right and left eyes. In relation to the **right eye**, the patient with the best improvement was **4**, increasing from 1.55 to 1.70 after treatment. This reflects that the game had positive implications on their visual perception. Patients **2**, **5**, **6**, and **8** also showed improvements, moving from 1.40 before treatment to 1.55 after. In contrast, patients **1**, **3**, and **7** maintained stable contrast in the right eye, suggesting, similar to other studies, maintenance rather than deterioration. In relation to the **left eye**, patients also showed improvements in contrast levels, with a focus on patient **3**, who showed a significant improvement, moving from 1.25 to 1.55 after treatment. Patients **5** and **6**, who already started with good values, were also able to show good results, encouraging the use of the game as a treatment, as it can further optimize visual function in patients with already good initial values. Patients **1**, **4**, and **8** maintained consistent values. Comparing both eyes, before treatment, some patients showed quite large differences in contrast between

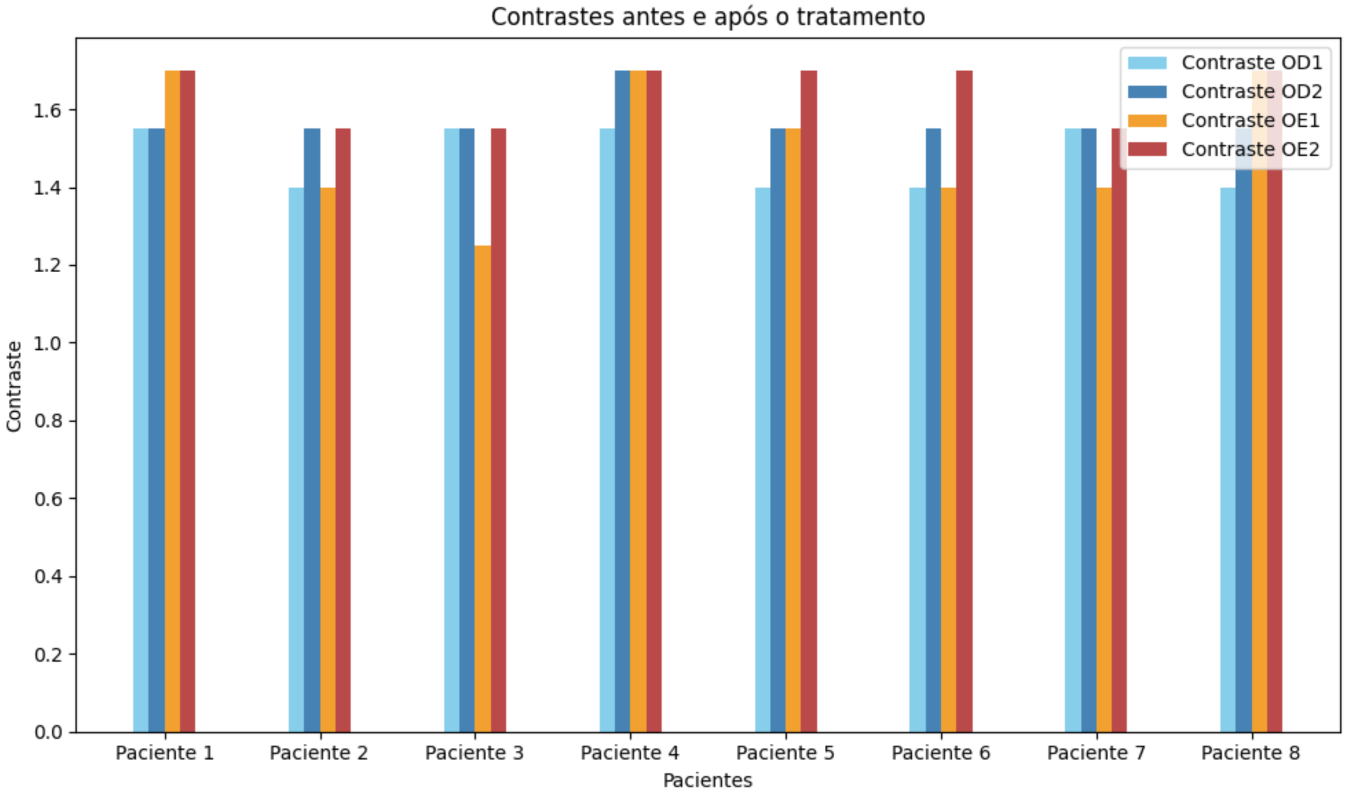

Figure 5.6: Contrasts - Pre and Post Treatment

the right and left eyes, which were maintained after treatment. This may indicate that the focus of the game is not to balance contrast between the two eyes but rather to improve each eye individually. Patient 7 maintained identical values before and after treatment, indicating that the treatment did not result in improvements, but they were still able to maintain good contrast levels. Patients 1 and 4, who already had good contrast levels, also maintained them, which can be seen as a success in preserving good visual function. In conclusion, the treatment proved effective overall, achieving improvements that can be significant in situations requiring good contrast perception, such as low-light environments. In patients who already had high contrast levels, the game proved effective in maintaining them, which is crucial to avoid harming any patient.

5.4 Intervention

The recommended treatment period consists of five hours of practice distributed over fifteen days, including daily 20-minute sessions. During these sessions, the patient wears anaglyph glasses so that the game can perform its function. The aim of this strategy is to increase visual contrast and, in turn, enhance the effectiveness of the therapy within a reasonable period of time, without leading the patient to monotony.

5.5 Discussion of Results

This section serves to analyze and interpret the results obtained in the tests conducted by healthcare professionals, as well as how these tests were performed. The study, which measured the three dimensions before and after the intervention, revealed even more notable changes than those frequently documented in other studies. These changes indicate that the use of the game in preschool children may have a positive impact compared to traditional treatments. However, the sample size was quite small, and the willingness and participation of the children during the consultations may have impacted the results. Consequently, despite the encouraging results, caution is necessary when interpreting them, and future research should consider using larger samples and more reliable techniques to reduce this variability.

1. Initial cohort of 15 patients, 8 completed the intervention – average age of 6.63 years, 12.5% females;
2. Of the 7 who did not complete, 4 did not adhere to the therapy – boys aged 8/9 with prior video game experience;
3. All patients who completed the intervention had anisometropic amblyopia, and 5 were undergoing occlusion therapy;

   Anisometropic: an eye condition where there is a significant difference in refractive power between the two eyes. This difference causes each eye to focus light differently.

   Occlusion therapy: the principle of occlusion therapy is to cover the eye with normal vision (the dominant eye) to force the use of the weaker eye (the amblyopic eye).
4. Improvement in visual acuity of the amblyopic eye by 10% (Standard Deviation (SD) 5%) – average 63% before the intervention, 73% after the intervention;
5. Improvement in contrast sensitivity of the amblyopic eye by 17% (SD 6%) (log contrast sensitivity) and stereopsis by 45.00 (SD 14.43) arc-seconds;

   The contrast sensitivity value, the **higher** it is, the better;

   The stereopsis value, the **lower** it is, the better.

The study of visual acuity, stereopsis, and contrast data from the tests provides valuable information about the effectiveness of the game. The three metrics, examined in eight patients, showed different values, which proves that there was an impact on vision. The visual acuity data suggest that, for most children, improvements were observed in the post-treatment levels. However, some patients showed no changes, raising questions about the treatment's efficacy. The conclusion drawn could be influenced by individual factors such as the severity of the pre-treatment acuity. The analysis of stereopsis data revealed significant improvements. This improvement may be related to performing activities that require perception. However, there are patients who did not show improvements, indicating a limitation of the game in more severe cases of amblyopia or visual perception. The contrast data showed that, overall, the game had a positive impact. These results are encouraging, as good contrast perception is necessary in everyday life. However, the maintenance of values in some patients may indicate that the efficacy is not universal, which could imply the need for other methods of evaluation by healthcare professionals. In conclusion, after studying the three levels of vision, the treatment was effective and positive for many patients, significantly improving visual abilities.

5.5.1 Limitations

The study on the effectiveness of this game, however, faced some obstacles. The first limitation relates to the sample size. A small sample can be misleading in the results it presents, as it does not account for all patient profiles. Secondly, the gaming time was not monitored, which could influence the interpretation of the results. The gaming time was defined before the treatment, but it is possible that various players played for less or even more time than recommended. Without this control, it is difficult to correlate the observed improvements with the gaming time. Another limitation was the association with occlusion therapy, which, although the plan was to complement the game with this treatment, the positive results may be attributed to this technique. This means that it is not possible to know for certain the individual contribution of the game. A control group is necessary to compare results between patients who received the intervention and those who did not. The lack of this group was another factor that limited the study in determining whether the improvements observed came from the game or other factors. Finally, cooperation in evaluations could cause a potential learning effect. More motivated patients may show better results, which means this variable could distort the data regarding the game's effectiveness.

5.6 Conclusion

Traditional treatments for amblyopia, such as atropine and occlusion, have demonstrated significant drawbacks, particularly in terms of patient adherence to therapy. According to studies, objective adherence to occlusion is only 44-57% of the recommended duration and tends to decrease over time. This decrease in adherence may be related to potential social challenges faced by patients, especially those involving children, as well as the physical and psychological discomfort associated with using eye patches for extended periods of time.

Even with its advancements, binocular treatments are still not a perfect substitute for atropine or occlusion. Although the use of both eyes simultaneously is encouraged by binocular therapies, which have shown promising effects, further clinical validation is needed before these therapies can be widely used. However, when combined, they can be a useful complement to traditional therapy, potentially increasing overall therapeutic effectiveness.

Digital technologies such as EYESCAPE and other proven binocular therapies, in particular, offer a new and possibly successful way of treating amblyopia. For many patients, these digital therapies can be quite useful, as they provide a more engaging and interactive option that can increase treatment adherence. To maximize patient participation and the effectiveness of these therapies, it is imperative that the software be appealing and tailored to their specific needs.

Chapter 6

Conclusion and future work

The goal of this dissertation was to create a game that could help treat children with amblyopia, providing an alternative to traditional techniques, such as stimulating the weaker eye through occlusion of the healthy eye. The proposed solution offered a simple, yet effective, game that supported the treatment, aiming to address the needs of children with this condition. In addition to meeting all implementation criteria and achieving the intended goals, this work also introduced new functions by initiative and in response to suggestions from medical professionals, increasing the overall value of the project and making it an ideal alternative for improving adherence to amblyopia treatment. Based on the positive results presented in the tests conducted on children, the game proves to be an excellent alternative to traditional treatments. Not only did it help with the primary objective, but it also contributed, according to the study of three visual levels, to improvements in visual acuity, stereopsis, and contrast. As the game showed no deterioration in vision, we conclude that, during the treatment period, it only brought improvements, making it a perfect interactive solution to this issue. It is concluded that this project represents a significant advancement in the approach to amblyopia treatment, which, by being engaging and yielding significant results, can increase patient adherence. The integration of technology and medicine seems to promise breakthroughs and innovative solutions, opening doors to new possibilities. The study presented in this dissertation is, therefore, an important step not only in amblyopia treatment but also in therapeutic approaches within pediatrics.

6.1 Future Work

There are several improvements and additions that could be made to this project to make the game more engaging, challenging, and useful for treating amblyopia. While the game already achieves its objectives, it can always be enhanced, especially in light of user feedback and the results from clinical trials. One of the initial concepts would be the creation of new levels. The player would encounter a greater variety of difficulties and challenges if more levels were made available, which would help prevent the game from becoming monotonous. Another idea would be to divide the game into worlds, with a set number of levels in each world. This way, the game's organization could be more effective, with clear goals and progress. The themes and obstacles could vary depending on the worlds, increasing the game's appeal and stimulating the player's mental engagement. It would be crucial to conduct a new study to ensure that the additional features do not divert from the game's primary goal, which is the treatment of amblyopia. The therapeutic value of each expansion, including the addition of characters, worlds, or additional levels, should be carefully considered. Such a study would need to assess whether the new features preserve the emphasis on the visual stimulation necessary to treat amblyopia, maintaining clinical success. The study should determine whether the new mechanics strike the right balance between enjoyment and therapeutic progress.

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