NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF PHYSICS

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Bachelor of Science in Biomedical Engineering

REHABVISUAL: ADAPTING AND TESTING THE VISUOMOTOR SKILLS STIMULATION PLATFORM ON PATIENTS WITH MULTIPLE SCLEROSIS

MASTER IN BIOMEDICAL ENGINEERING

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”

“Paciência e tenacidade valem mais que o dobro da habilidade.”

— Avô Zé

Abstract

Multiple Sclerosis (MS) is the most prevalent immune-mediated inflammatory demyelinating disease, affecting the Central Nervous System (CNS). Although the incidence and prevalence of this condition can be difficult to quantify accurately, it is estimated that 2.8 million people globally suffer from this pathology.

While MS patients may experience a variety of neurological symptoms depending on the locations of the lesions in the CNS, visual impairments are among the most common ones. However, conventional methods used in both assessment and rehabilitation of the visuomotor competences are not sufficient to deliver objective assessments, nor therapies tailored to the patient's needs.

In this sense, the present dissertation emerged, with the objective of adapting and testing the usability of the RehabVisual platform in MS patients. This platform was developed as part of previous master's dissertations, serving as a tool for conducting objective and standardized assessments of visuomotor skills and aiming to provide a specific monitoring and clinical intervention. This result is obtained through the utilization of an eye tracking system, implemented to integrate the platform.

Before applying RehabVisual in a clinical context, a normative base was established using 50 healthy individuals for later comparison. The experimental group consisted of 25 individuals diagnosed with MS, with and without confirmed visuomotor alterations. The protocol, identical for both groups, involved watching three videos, each with a visual stimulus describing a different path. By recording the individuals while they watched the videos, it was possible to calculate the Mean Euclidean Distance between the gaze and stimulus positions for each video and each participant, using the mentioned eye tracking system. This allowed assessing the patients' performance in tracking the stimulus, evaluating their visuomotor competencies.

The results obtained demonstrated that this platform had a promising performance in the assessment of visuomotor alterations, as well as in their quantification, representing a potential auxiliary tool for the healthcare professionals.

Keywords: Multiple Sclerosis, Visuomotor Skills, Visuomotor Rehabilitation, Eye Tracker, RehabVisual

Resumo

A Esclerose Múltipla (EM) é a doença desmielinizante inflamatória imunomediada mais prevalente, afetando o Sistema Nervoso Central (SNC). Embora a incidência e a prevalência desta condição possam ser difíceis de quantificar com precisão, estima-se que 2,8 milhões de pessoas em todo o mundo sofrem desta patologia.

Embora os pacientes com EM possam experienciar uma grande variedade de sintomas neurológicos consoante a localização das lesões no SNC, as alterações visuais estão entre os sintomas mais comuns. No entanto, os métodos convencionais usados tanto na avaliação como na reabilitação das competências visuomotoras não são suficientes para fornecer avaliações objetivas nem terapias adaptadas às necessidades do paciente.

Neste sentido, a presente dissertação surgiu com o objetivo de adaptar e testar a usabilidade da plataforma RehabVisual em pacientes com EM. Esta plataforma foi desenvolvida ao longo de dissertações anteriores, servindo como uma ferramenta para realizar avaliações objetivas e padronizadas das competências visuomotoras e visando fornecer uma monitorização e intervenção clínica personalizadas. Este resultado é obtido através da utilização de um sistema de *eye tracking* implementado para integrar a plataforma.

Antes de aplicar a RehabVisual num contexto clínico, foi criada uma base normativa com 50 indivíduos saudáveis para posterior comparação. O grupo experimental consistiu em 25 indivíduos diagnosticados com EM, com e sem alterações visuomotoras confirmadas. O procedimento, igual para ambos os grupos, consistiu na visualização de três vídeos com um estímulo visual que descreve um percurso diferente para cada vídeo. Através da gravação dos indivíduos enquanto visualizavam os vídeos, foi possível calcular a distância euclidiana média entre as posições do olhar e do estímulo para cada vídeo e para cada participante, utilizando o sistema de *eye tracking* referido. Assim, foi possível avaliar a performance dos pacientes no seguimento do estímulo, avaliando as suas competências visuomotoras.

Os resultados obtidos demonstraram que esta plataforma teve um desempenho promissor na avaliação de alterações visuomotoras, bem como na sua quantificação, representando uma potencial ferramenta auxiliar para os profissionais de saúde.

Palavras-chave: Esclerose Múltipla, Competências Visuomotoras, Reabilitação Visuomotora, *Eye Tracker*, RehabVisual

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Abbreviations

ANS Autonomic Nervous System *(p. 5)*

CIS Clinically Isolated Syndrome *(p. 8)*
CNS Central Nervous System *(pp. v, 1, 8)*
CSS Cascading Style Sheets *(p. 14)*

EOG Electrooculography *(pp. 10, 11)*

FPS Frames per second *(p. 24)*

HGO Hospital Garcia de Orta *(pp. 2, 14, 18, 22, 28, 39, 40, 61)*
HTML HyperText Markup Language *(p. 14)*

INO Internuclear Ophthalmoplegia *(pp. 9, 11, 28, 29, 32, 34)*

JS JavaScript *(p. 14)*

MRI Magnetic Resonance Imaging *(p. 12)*
MS Multiple Sclerosis *(pp. v, vii, viii, 1–4, 7–13, 15, 18–20, 22, 28, 33, 37–40, 61)*

PHP Hypertext Preprocessor *(p. 14)*
PPMS Primary Progressive Multiple Sclerosis *(p. 8)*

RRMS Relapsing-remitting Multiple Sclerosis *(pp. 8, 28)*

SPMS Secondary Progressive Multiple Sclerosis *(pp. 8, 29)*
SQL Structured Query Language *(p. 14)*

VOG Videooculography *(p. 11)*

1 Introduction

1.1 Context and Motivation

Multiple Sclerosis (MS) is the most prevalent immune-mediated inflammatory demyelinating disease, affecting the Central Nervous System (CNS). Although the incidence and prevalence of this condition can be difficult to quantify accurately, according to estimates from 2020, there were 2.8 million MS patients globally, affecting women more than men. As regards the incidence of MS in Portugal, there are studies pointing to a figure of nearly 60 patients per 100,000 inhabitants. Even still, based on the medication dispensation records maintained by pharmaceutical laboratories, it is believed that this number is higher, reaching between 70 and 80 MS patients per 100,000 inhabitants [2–5].

Patients suffering from MS may have a variety of neurological symptoms depending on the location of the CNS lesions, making the disease's course unpredictable and unknown. Visual impairments are among the most common symptoms and are often the first sign of the disease, altering significantly the patients' quality of life. In addition, studies suggest that the oculomotor behavior can be an indicator of the neurological status of the patient or even the efficacy of their therapy. However, the evaluation of this system is typically based on the subjective observation of the physicians, since it is usually performed by the naked eye [6, 7]. In this sense, it is clear that both clinical practice and research will benefit from the inclusion of objective and accurate methods to assess oculomotor function, as it will be beneficial both in diagnosing MS and in the rehabilitation area. Besides these applications, this innovation will also facilitate long-term patient monitoring and the execution of prospective longitudinal studies.

In the occupational therapy area of the department of Medicina Física e de Reabilitação of the Hospital Dona Estefânia, it was felt the need to improve the methodology used in the assessment and intervention of visuomotor skills in infants with developmental abnormalities. In this regard, a master's thesis project resulted in the creation of the computer application RehabVisual, which offers a number of diagnostic and therapeutic protocols based on visuomotor stimuli [8, 9]. In addition to these protocols, this platform enables the development of clinical reports and a database to store the patients' personal

and clinical data. After four master's theses [10–13], the platform now includes an eye tracking system that underwent a validation procedure in contrast to the professional *Tobii Pro Nano* eye tracker, considered as the gold-standard. Furthermore, RehabVisual has also been tested on a sample of Stroke patients in a clinical context and it has been demonstrated to be a possible future of clinical practice in visuomotor rehabilitation, assisting with both the diagnosis and treatment of these skills.

Furthering this, the current dissertation collaborates with the Hospital Garcia de Orta (HGO) to expand the RehabVisual platform for patients with MS, in order to, as was suggested before, obtain higher objectivity and quantification in the diagnosis and progression of the condition, as well as assist in visuomotor rehabilitation.

1.2 Objectives

The main objective of this dissertation is to test the usability of the RehabVisual platform on individuals diagnosed with MS, extending the work that has been done over the past theses in this software. This project seeks to close the abovementioned gap of subjectivity in the assessment and rehabilitation of visuomotor competencies, namely in MS patients.

To achieve the proposed objective, the following tasks were then established:

1. Adapt and extend the RehabVisual platform for MS. This step includes primarily the addition of the pathology in the already existing functionalities, as well as the addition of specific features for MS, if necessary. Additionally, potential bugs and relevant missing functionalities of the platform should be resolved.

2. Establish an experimental protocol. This process should be done in collaboration with HGO's neurology department and should encompass the selection of the stimuli to be integrated into the experimental procedure.

3. Create a normative base. To accomplish this, it is necessary to apply the experimental protocol to a group of individuals without associated pathology (control group) in a laboratory setting.

4. Collect data from MS patients. The application of the protocol to patients with MS should be carried out at HGO, where the patients are monitored.

5. Assess the platform usability in MS patients. This final step consists of comparing the results of both groups, evaluating the patients' performance relatively to the control group.

The research work described in this dissertation was carried out in accordance with the norms established in the ethics code of Universidade Nova de Lisboa. The work described and the material presented in this dissertation, with the exceptions clearly indicated, constitute original work carried out by the author.

1.3 Document Structure

This document is divided into seven Chapters. The first and current Chapter introduced the dissertation, discussing its context, motivation and main objectives. The second Chapter covers the essential theoretical concepts for the development of this dissertation. The third Chapter contemplates a literature review on the assessment and rehabilitation of visuomotor skills, focusing on the application of eye tracking systems and computer platforms to MS patients, as well as the presentation of the RehabVisual platform. In the fourth Chapter, the adaptation of the RehabVisual platform is presented, including the new features implemented and the alterations made to the developed eye tracker. The fifth Chapter provides a description of all the process related to the construction of the normative base, gathering information from the methodologies to the analysis of the results obtained. The sixth Chapter describes the application of the eye tracker to an experimental group of MS patients, also including the comparison and analysis of the results obtained in clinical context. Lastly, the seventh Chapter concludes the current dissertation, outlining the main contributions and findings, as well as limitations and future work.

2

Theoretical Concepts

This chapter is designed to provide a detailed overview of the key concepts that are relevant to the present dissertation. In this regard, in Section 2.1 the human visual system is presented, including the anatomy of the eye and the image formation process. Additionally, MS is discussed in Section 2.2, along with a description of the condition and related visual impairments.

2.1 Human Visual System

The visual system is a complex network of structures and processes that work together to enable vision. It takes information from the environment in the form of light and converts it into a neural sign to analyse and interpret the data, enabling us to successfully navigate the physical space and interact with the surrounding environment. Consequently, understanding the anatomy and physiology of the visual system is essential for the diagnosis and treatment of eye disorders [14, 15].

2.1.1 Anatomy of the Human Eye

The human visual system is constituted by the eye, represented in Figure 2.1, and the visual pathways, which in turn involve the optic nerves, the optic tract, the lateral geniculate nucleus, the optic radiation and the visual cortex. A scheme of the complete system can be found in the next section (Figure 2.2) [14].

The eye is a specialized organ composed of three coats or tunics:

1. The outer fibrous layer of connective tissue - cornea and sclera
2. The middle vascular layer - iris, ciliary body and choroid
3. The inner neural layer - retina

The eye's exterior, dense connective tissue serves as a protection for the internal structures, preserves the eye's globular form, and provides resistance to the fluid pressure. It also provides important structural support for attachment of extraocular muscles, which

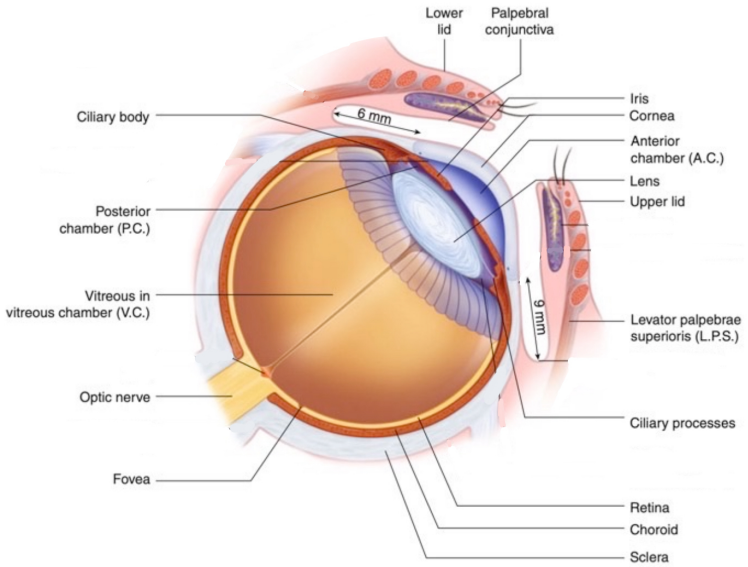

Figure 2.1: Anatomy of the human eye (adapted from [16]).

control and direct the eye's movements, coordinating the movements of both eyes to provide binocular vision. The conjunctiva, a transparent tissue, covers the opaque white portion of the eye called the sclera. The cornea, located at the anterior part of the eye, is a transparent structure that allows light to enter and refracts it to bring it into focus on the retina. The limbus is the region at which the cornea transitions to sclera and conjunctiva [14, 15].

The middle vascular layer of the eye - uvea - is composed of the iris, the ciliary body and the choroid, which are continuous with one another and have an opening anteriorly, the pupil. The iris is a thin, highly colored, contractile circumferential disk that functions as a diaphragm, controlling the amount of light that enters the eye via the pupil. The diameter and shape of the pupil is regulated by two pupillary muscles that are innervated by the Autonomic Nervous System (ANS). The ciliary body produces the components of the aqueous humor and houses the muscle (ciliary muscle) that regulates the shape of the lens, altering its refractive power. Lastly, the choroid is situated between the sclera and the retina at the posterior part of the uvea. Its principal function is to nourish the outer retinal layers [14, 15].

The retina is the focal plane of the eye's optical system and is composed of specialized cells that convert the light into electrical signals. These signals are then transmitted to the brain via the optic nerve, which is continuous with the retina posteriorly, and other neural pathways [14, 15].

As shown by the prior illustration, it is also possible to distinguish three chambers: the anterior chamber, the posterior chamber and the vitreous chamber. The first one is bordered in front by the cornea and posteriorly by the iris and anterior surface of the lens. It is connected by the pupil to the posterior chamber, which lies behind the iris and is bounded posteriorly by the ciliary body. Both chambers contain the aqueous humor

that nourishes the surrounding structures, especially the cornea and lens. The vitreous chamber, which is the larger space, is located adjacent to the inner retinal layer and is bounded in front by the lens. The latter contains a gel-like substance called vitreous humor [14].

Finally, it is important to mention the flexibility of the crystalline lens. This structure is able to change its shape in response to signals from the ciliary muscle, which is controlled almost entirely by parasympathetic nerve signals. When the ciliary muscle contracts, it causes the lens to become thicker and more curved, increasing its refractive power and allowing it to focus on nearby objects. This mechanism is called accommodation, which is one of several processes that work together to maintain a clear vision [14, 17].

2.1.2 Processing Visual Information

The visual pathway, represented in Figure 2.2, begins with photoreceptors of two types in the retina: rods and cones, which contain chemicals that decompose on exposure to light and stimulate the nerve fibers leading from the eye. Rods have a distinct function in perceiving objects in the periphery and in low light settings. Cones, in contrast, are active in bright light conditions and contribute to discriminating fine details in central vision and detecting color. The area specialized in the acuity of vision is the macula. Within this structure lies the fovea, a small depression which is the area of greatest visual acuity in the retina. Photoreceptor-generated action potentials are transmitted to large ganglion cells in the retina, which represent the final retinal connection in the visual pathway. These ganglion cell axons converge at the optic disk or optic papilla, a region without photoreceptor cells that creates a blind spot. The axons then form a layer of nerve fibers that exit the eye through the posterior scleral foramen and form the optic nerve. The nerve impulses are subsequently carried to the visual cortex, through the optic nerves, optic tract, lateral geniculate nucleus, and optic radiation as depicted in figure 2.2 [18].

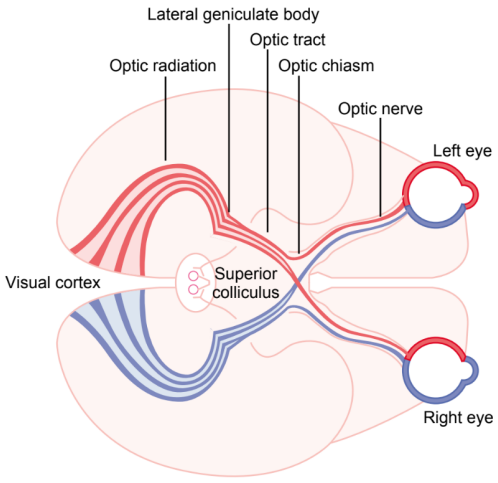

Figure 2.2: Principal visual pathways from the eye to the visual cortex (adapted from [17]).

The visual field of each eye can be divided into temporal (lateral) and nasal (medial) parts. The temporal part of the visual field is projected onto the nasal retina, while the nasal part is projected onto the temporal retina. The optic nerve fibers from each retina cross at the optic chiasm, forming, from this location, the optic tracts, which run to the respective lateral geniculate nuclei. As a result, the right hemisphere receives the visual information from the right temporal retina and the left nasal retina, while the left hemisphere receives the information from the left temporal retina and the right nasal retina. In essence, the right hemisphere of the brain receives information from the left visual field and the left hemisphere receives information from the right visual field [18].

The visual cortex is located in the occipital lobe of the brain and is divided into a primary visual cortex and secondary visual areas. The processing of visual information, including recognition of patterns and static/moving objects, takes place in the primary visual cortex. From there, the information is transmitted to the other visual areas through two pathways - the ventral and dorsal streams. The ventral stream moves from the occipital lobe to the temporal lobe and is responsible for the interpretation of the received visual information, aiding in object and face recognition and perception of color and form. On the other hand, the dorsal stream travels to the parietal lobe and is associated with spatial and motion characteristics as well as motor coordination. The visual pathways interact with each other constantly, thus normal vision depends on the correct integration of information from all these areas [17].

2.2 Multiple Sclerosis

MS is a chronic and progressive neurological disease characterized by inflammation, demyelination, and axonal damage (neurodegeneration). The immune system mistakenly recognizes myelin as a foreign substance and launches an attack against it. This triggers an immune response that leads to the release of inflammatory cytokines, chemokines and other immune molecules. These inflammatory molecules then attract other immune cells, such as T cells and B cells, to the site of injury, where they further attack and damage the myelin and axons. The myelin is the protective covering of nerve fibers that allows efficient transmission of electrical signals between the brain and the rest of the body. Therefore, when the myelin is damaged or destroyed (demyelination), these signals can become slower, distorted, or completely blocked, leading to a wide range of neurological symptoms [19, 20].

The etiology of MS is complex and not yet fully understood. MS is believed to be a multifactorial disease with both genetic and environmental factors playing a role in its development. Several genes have been identified that may increase susceptibility to MS, including genes involved in immune regulation and responses to infections. Environmental factors, such as exposure to viruses and toxins have also been linked to MS. It is thought that these environmental factors may trigger an abnormal immune response in genetically susceptible individuals, leading to the development of MS. In addition, there

is evidence that lifestyle factors, such as smoking and diet, may also contribute to the development of the disease [6, 19].

Since MS can affect any region of the CNS, its symptoms are unpredictable, depending from one person to another and in the same person over time. Therefore, a wide range of symptoms may occur, including fatigue, pain, spasticity, visual disturbances, cognitive impairment and mobility limitations [6].

In 2013, four subtypes were revised for MS by Lublin et al. [21]:

- Clinically Isolated Syndrome (CIS) - initial clinical manifestation of a disease that displays features of inflammatory demyelination, which may suggest the possibility of MS, but has not yet met the criteria for temporal dissemination.
- Relapsing-remitting Multiple Sclerosis (RRMS) - the most common disease course. Patients experience relapses (attacks or exacerbations) of neurological symptoms, followed by periods of partial or complete recovery (remission).
- Secondary Progressive Multiple Sclerosis (SPMS) - the disease starts as relapsing-remitting but then progresses to a steady decline in neurological function. There are no relapses or remissions, yet there are still occasional temporary improvements.
- Primary Progressive Multiple Sclerosis (PPMS) - it is characterized by a gradual loss in neurological function when symptoms first appear. There are no relapses or remissions, but there may be sporadic plateaus.

However, an international committee composed by Vollmer et al. [22] in 2021 has proposed that these apparent subgroups are a part of a spectrum, describing MS as a continuous disease process that is shaped and propelled by fundamental mechanisms of damage to the nervous system.

2.2.1 Visual Dysfunctions in Multiple Sclerosis

Changes in visual ability may be brought on by demyelination and other injuries at any level of the visual pathways. Therefore, patients with MS frequently experience visual impairments, which can be chronically injured, acute, or iatrogenic, since pharmacologic therapies used during the treatment can also have side effects interfering with the visual system in various ways [23].

As was previously noted, visual impairments are quite frequent and have a substantial negative impact on the patients' quality of life, hence the importance of not overlooking them both in their identification and evolution. Below are the most common and relevant visual disorders that may affect MS patients.

Optic neuritis The primary clinical symptom of MS is frequently optic neuritis, as it is also one of the most common inflammatory demyelinating exacerbations, affecting up to 90% of patients at some point in the course of their disease. Optic neuritis is a condition

in which one or both optic nerves become inflamed, resulting in a variety of symptoms and commonly affecting individuals with between 20 and 50 years old. There may be a variable loss of visual acuity, visual field deficits and vision loss (usually gradual over a period of 7 to 10 days). Colour perception and contrast sensitivity impairments are also common, as the visual field deficit tends to involve the macula. There may also occur pain with ocular movements [24].

Ocular mobility disorders Injury or degeneration of nerve fibers from nuclei in the brainstem and cerebellum can give rise to ocular mobility disorders, often producing long-lasting visual symptoms like diplopia (double vision) and saccadic intrusions (rapid and involuntary eye movements disrupting smooth gaze tracking). Another common disorder is called nystagmus and is characterized by involuntary rhythmic eye movements. This occurrence often points to lesions in the neural mechanisms responsible for maintaining steady eye positioning. Additionally, affecting more than 20% of MS patients, Internuclear Ophthalmoplegia (INO) results from damage to the Medial Longitudinal Fasciculus in the brain, which plays a critical role in coordinating eye movements, particularly the conjugate movement of both eyes, allowing them to move in the same direction at the same time. It is distinguished by the limitation or slowing of the adducting ipsilateral eye relative to the abducting eye, often accompanied by abducting nystagmus in the contralateral eye. This discrepant movement of the two eyes during saccades results in a break in binocular vision, which can lead to visual confusion, diplopia and reading fatigue [23, 24].

3

State of the art

This chapter provides a literature review of the contents of interest for the present dissertation and is divided into three sections. Section 3.1 focuses on the application of eye tracking systems for ocular mobility assessment. On the other hand, Section 3.2 explores the visuomotor rehabilitation in MS patients, including information technologies employed in this area. Lastly, Section 3.3 discusses the RehabVisual platform and its development, as well as its application in a clinical context.

3.1 Eye Tracking Systems for Ocular Mobility Assessment

Oculomotor behaviour is mostly made up of smooth pursuits, saccades and fixations, involving the various structures of the visual system. In this sense, lesions at the level of any of these structures will cause alterations in eye movements and, therefore, in oculomotor behavior, making it a good metric to assess the neurological status of an individual [7].

Accordingly, an assessment of oculomotor function is frequently part of a clinical vision examination. However, this evaluation is typically subjective to the observation of the health professional, which motivated researchers to explore more objective and accurate methods to assist this assessment [25].

Eye movement recording, commonly known as eye tracking, has come a long way since its beginning with invasive and mechanical procedures. One of the first noninvasive measurement techniques to become widely used was the Electrooculography (EOG), which is still utilized nowadays. By placing skin electrodes near the eyes, it can record changes in the electrical field created by eye movements, providing information about their direction and magnitude. EOG has multiple advantages, including the fact that it is not affected by lighting conditions or head movements. Additionally, this technique is still the only one that enables the recording of closed-eye ocular movements, making it very interesting for the study of sleep [26].

Another noninvasive measurement technique is the pupil-corneal reflex tracking method, which employs infrared reflection devices. An infrared light is shined into

the eye, creating a light spot through the reflection in the cornea, which is captured and received by a video camera or another optical receiver. Although the angle of light changes as the eye moves, the position of the light spot remains fixed and can serve as a reference point. In contrast, the center of the pupil always moves in the direction of gaze. The vector formed between the cornea's bright spot and the pupil's center, which varies with eye movement, can be used to assess the direction of vision [27]. There are some eye trackers in the market that use this technique, including the ones from Tobii, which can capture data at sampling rates ranging from 60 to 1200 Hz [27, 28].

With the evolution of computer-based image processing, another eye tracking technology called Videooculography (VOG) has been growing. A video camera is used to record a video, which is later processed in order to detect the center of the pupils. Based on the detected location, the direction of gaze is estimated. This method makes it possible to evaluate ocular mobility without the need for expensive specialized hardware, which is a significant advantage [25, 26].

3.1.1 Eye Tracking Systems Applied to Multiple Sclerosis Patients

As it was mentioned earlier, an objective measure of the oculomotor behaviour would be beneficial to estimate the neurological status of an individual. In this regard, some eye tracking systems were already employed in clinical practice with MS patients.

In 2003, Frohman et al. [29] contrasted the reliability of quantitative infrared oculography (infrared eye tracking) with that of clinical detection of INO. They concluded that INO may be overlooked, and the use of a quantitative system provides greater precision in the diagnostic confirmation.

A study conducted in 2011 [30] also came to a similar conclusion. It used EOG to assess smooth pursuit disturbances in MS patients. The results were favorable and indicated that it is a useful tool to complement the clinical bedside examination, as it was able to detect subclinical cases.

Research carried out in 2020 by Sheehy et al. [31] utilized a retinal eye tracking system to objectively measure fixational microsaccades (small, rapid, and subtle eye movements that occur during fixation on a stationary target) in MS patients. The results indicated that these could serve as an effective measure of disability in MS, with a higher frequency of fixational microsaccades associated with greater neurological disability.

As evident from these studies, eye tracking systems are increasingly finding application in the realm of healthcare, particularly in the context of neurological disorders. These tools, despite being expensive and requiring expertise to analyse data, hold significant promise in assessing visual function and oculomotor disturbances. Ongoing research efforts aim to further refine these technologies, striving for enhanced accessibility and accuracy.

3.2 Visuomotor Rehabilitation in Multiple Sclerosis Patients

A treatment option for MS involves the use of medications that can have a favorable impact on the frequency of relapses, the advancement of lesions on MRI scans, and the overall course of the disease. Although these medications are often successful in improving specific outcomes like walking ability, tiredness, and stiffness to some extent, researchers indicate that they may have little effect on pre-existing neurological impairments. Therefore, neurorehabilitation may have an important role in the lives of individuals diagnosed with MS, as adaptive neuroplasticity may occur after functional cognitive training [32, 33].

The goal of visuomotor rehabilitation is to improve the patient's visuomotor coordination and spatial awareness and to prevent their symptoms from developing, enhancing their ability to perform daily activities independently. It should be tailored to the individual's specific needs and abilities, and may involve a multidisciplinary team of healthcare professionals, including occupational therapists, physiotherapists, and ophthalmologists/neuro-ophthalmologists.

Rehabilitation methods, such as eye movement exercises, have been demonstrated to be effective in improving eye movement patterns in individuals with neurological disorders such as MS [34]. Cawthorne-Cooksey exercises, for example, are often applied to MS patients to help improve balance, coordination, and reduce dizziness or vertigo [35].

In 2021 [36], the efficacy of these exercises was assessed in a MS patient experiencing diplopia. Although the results were very satisfying and the patient did notice a decrease in diplopia and an improvement in balance, the reported enhancements were subjective to their opinion, which implies that the current methods of evaluating oculomotor dysfunctions in a clinical context may be insufficient [37]. In this regard, it is also relevant to integrate new technologies like eye trackers to assist health professionals in quantifying eye mobility for rehabilitative purposes.

Additionally, a study including 23 MS patients and 12 healthy controls [38] used functional MRI to examine the visuomotor performance of both groups after a short-term practice (12 minutes of a visuomotor task) and a long-term practice (daily home practice of the same task for at least 15 days). Both groups showed improvements in visuomotor performance, and there was evidence of preserved brain plasticity in MS patients, as it was suggested before, highlighting the role of rehabilitation in these individuals. Furthermore, it is evident that a remote therapy option is beneficial, once again leading us to believe that the introduction of new technologies in the rehabilitation area is valuable.

3.2.1 Information Technologies for Rehabilitation

The introduction of new technologies offers several advantages in the field of rehabilitation beyond what has already been mentioned, such as allowing the creation of a history of the patients' evolution, as well as the creation of training plans tailored to their needs. In contrast, conventional approaches have some drawbacks, foremost among them being the

necessity for patients to travel to a designated facility. Moreover, these methods can be very repetitive and monotonous, leading to reduced motivation and engagement [39].

Another significant application of new technologies in the field of rehabilitation is the prediction of the patient's capacity for functional improvement, which can greatly assist in the clinical management of MS patients. A study conducted by Lipp et al. [40] employed a predictive statistical model to identify factors that could predict improvements in visuomotor performance. The results were promising, indicating that several factors predicted the observed enhancements, including younger age, less disability and better visuomotor abilities.

Furthermore, computer programs have been effectively used for cognitive rehabilitation in MS patients, namely the RehaCom platform, which is detailed in the next section.

Moreover, it is evident that the combination of computer-based rehabilitation with eye tracking systems would yield valuable advantages, starting with the possibility of conducting both the rehabilitation session and oculomotor assessment remotely and quantitatively rate the visuomotor disability.

3.2.1.1 RehaCom

RehaCom is a software platform designed for computer-assisted cognitive rehabilitation. It can help users improve their performance in tasks that require attention, memory, perception, and more. This platform can be used remotely without the therapist's physical presence [41].

RehaCom has about 30 modules, each designed to train a specific cognitive deficit. They are divided into five groups: attention training, memory training, executive functions training, visual field training, and visuomotor abilities. After identifying the appropriate module, the therapist can customize various parameters such as session duration, starting level, and adaptivity sensitivity. In addition, specific variables are available, including time limit to solving tasks, audio feedback, stimuli choices and others. However, the modules adapt automatically to the patient's level, taking into account their performance [41].

Once the training is complete the therapist can review the session, particularly the level progression, the number of mistakes made, and the time taken for each task. The platform records and stores data on the patient's progress over time, which allows for the monitoring and tracking of the patient's cognitive rehabilitation progress, as well as the ability to adjust the therapy plan as needed [41].

Regarding visuomotor abilities training, it involves an exercise of tracking a stimulus. On the screen, a circular disk and a differently colored point are displayed. During the exercise, the disk follows an unpredictable path, and the goal is to move the point within the circular disk using either a joystick or the computer mouse [41].

RehaCom has been subject to investigation to ascertain its utility in the field of cognitive rehabilitation for MS patients. Within these researches, improvements in cognitive function were detected, namely visuospatial memory and visuomotor skills [33, 42].

Although RehaCom is already in use throughout Europe, there are some limitations that should be taken into account in the development of RehabVisual, such as the absence of an integrated eye tracking system to allow the quantification of ocular mobility.

3.3 RehabVisual

In the occupational therapy area of the department of Medicina Física e de Reabilitação of the Hospital Dona Estefânia, it was identified the lack of methodology used in the assessment and intervention of visuomotor skills in infants up to 18 months old with developmental abnormalities. In this sense, the RehabVisual platform was developed with physicians and occupational therapists in order to address this problem [8].

The aim of this computer application was to provide individualized and specific treatment to meet the needs of the underdeveloped children and to monitor their therapeutic progress. Therefore, two sections were designed: a database to record all the relevant clinical information of the patient and protocols with stimuli according to the development of the child (differing in form, dimension, color, contrast, movement and presentation distance). In addition, RehabVisual was primarily projected for allowing access to three types of users: physicians, occupational therapists and caregivers, each one having different permissions [8].

After an initial behavioral assessment of the infants, the therapists selected the most appropriate stimuli available on the platform based on the outcomes of this assessment. The videos presented in the subsequent sessions always depended on the results of the previous sessions. Hence, the platform allows a global and integrated evaluation and intervention, operating in both assessment and rehabilitation aspects [8].

The computer application was developed using various programming languages, including JS, PHP, HTML, and CSS, while SQL was chosen to create the database [8].

Later on, the opportunity arose to collaborate with the Instituto Politécnico de Beja to test the platform on individuals who have experienced a Stroke, assessing whether its implementation aids in visual rehabilitation. In this context, RehabVisual was tailored for the adult population, incorporating more suitable and challenging stimuli [11, 12].

Additionally, an eye tracking system was also developed to integrate the RehabVisual platform. This latter component offers an advantage that has been discussed previously, enabling the quantification of ocular mobility [11, 12].

The work was continued in 2022 in another dissertation project [13], where both the platform and the eye tracker were refined and tested in a clinical context with post-Stroke patients monitored at HGO. A summary of the methodology and results can be found in Section 3.3.1.

3.3.1 RehabVisual on Stroke Patients

The latest thesis regarding the RehabVisual platform, as it was mentioned above, aimed to evaluate the usability of this rehabilitation tool with Stroke patients. In this respect, some adjustments have been made to meet the patients' needs and the accessibility of the platform, since the previous studies allowed to gather feedback from its users. These included alterations regarding the visualization, such as correction of spelling and image formatting errors, as well as addition of new features, like the recording of the patient and the stimulus simultaneously [13].

The stimuli were also updated, since they proved to be unchallenging, predictable, and too slow for the adult population. The modifications made involved changing the initial directions of the stimuli movements, in order to prevent their predictability after a few viewings, and their speed, so that adults did not lose attention and concentration throughout the intervention. However, it was decided to keep the figures simpler and with the minimum possible detail, which were previously used in therapy with children and supported by bibliographic research: squares, circles, and triangles [8, 13].

At this point, the platform allowed access to 5 different users (administrator, physician, technician, occupational therapist and caregiver), whose permissions are shown in Appendix A, Table A.1. In addition, it contained the following sections: the patient's medical record, a general ophthalmological assessment, a behavioral assessment, a functional assessment and an intervention program.

Regarding the eye tracker, a comparison was made between the system developed and *Tobii Pro Nano*, considered as gold-standard. This procedure was carried out on 50 healthy volunteers and led to the validation of the developed eye tracker, which was subsequently employed with the post-Stroke patients.

This project's findings indicate that the RehabVisual platform holds promise for enhancing the rehabilitation of visuomotor skills in post-Stroke individuals. Therefore, some developments and improvements were mentioned for future work, as well as new applications. Among these, the exploration of other neurological problems, such as MS, stands out, evaluating the usefulness of the platform in the assessment and rehabilitation of these pathologies [13].

3.3.1.1 Operation of the Eye Tracker

In this section, a concise explanation of the operation of the developed eye tracking system integrated into RehabVisual is provided. This technology was created using *Matlab R2017a* software and operates offline, only requiring prior recording of the participant's face during stimulus observation for subsequent analysis.

The eye tracking system is a semi-automated process that starts with the selection of the video to be analysed. Subsequently, the user is prompted to mark the individual's eyes and a reference point (usually the nose) in the first frame of the video. After the user's input, the automated process of eye detection in each frame ensues, with user

intervention requested only in cases of detection failure, namely in the event of a loss of the reference point, in which case its marking is again prompted. This manual marking facilitates the creation of two-fixed boxes to track the movement of each eye. For each box, image processing is applied to every frame to ultimately ascertain the coordinates of the eyes' centers.

The image processing initiates by converting the image into grayscale and identifying the darkest point (lowest intensity), which is presumed to belong to the pupil. Utilizing this pixel as a basis, an image segmentation technique based on similar intensity values is performed, through *grayconnected()* Matlab function. This technique achieves iris segmentation, necessitating the manual specification of a tolerance value to define the approved range of similar intensity values, ranging from 0 to 1 and contingent upon the image's lighting conditions.

Following this step, the detection of the iris center is performed using the *imfindcirles()* function, which is programmed to identify circles within a binary image and store their positions and radii in matrices. The coordinates of the reference point are also stored in a matrix.

To determine gaze positions, the distances between the reference point and the eyes are converted into screen positions in pixels corresponding to where the user is looking, using a calibration system. This system involves prompting the user to gaze at the screen's edges trough a calibration video. Consequently, the maximum and minimum deviations between the eyes and the reference point correspond to the screen's edges. Knowing the screen dimensions in pixels, a conversion factor is obtained, which may be employed to determine gaze positions in pixels.

The final outcome is a matrix of pixel coordinates representing the gaze position for each eye. Additionally, the stimulus coordinates are also determined in pixels for each frame, allowing the correlation of both values. For the presentation of this outcome, the program generates graphs, notably depicting the overlay of the stimulus position with the position of each eye (both in pixels) as a function of the video frame number. These correlations are separated for each vertical and horizontal axes.

Through the evaluation and validation of the eye tracker in the latest thesis, two metrics were tested for assessing the participant's performance in tracking the stimulus, the time in area of interest and the mean Euclidean distance between the gaze and the stimulus positions. It was determined that the most suitable metric between these was the latter. From the established normative basis, and considering the sole video showed to the participants, it was assumed that uncomplicated tracking occurred for distances below 200 pixels. Otherwise, it was considered that the patient had difficulties following the stimulus [13].

Although the eye tracker has been validated, the present dissertation faced some relevant limitations related to this system. When using the *imfindcirles()* function, several circles are found and stored in an array, sorted based on their strength. In the developed eye tracker, it was always chosen the first circle, which led to a significant error, since the

strongest circle in the binary image may not be the iris. In addition, this function has a sensitivity factor, specified as a number ranging from 0 to 1 that alters the quantity of circles detected. Increasing the sensitivity factor leads to a higher number of circles, also increasing the risk of false detection. The chosen value (0,90) was not sufficient to detect the circle of interest in a significant number of frames, making this also a limitation that needed to be addressed.

4

RehabVisual: Adaptation for MS Patients

In this chapter, the work carried out as a continuation of previous dissertations is described, both with respect to the RehabVisual platform and the developed eye tracker. In this sense, the results of the usability test performed within the past dissertation were taken into consideration.

Section 4.1 details the modifications implemented on the platform in order to adapt it to the new pathology and Section 4.2 outlines the alterations made to the developed eye tracker. Additionally, a user guide targeted at MS can be found in Appendix A.

4.1 Platform Expansion and Adaptation

To achieve the proposed task of extending the RehabVisual platform for MS patients, the presented requirements were defined in collaboration with the clinic, particularly with Dr. Irene Mendes, a highly experienced neurologist at HGO. To start, it was considered relevant to introduce a new assessment menu, the Neuropsychological Assessment ("Avaliação Neuropsicológica") detailed in Section 4.1.4, which is typically performed in MS patients to assess the presence of cognitive impairments. Furthermore, it was suggested that the Behavioral Assessment ("Avaliação Comportamental") was not used since the relevant information was already included in the other assessments. Therefore, the module for MS was not added to this menu.

Regarding the Intervention Program menu ("Programa de Intervenção"), no changes were made as this study focused more on the assessment area, for diagnostic confirmation and disease progression monitoring. In this sense, options for the patients' rehabilitation were not explored yet.

In addition to the specific alterations for MS abovementioned and detailed in the sections bellow, the following general changes were also made:

- Correction of spelling errors and bugs;
- Aesthetic changes, such as aligning text and buttons;

- Addition of a “Back” (“Voltar”) button on all pages to facilitate the navigation within the different pages of the platform;
- Updating the team members and the contact form on the respective pages.

4.1.1 Main Page

The information on the initial page (Appendix A, Section A.1), before the login, has been updated with relevant content regarding the project and the platform in question. Consequently, the sections “Visuomotor Skills” (“Competências Visuais”) and “The Project” (“O Projeto”) have been reorganized to be more engaging and comprehensive.

4.1.2 Clinical Record

In the Clinical Record menu ("Ficha Clínica do Paciente"), the option to submit files and associate them with the patient’s record has been added. This functionality was deemed relevant as it was suggested in the usability questionnaire of last year’s thesis. As for the remaining information, the same data has been retained, with changes made only to the available diagnosis options, as it was expected. The clinical record form is presented in Appendix A, Section A.4.

4.1.3 General Ophthalmological Assessment

It was considered relevant to separate the General Ophthalmology Assessment (“Avaliação Oftalmológica Geral”) into modules according to the different pathologies, as it had already been made for the other assessments. Beyond this, the assessment added for MS differs from the others, as it includes the relevant information for the pathology in question. This page can be found in Appendix A, Section A.5.

4.1.4 Neuropsychological Assessment

As mentioned above, the Neuropsychological Assessment (“Avaliação Neuropsicológica”) is typically carried out on MS patients. As noted in Appendix A, Section A.6, it evaluates whether or not the patient has executive changes, and it is also possible to add observations if the healthcare professional wishes to. Executive alterations refer to cognitive difficulties or dysfunctions related to the executive system which are diagnosed by a neuropsychologist and are relevant in evaluating the progression of the pathology, hence the integration of this assessment in the platform. Being a new evaluation, the permissions for different user types were defined in accordance with other assessments (see Table A.1).

4.1.5 Functional Assessment

The last year’s implemented feature of simultaneously recording the patient’s face and the visualized stimuli was used for the Functional Assessment (“Avaliação Funcional”)

of MS patients. Therefore, in this assessment, it is possible to play the three new videos shown during the experimental procedure, which are described in Section 5.2, and record both the stimulus and the patient.

Nonetheless, the new feature added lies in the capability to incorporate the graphs generated by the eye tracker in the database, as they are important for evaluating the patients' performance. These new pages can be found in Appendix A, Section A.7.

4.2 Advancements in the Developed Eye Tracker

While analysing the data collected from the volunteers who make up the normative base (procedure explained in Chapter 5), the developed eye tracker exhibited some limitations that had a negative impact on the results. Therefore, some changes were made with the aim of maintaining the feasibility of the values.

As previously explained in Section 3.3.1.1, the eye tracker uses the *imfindcircles()* function to locate the iris. The first modification was made in the arguments used, where the 'Method' argument was changed from 'PhaseCode' to 'TwoStage'. The latter computational method is designed to be a more robust approach, using the two-stage circular Hough transform [43]. Furthermore, the sensitivity factor ('Sensitivity' argument) was also increased to a higher value (0,97), allowing for the detection of more circles and thus reducing the previous issue of not detecting any circles. The range of radii of interest was also altered to a narrower interval, between 80% and 120% of the first detected radius, instead of 70% and 130%.

After applying this function, instead of immediately selecting the strongest circle, the code was altered to save the two first circles found, i.e. the strongest two. From these, the one closest to the last saved circle is chosen. However, if the distance between them is greater than 45% of the initial radius dimension, no circle is selected, assuming that the iris is not correctly detected. These values were determined through the analysis of the collected data, relying empirically on the quality of the results obtained.

5

RehabVisual: Contributions to the Normative Base

The present chapter describes all the steps required to establish the normative base, thereby fulfilling the third task proposed to achieve the main objective of this dissertation. Section 5.1 provides details on the sample characterization, while the experimental protocol is addressed in Section 5.2. Section 5.3 introduces the data collection and processing methodologies. Lastly, in Section 5.4, the obtained results are presented and interpreted.

The presented experimental protocol was reviewed and approved by the NOVA School of Science and Technology Ethics Committee.

5.1 Sample Characterization

Two inclusion criteria were defined for the selection of the control group: the participant had to be over 18 years old and could not suffer from any pathology that would affect ocular movements in any way. Additionally, all participants willingly agreed to collaborate in the study and their informed consent (see Appendix B) was obtained before initiating the experimental protocol.

Considering this, data collection was carried out in a sample of 50 volunteers, among whom 38 (76%) were female and 12 (24%) were male. The study population had ages ranging from 19 to 63 years, with an average age of 30,3 years old with a standard deviation of 13,3 years.

5.2 Experimental Protocol

The experimental protocol followed was centered around the visualization of three videos, detailed in Section 5.2.1, which were presented to the participants always in the same order.

The initial step consisted in explaining the study and the protocol to the volunteer, followed by the filling of the informed consent and a questionnaire for sample characterization, detailing the participant's sex and age. Subsequently, the individual viewed the

three videos, with intervals in between, while resting their head on a support, and an external camera recorded their face. The details of the experimental setup can be found in Section 5.2.2.

If the participant were wearing glasses, they would be asked to remove them to prevent interference with the detection of the eyes by the eye tracker. Nevertheless, it was ensured that the stimulus recognition was not affected. Additionally, to ensure the acquired videos met quality standards for analysis, the subject was instructed to follow the stimulus solely with their eyes, keeping their head immobile.

5.2.1 Presented Stimuli

The stimuli created were designed and planned in collaboration with the neurologist who supervised the application of the eye tracker in a clinical context at the HGO (Chapter 6). Each stimulus had the purpose of assessing the presence of specific abnormal eye movements observed in some cases of MS (see Section 2.2.1).

A black circular stimulus with a red center in a white background, as represented on the left side of Figure 5.1, was used, presenting a high contrast and a diameter of approximately 2 cm in the monitor utilized.

Three different videos were created, using the *Microsoft PowerPoint* software, and were presented always in the same order, increasing in complexity of movements. However, all three started with a calibration, where the stimulus covers the maximum and minimum vertical and horizontal values on the screen, according to the scheme detailed on the right side of Figure 5.1

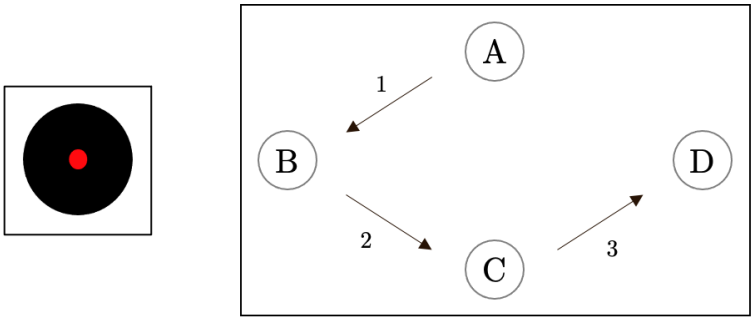

Figure 5.1: Stimulus presented in the three videos (on the left) and calibration path scheme (on the right).

The first video was included with the goal of assessing the presence of nystagmus by examining the ability to gaze steadily at a fixed point. It has a duration of 29 seconds, where, following the calibration, the stimulus moves to the center of the screen and remains static for 10 seconds.

In the second video, with a total duration of 41 seconds, the stimulus performs vertical and horizontal movements after the calibration, following the path schematized in Figure 5.2. Its objective was to assess if the participants could achieve a smooth pursuit of the stimulus, indicating the presence or absence of saccadic intrusions.

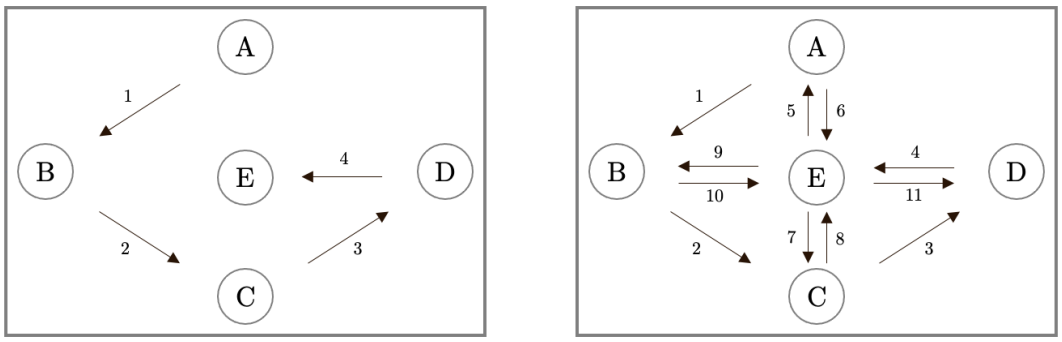

Figure 5.2: Schemes of the first (left) and second (right) stimuli.

The third video is the most complex one, with a total duration of 1 minute and 40 seconds. In the first part, the stimulus follows the path B-D-H-F-E-B-H-I-A-G-C, according with the positions presented in Figure 5.3. Posteriorly, the stimulus disappears and reappears in another area, where it remains static for 3 seconds, describing an intermittent movement following the sequence E-A-I-D-F-B-G-C-H (in accordance with the scheme in Figure 5.3). With this stimulus, the visual field and the visual attention were assessed, since there could be difficulties in locating the stimulus once it reappeared in the screen if the patients' visual field was affected, namely due to optic neuritis.

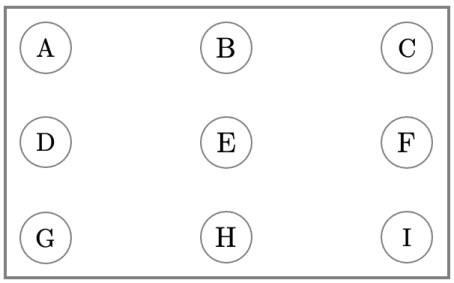

Figure 5.3: Screen locations of the stimulus's path for the third video.

5.2.2 Experimental Setup Description

The experimental setup is shown in Figure 5.4 (on the left) and is constituted by a laptop, a head-immobilizer, an external webcam, and an external screen. The laptop was used to control the RehabVisual platform, while the extra monitor was employed to reduce the visual clutter for the subject, displaying only the visual stimuli intended to be shown. Accordingly, an extra camera was necessary to record the participant's face while they visualized the videos. The support, Figure 5.4 (on the right), was used to immobilize the head, as the subject was instructed to rest their chin and forehead during the acquisition.

The monitor and the camera were positioned at approximately 15 cm in height to align with the eye level, and at a distance of approximately 60 cm from the subject, allowing a comfortable viewing of the stimuli in the participant's field of view.

Figure 5.4: Experimental setup (on the left) and used support for the head and chin (on the right).

The camera used was a Logitech C920 HD PRO Webcam, which offers a 78º field of view and a recording resolution of 1920x1080 pixels (full HD) at 30 frames per second, while the display (22") presented a resolution of 1680x1050 pixels at 60 Hz. The laptop utilized to control the stimuli, as well as record and process the webcam data was an Acer Aspire E15.

5.3 Data Collection and Processing Methodologies

The video containing the stimulus was shown on the external monitor, while the external camera recorded the participant. This recording must include the subject's face with their eyes uncovered, and with their head rested and immobile on the abovementioned support. Furthermore, the lighting conditions should be favorable, allowing for a clear recognition of the eyes without shadows or reflections on the participant's ocular surface. Additionally, this video should be recorded at approximately 30 FPS since recording at a lower frame rate could result in the loss of relevant eye movement information.

Because it was not possible to start recording the video on the external camera and initiate the stimulus video at the same time, the recording was started first, and the stimulus video was initiated later. However, it was possible to finish both at the same time, so it was necessary to manually trim only the initial part of the recording and consider the last frames.

The data processing was executed using *Matlab 2023a* software, using the participant's recording as input. At the beginning of the analysis, a specific tolerance value was defined for each video, depending on factors such as the participant's eye color and the brightness of the image. These values ranged between 0,09 and 0,33.

Subsequently, the metric of interest selected in the previous dissertation (mean Euclidean distance between the stimulus and the gaze positions) was calculated automatically.

5.4 Results Presentation and Discussion

As previously explained, the metric used to quantify stimulus tracking by the participants was the mean Euclidean distance between the stimulus and the gaze positions. In this regard, this value was calculated for the first two videos and for each participant. The third stimulus was analysed separately, hence a normative baseline value was not established. Table 5.1 presents the results obtained using the eye tracker with the improvements described in section 4.2.

Table 5.1: Descriptive Statistics of the mean Euclidean distance between the stimulus and the gaze positions for the first two videos and for both eyes of the control group.

Mean Euclidean Distances (in pixels)	**1st Video**		**2nd Video**	
	Right Eye	Left Eye	Right Eye	Left Eye
Maximum	125	119	137	149
Minimum	49	44	53	61
Mean	84	89	109	116

As can be observed, the distances, in general, are greater for the second video. This result was expected and may be attributed to several reasons. Firstly, it may be related to participant performance. A longer video demands a longer attention span and can lead to visual fatigue. Moreover, a longer time interval also allows for more errors in the eye tracking system. An initial imprecise calibration results in more inaccurate values in a longer video, thus leading to a higher mean Euclidean distance. Furthermore, there is also a higher chance of situations where the eye is not correctly detected, namely due to blinking and momentary changes in brightness, which affected again the eye detection.

Following the same approach of the previous dissertation [13], given that the study population (control group) was able to track the stimulus without difficulties, we can rely on these values to establish a reference threshold for the distinction between successful and unsuccessful stimulus tracking. In other words, considering the maximum values recorded for the distance from the stimulus, it can be deemed that tracking occurred without difficulties for distances lower than 130 pixels in the first video and 150 pixels in the second video (approximate maximum distances).

The following figures depict the graphs generated by the eye tracking system for one of the participants, corresponding to the visualization of the three videos, respectively. The graphs are separated in the two directions, horizontal (top) and vertical (bottom), and measure screen positions in pixels as a function of the video's frame number. The red line translates the location of the stimulus and the green line represents the gaze direction for both eyes, left eye (left side of the figures) and right eye (right side of the figures).

In Figure 5.5, it is simple to identify the static position of the stimulus in the end of the video, explained earlier in Section 5.2.1. The horizontal line in the four graphs represents

the stimulus's unchanged position, as its coordinates remain the same throughout the frame number increment.

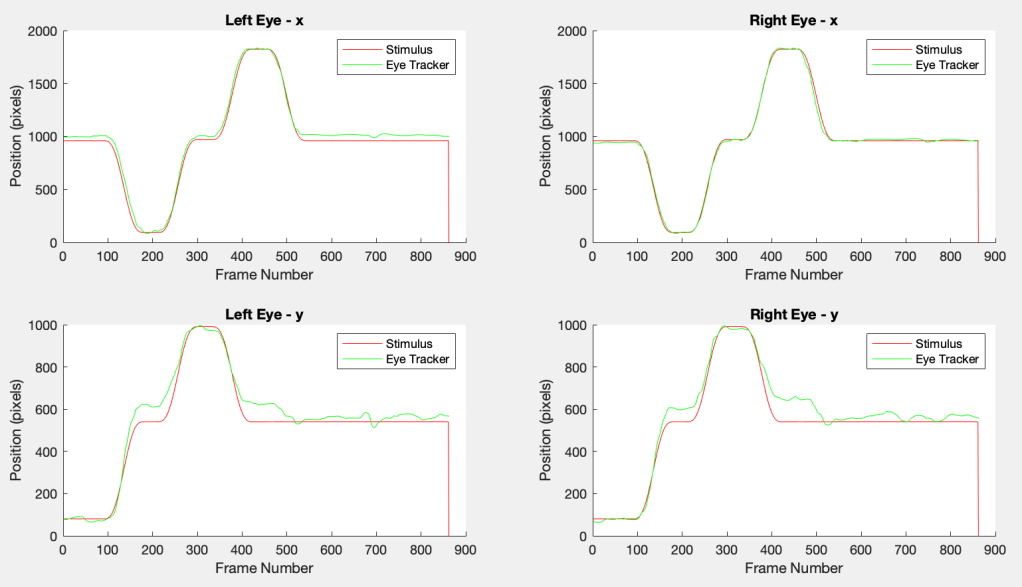

Figure 5.5: Coordinates in pixels of the first stimulus (red) and the gaze (green) of participant 6 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

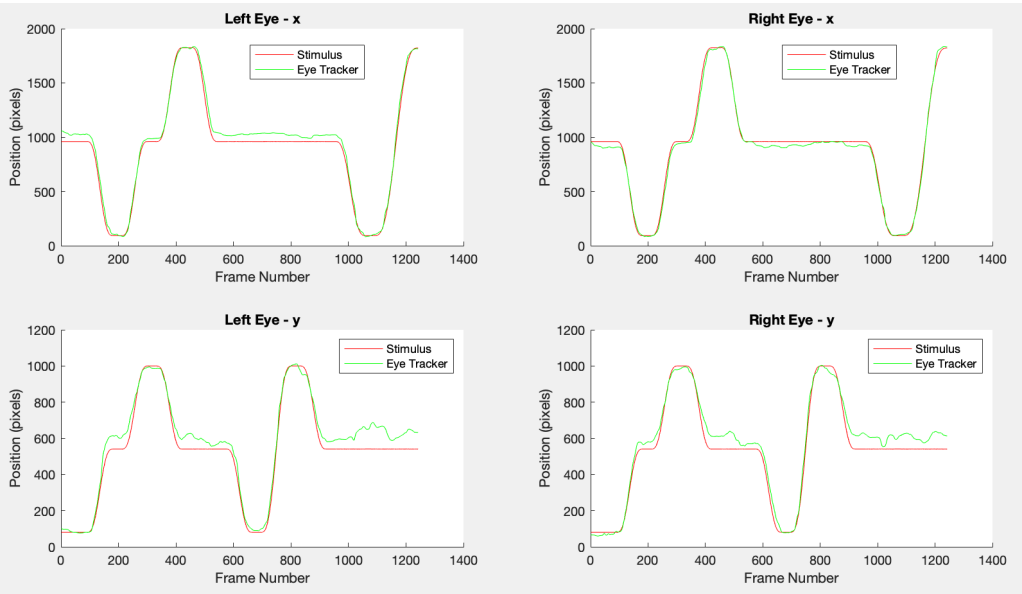

Figure 5.6: Coordinates in pixels of the second stimulus (red) and the gaze (green) of participant 6 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

Accordingly, in Figure 5.6, during the vertical movements, the graphs corresponding to the movement in the x axis (top) show a horizontal line, as the stimulus does not change

its x coordinate. On the other hand, during the horizontal movements, there is no change in the y coordinate of the stimulus, hence the horizontal line in the graphs that correspond to the movements in the vertical direction (bottom).

Lastly, in Figure 5.7, we can observe abrupt changes in the graphs of both directions, corresponding to the intermittent movement of the stimulus. When the stimulus is not present at the screen, its position in pixels is zero.

Analysing the generated graphs, it is evident that the curves representing the participant's gaze are noisier than the curves representing the stimulus. Yet, all the transitions and fixations are correctly identified, and there are no significant delays of anticipations by the participant.

Another outcome worth mentioning is that the vertical coordinate estimation of the eye movement is less accurate than the horizontal coordinate. This phenomenon can be observed in the three figures presented in this chapter, and was also concluded in the previous dissertation [13]. Said discrepancy might be caused by differences in eyelid opening during vertical movements, which do not occur during horizontal ones.

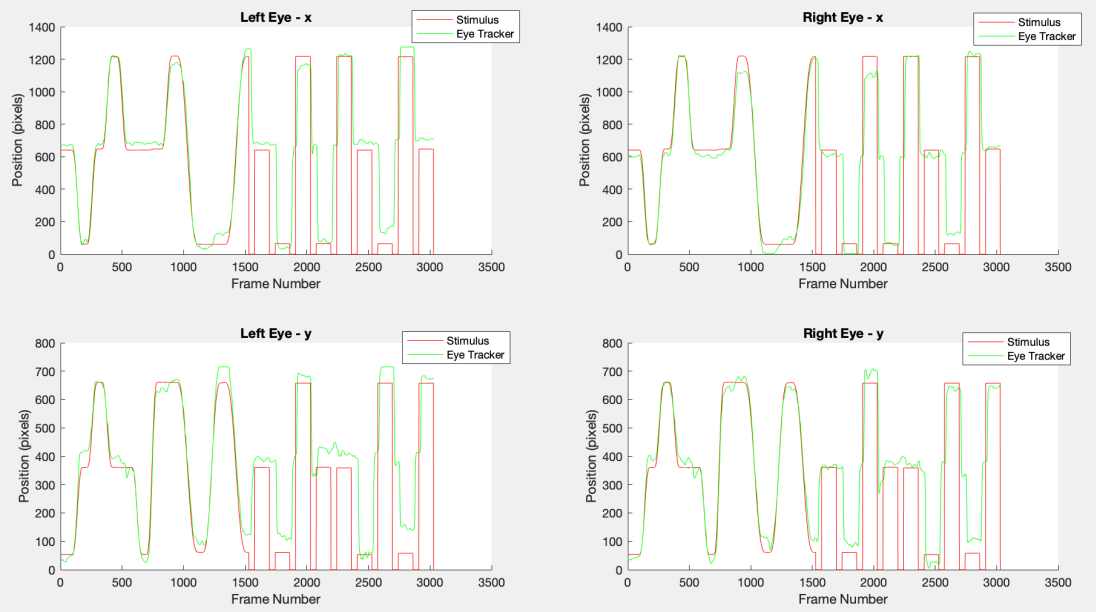

Figure 5.7: Coordinates in pixels of the third stimulus (red) and the gaze (green) of participant 6 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

Regarding the comparison between both eyes, when evaluating the mean values (first video: 84 ± 50 pixels for the right eye and 89 ± 53 pixels for the left eye; second video: 109 ± 84 pixels for the right eye and 116 ± 92 pixels for the left eye), we can conclude that no significant differences were found. However, in some cases, a discrepancy was observed, which may be attributed to external conditions, such as inadequate lighting or reflections on the ocular surface.

6

Eye Tracker Application in Clinical Context

After establishing a normative base from a control group of healthy individuals, the experimental protocol was repeated in a population of individuals diagnosed with MS. This procedure was made in collaboration with HGO, where the patients are monitored. The Ethics Committee of the HGO reviewed the protocol employed and allowed its execution.

The sample characterization and the experimental protocol are discussed in Section 6.1, while the data collection and processing methodologies are covered in Section 6.2. Lastly, Section 6.3 presents the results and their interpretation and discussion.

6.1 Sample Characterization and Experimental Protocol

The sample used for data acquisition in a clinical context was chosen by Dr. Irene Mendes from among her patients followed at HGO. Two inclusion criteria were established: having a diagnosis of MS and having had the last relapse more than 6 months earlier.

Before initializing the experimental protocol, all participants were fully informed about the aim of the study and procedures involved and all provided free informed consent (see Appendix C).

The data acquisition initially involved 28 participants. However, during one of the data collection sessions, an error was detected in the external camera, and the recordings related to that patient were not used. Additionally, two other female patients presented motor disabilities that influenced the acquisition, as they were also excluded from the study. Therefore, the final sample consists of 25 individuals who meet the inclusion criteria. The characterization of the sample, detailed in Table 6.1, also took into account whether the patients had previously received diagnoses of INO, optic neuropathy, or executive alterations, which are common symptoms related to MS (addressed in Section 2.2.1).

The study population consists of 18 females (72%) and 7 males (28%). Their ages range from 19 to 63 ears old (mean 41,8 ± 11,7 years). The most common subtype of MS is RRMS,

accounting for 22 (88%) of the participants, while the other 3 (12%) are diagnosed with SPMS. Regarding the neurological symptoms mentioned, 9 patients (36%) have already been diagnosed with INO, 9 patients (36%) with optic neuropathy and 12 (48%) with executive alterations.

The experimental protocol employed was the same explained in Chapter 5. In accordance, participants were asked to take their glasses off in order to improve the eye's detection by the eye tracker and it was ensured that the stimulus recognition was not affected.

Table 6.1: Experimental group characterization.

Patient	Age	Sex	Pathology	Internuclear Ophthalmoplegia	Optic Neuropathy	Executive Alterations	Acquisition Date
1	47	M	SPMS	Y	Y	Y	08/08/2023
2	46	F	SPMS	Y	Y	Y	09/08/2023
3	36	F	RRMS	Y	Y	U	10/08/2023
4	30	F	RRMS	N	Y	U	11/08/2023
5	42	F	RRMS	Y	N	Y	11/08/2023
6	41	F	RRMS	N	N	U	11/08/2023
7	60	F	RRMS	N	Y	Y	11/08/2023
8	28	F	RRMS	N	N	U	16/08/2023
9	25	F	RRMS	N	N	Y	16/08/2023
10	39	M	RRMS	N	Y	Y	18/08/2023
11	46	F	RRMS	Y	N	Y	18/08/2023
12	19	M	RRMS	N	N	U	18/08/2023
13	38	M	RRMS	Y	Y	U	18/08/2023
14	63	F	RRMS	Y	N	U	21/08/2023
15	28	F	RRMS	N	N	Y	21/08/2023
16	59	M	RRMS	N	N	Y	22/08/2023
17	33	F	RRMS	N	N	Y	23/08/2023
18	47	F	RRMS	N	N	U	24/08/2023
19	49	F	RRMS	N	N	U	25/08/2023
20	51	M	SPMS	Y	Y	Y	28/08/2023
21	50	F	RRMS	N	N	N	29/08/2023
22	48	F	RRMS	N	N	N	31/08/2023
23	24	F	RRMS	N	N	Y	01/09/2023
24	50	M	RRMS	N	N	N	01/09/2023
25	45	F	RRMS	N	N	N	01/09/2023

M – male; F – female; SPMS – Secondary Progressive Multiple Sclerosis; RRMS – Relapsing-Remitting Multiple Sclerosis; Y – yes; N – no; U – unknown.

6.2 Data Collection and Processing Methodologies

The methodology employed for data collection and analysis in patients was consistent with that used for the normative base dataset of healthy volunteers. However, concerning the data collection procedure, some patients were unable to follow the instructions, resulting

in noticeable head movements and, therefore, the reference point did not remain relatively stable, as was ideal. This divergence from the healthy participants might be attributed to the presence of executive impairments in patients, affecting, for example, their ability to sustain focus and follow instructions.

Additionally, the advancements presented in Section 4.2 were implemented empirically using records from individuals that did not present visual dysfunctions. Nevertheless, when applying the eye tracker to patient recordings, it was observed that reliable results were not consistently attainable due to abnormal eye movements. In certain specific cases, the previous code was used. Consequently, the metric employed may not consistently reflect the individual's ability to track the stimulus, but it may reflect difficulties in eye recognition by the eye tracker.

6.3 Results Presentation and Discussion

Similar to the analysis made within the control group, Table 6.2 presents the descriptive statistics of the mean Euclidean distance between the stimulus and the gaze positions for the first two videos.

Table 6.2: Descriptive Statistics of the mean Euclidean distance between the stimulus and the gaze positions for the first two videos and for both eyes of the experimental group.

Mean Euclidean Distances (in pixels)	**1st Video**		**2nd Video**	
	Right Eye	Left Eye	Right Eye	Left Eye
Maximum	336	346	367	457
Minimum	58	48	81	72
Mean	113	128	159	171

Upon initial examination, we can deduce that, on average, the values are higher for this group of individuals than for the group studied in the previous chapter. This observation was expected since the experimental group includes patients with diagnosed visual impairments.

Furthermore, and in accordance with what was observed in Chapter 5 (Section 5.4), the values for the second video are higher than those for the first video. The given justification for this phenomenon remains applicable in this context, underscoring the significance of factors associated with the performance of the patients, particularly due to the potential presence of executive impairments, as discussed in Section 6.2.

The following sections analyse the results of the three stimuli individually, presenting noteworthy findings.

6.3.1 First Stimulus

The results of the mean Euclidean distance between the gaze and the stimulus positions for each patient are presented in Table 6.3, along with a column referring to the patient's performance, based on the video and the graphs obtained through the eye tracker.

Table 6.3: Results obtained from the eye tracking system for the first video.

Patient	Performance in following the stimulus	MED – Right Eye (pixels)	SD – Right Eye (pixels)	MED – Left Eye (pixels)	SD – Left Eye (pixels)
1	Discontinuous movements in H-F and F-E	106	106	168	155
2	Blinked frequently, which interfered with the eye recognition	132	70	140	81
3	Slight rapid eye oscillations (video)	58	29	74	35
4	Discontinuous movements in B-D, D-H and H-F	139	119	197	126
5	Anticipated the movement in H-F	124	129	120	59
6	Followed the stimulus without difficulty	78	42	57	51
7	Discontinuous movements in D-H, H-F and F-E	134	125	105	114
8	Followed the stimulus without difficulty	61	34	49	40
9	Discontinuous movements in F-E	67	35	103	49
10	Discontinuous movements in H-F	97	54	83	35
11	Anticipated the movement in H-F and F-E	120	70	133	69
12	Followed the stimulus without difficulty	72	40	75	57
13	Discontinuous movements in H-F and F-E	108	78	131	73
14	Followed the stimulus without difficulty, but the luminosity interfered with the eye recognition	204	132	156	156
15	Discontinuous movements throughout the entire path	159	96	134	113
16	Followed the stimulus with their head	336	211	346	250
17	Followed the stimulus without difficulty	84	42	89	49
18	Followed the stimulus without difficulty	100	77	104	85
19	Discontinuous movements throughout the entire path	98	71	113	58
20	Followed the stimulus with their head	77	35	128	80
21	Followed the stimulus without difficulty	96	65	88	94
22	Followed the stimulus without difficulty	113	46	48	44
23	Discontinuous movements in D-H and H-F	87	57	96	63
24	Followed the stimulus without difficulty	96	299	114	30
25	Discontinuous movements in D-H and H-F	83	54	332	209

MED – Mean Euclidean Distance between the stimulus and the gaze positions; SD – Standard Deviation.

The aim of the first video was to assess the presence of nystagmus. However, it was not possible to draw any conclusions regarding this visual alteration. This could be due to a low accuracy of the eye tracker or a low incidence or intensity of nystagmus in the patients studied.

On the other hand, it was possible to confirm the presence of abnormal eye movements

in some cases, confirming the diagnosis of visuomotor alterations, which can be observed in the following figures.

Starting with the values that stood out for being significantly high, it is worth mentioning three patients: 14, 16, and 25. Patient 14 displayed elevated numbers for the metric of interest due to unfavorable lighting conditions, leading to increasing difficulty in identifying the gaze position by the eye tracker. On the other hand, patient 16 moved his head excessively, which exacerbated the results due to poor and incorrect calibration. Lastly, patient 25 exhibited a significant discrepancy between the two eyes, as the left eye was more closed than the right, compromising its detection in some frames.

Associating the results obtained with the sample characterization presented in Section 6.1 (Table 6.1), it is possible to see the relation between the absence of diagnosed visual impairments and the performance of the patients. All patients who had no difficulty in following the stimulus (patients 6, 8, 12, 17, 18, 21, 22, and 24) never had a diagnosis of INO nor optic neuropathy, resulting in mean Euclidean distances between the gaze and the stimulus positions within the reference value established through the normative base (below 130 pixels), as expected.

On the other hand, if we analyse the graphs with values exceeding 130 pixels, we encounter abnormal movements, as seen in the case of patient 15, depicted in Figure 6.1.

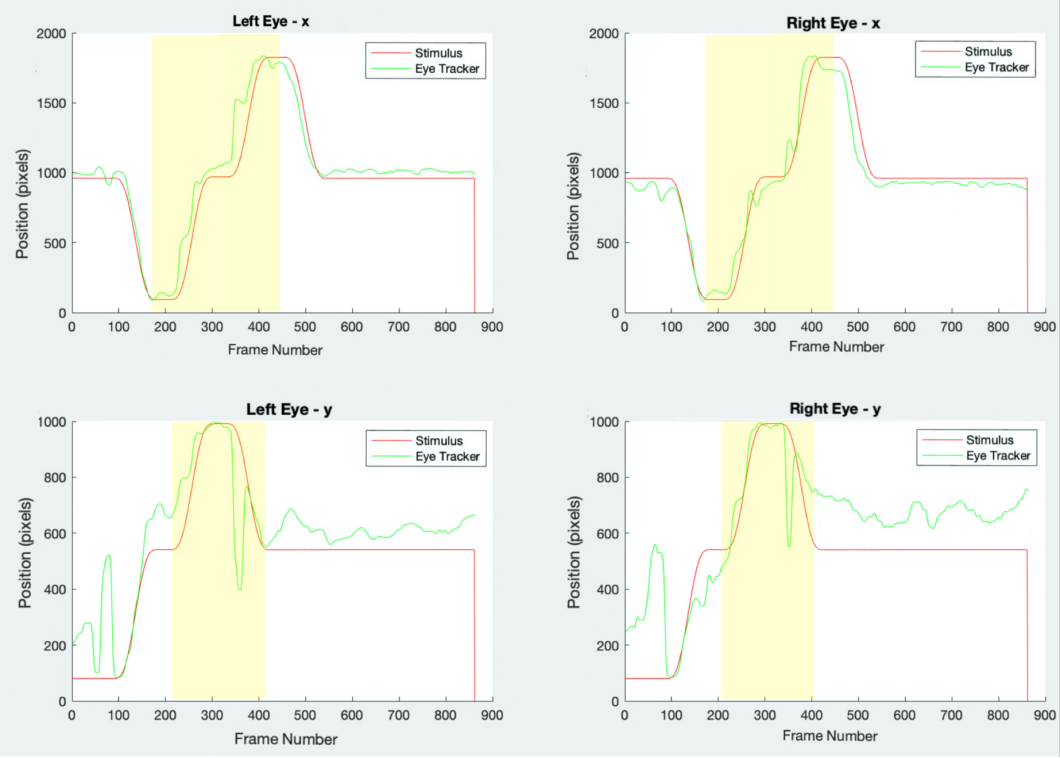

Figure 6.1: Coordinates in pixels of the first stimulus (red) and the gaze (green) of patient 15 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

As can be seen in Section 6.1, patient 15 has no diagnosed visual alterations, so it was expected that the graphs would show a smooth pursuit of the stimulus. However, when analysing these graphs and the video, it is clear that the patient did not follow the stimulus's continuous movement. This is particularly evident in the highlighted areas of Figure 6.1, where the line is irregular. These abnormal oscillations may indicate the presence of saccadic intrusions, which is one common oculomotor disorder that occurs in MS patients (see Section 2.2.1).

Furthermore, it is important to note that, as can be seen in Table 6.3, visual alterations, such as discontinuous tracking of the stimulus or anticipation of movement, were observed in cases where the metric value falls below the threshold. When analysing the graphs corresponding to patient 19, presented in Figure 6.2, it is noticeable that the patient was not able to follow the continuous movement of the stimulus, presenting peaks at frames 355 and 495, approximately.

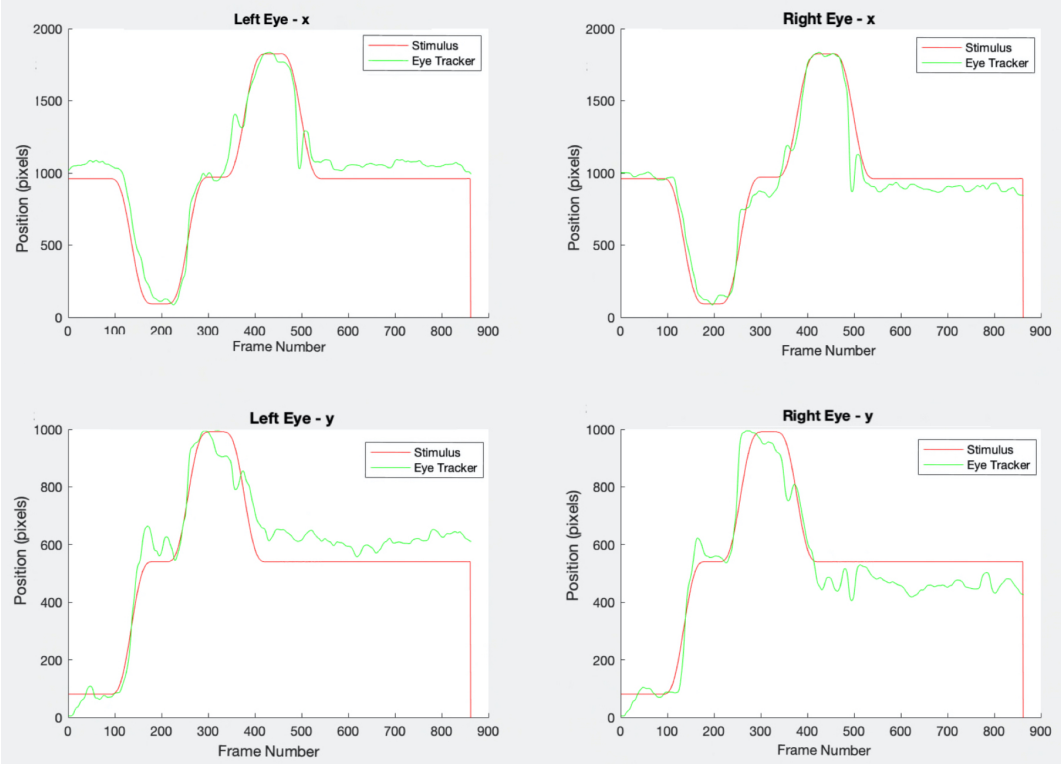

Figure 6.2: Coordinates in pixels of the first stimulus (red) and the gaze (green) of patient 19 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

Since the chosen metric (mean Euclidean distance between the gaze and the stimulus positions) was not useful for indicating the presence of visuomotor alterations in this case, a new option was explored: the length of the graph line. In this sense, the line length of the x graphs of both eyes was calculated, since the eye tracker is more precise in this axis.

From the initial frame to frame 543, which marks the end of the stimulus movement,

the stimulus covers a distance of approximately 3713 pixels in the x-axis. For the patient 19, it was observed that the graph line between frames 1 and 543 has a length of approximately 4306 pixels for the left eye and 5078 pixels for the right eye, showing a significant difference in both eyes comparing with the theoretical value. Therefore, it can be noted that when there are visible changes in the graphs that are not reflected in the mean Euclidean distance between the stimulus and gaze positions, the length of the graph line may be a good metric for analysis.

6.3.2 Second Stimulus

The second video consists of both vertical and horizontal movements, and its purpose was to evaluate the participants' ability to track continuous motion. Although the first video had already provided some information about these movements, it was possible to observe visuomotor alterations with this video as well, as expected. Table 6.4 presents the mean Euclidean distances between the stimulus and the gaze positions calculated for each patient. The second column describes the patient's performance based on the video and the respective graphs.

In accordance with the results from the analysis of the first stimulus, patients 6, 8, 12, 17, 18, 21, 22 and 24 did not demonstrate difficulties while following the stimulus, resulting in mean Euclidean distances below the threshold of 150 pixels.

Considering the results above the threshold, we can see that they indicate the presence of visual alterations. Patient 5 had already been diagnosed with INO and executive changes, so it would be expected to find evidence of abnormal eye movements. The graphs for this patient corresponding to the visualization of the second video are presented in Figure 6.3. There is a peak at approximately frame 380, leading to a steeper slope of the graph line representing the gaze position (green) compared to the slope of the line representing the stimulus position (red). This indicates that the patient anticipated the movement, resulting in a discontinuous motion and, therefore, an inability to properly follow the stimulus. The same situation repeats in the E-D path, where it is clear that the graph line is not linear, also representing discontinuous tracking.

Similarly to what occurred in the analysis of the first stimulus, changes in eye movements were observed even for values below the threshold. Figure 6.4 displays the graphs of patient 23.

It is readily observable that patient 23 was not able to track the stimulus smoothly. This conclusion becomes evident through the "jumps" that the green line exhibits (approximately at frames 240, 375, and 1005 on the x-axis), as well as through a higher slope of the gaze position (green) compared to the stimulus (red), indicating an anticipatory movement. In this sense, the line length of the x graphs of both eyes was calculated, in accordance with the analysis of the previous stimulus.

Table 6.4: Results obtained from the eye tracking system for the second video.

Patient	Performance in following the stimulus	MED – Right Eye (pixels)	SD – Right Eye (pixels)	MED – Left Eye (pixels)	SD – Left Eye (pixels)
1	Discontinuous movements throughout the entire path	111	100	165	99
2	Blinked frequently, which interfered with the eye recognition	165	138	185	157
3	Slight rapid eye oscillations (video)	93	75	95	79
4	Discontinuous movements in B-D and H-F	116	86	132	80
5	Discontinuous movements throughout the entire path	153	161	157	144
6	Followed the stimulus without difficulty	112	66	102	73
7	Discontinuous movements in B-D-H-I and B-H	277	191	207	161
8	Followed the stimulus without difficulty	81	46	72	57
9	Discontinuous movements in B-D, H-F and E-F	142	147	170	299
10	Discontinuous movements in H-F and E-D	156	163	256	307
11	Discontinuous movements throughout the entire path	281	370	125	123
12	Followed the stimulus without difficulty	133	88	128	101
13	Discontinuous movements in H-F and E-D	167	126	146	98
14	Discontinuous vertical movements	267	233	394	273
15	Discontinuous movements throughout the entire path	132	92	118	109
16	Followed the stimulus with their head	187	141	183	149
17	Followed the stimulus without difficulty	112	99	95	102
18	Followed the stimulus without difficulty	118	73	120	89
19	Discontinuous movements throughout the entire path	166	170	181	159
20	Followed the stimulus with their head	367	297	457	322
21	Followed the stimulus without difficulty	139	99	135	87
22	Followed the stimulus without difficulty	121	71	107	72
23	Discontinuous movements throughout the entire path	121	121	143	135
24	Followed the stimulus without difficulty	133	128	113	142
25	Discontinuous movements in D-H-F and E-D	129	115	264	369

MED – Mean Euclidean Distance between the stimulus and the gaze positions; SD – Standard Deviation.

For this stimulus, it was considered relevant to include the entire length of the video (1243 frames), which translates into a distance of approximately 9028 pixels covered by the stimulus in the x-axis. The values calculated for the length of the green line, representing the patient's gaze, are 9914 pixels for the right eye and 10210 pixels for the left eye, both in the horizontal axis. As expected, these lengths are considerably higher when compared with the length of the stimulus's path, indicating that there may be undesirable eye movements.

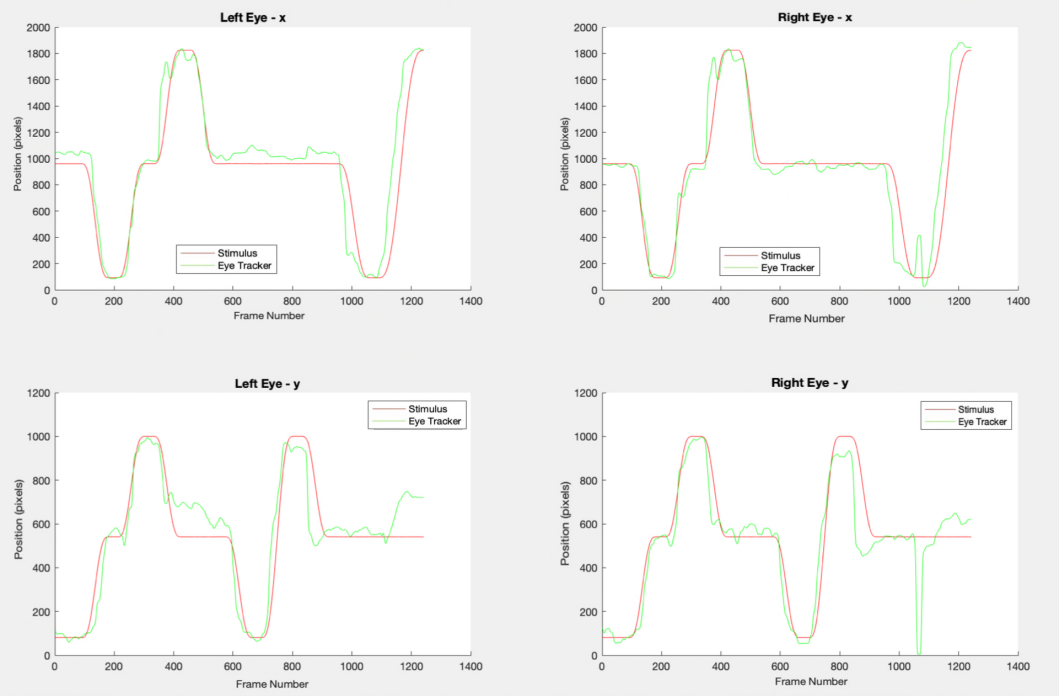

Figure 6.3: Coordinates in pixels of the second stimulus (red) and the gaze (green) of patient 5 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

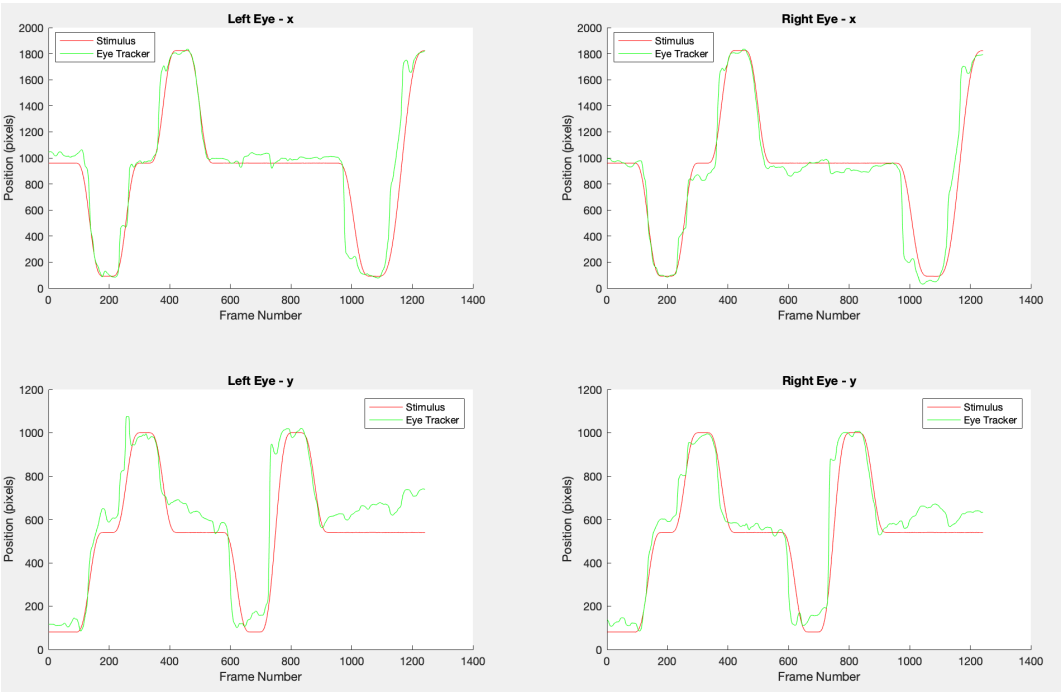

Figure 6.4: Coordinates in pixels of the second stimulus (red) and the gaze (green) of patient 23 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

6.3.3 Third Stimulus

As previously mentioned during the presentation of the stimuli in Section 5.2.1, the objective of this video was to assess the patients' field of vision as well as their visual attention. This stimulus was applied during the course of the previous thesis [13] to post-Stroke patients exhibiting visuomotor alterations. In that context, favorable results were obtained, with a notable difficulty observed in locating the stimulus when it was positioned in an affected area of the visual field, which was identified with the eye tracking system. This phenomenon was associated with the presence of neglect (neurological disorder associated with loss of awareness of one side of the visual field due to brain damage) as a symptom in this type of patients, being a consequence that frequently follows a Stroke.

In MS, the visual field may be affected due to the inflammation of the optic nerve. However, at the time of the acquisition, none of the patients was in this situation, so none of them exhibited a loss of the visual field, and therefore, no new results were expected in comparison to the outcomes obtained with the two previous stimuli. This hypothesis was corroborated, as the patients did not encounter difficulties that had not already been identified with the initial videos, nor did they experience difficulties in locating the stimulus during intermittent movement.

Figure 6.5 presents the graphs obtained through the eye tracker for patient 15, who exhibited visuomotor alterations at the first two stimuli.

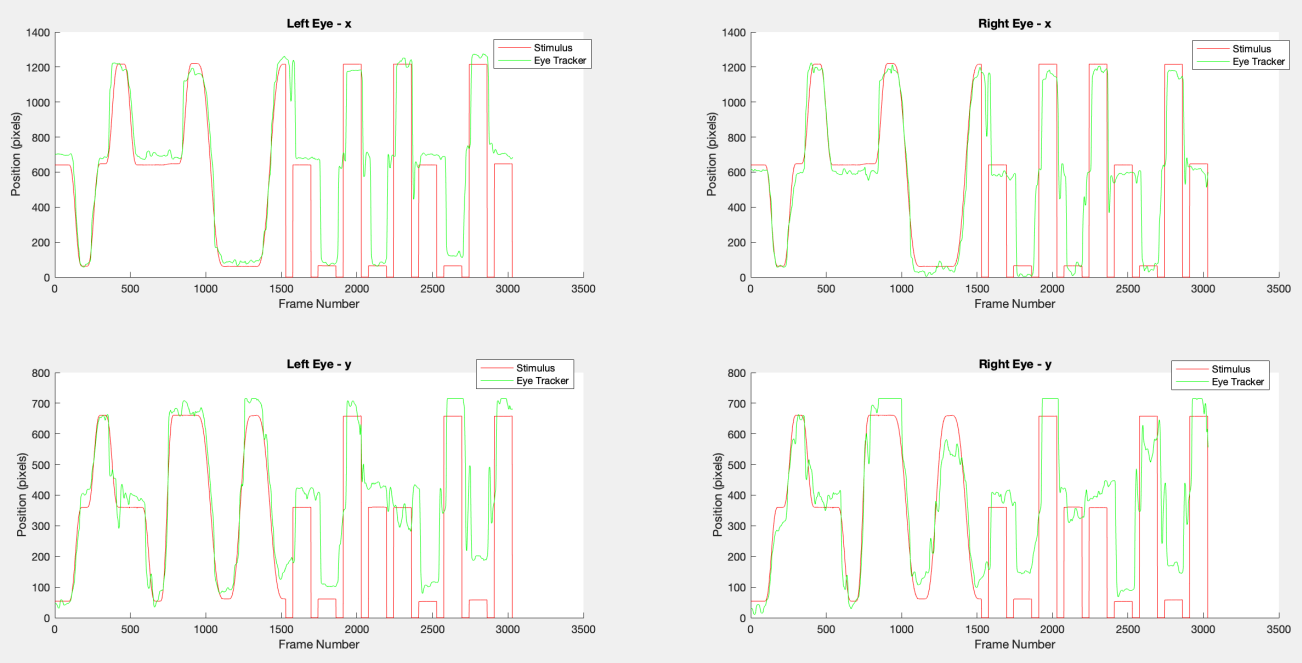

Figure 6.5: Coordinates in pixels of the third stimulus (red) and the gaze (green) of patient 15 as a function of the frame number. On the left side, the x positions (top) and y positions (bottom) are presented for the left eye, and on the right side, the x positions (top) and y positions (bottom) are presented for the right eye.

It is clear that patient 15 exhibits alterations during the first part of the video, where the stimulus follows a continuous movement. However, this result was already observed during the first video (see section 6.3.1). In this sense, and in accordance with the abovementioned, the third stimulus did not provide us with new information about the disabilities present in MS patients, as none of the individuals of the experimental group showed difficulties in locating the stimulus during the intermittent movement.

6.3.4 Final Discussion

The use of the eye tracker in the current clinical context has proven to be highly relevant, considering the results presented in the previous sections. However, it is evident that the mean Euclidean distance between the gaze and the stimulus positions metric is not sufficient to determine if an individual has or has not difficulties in following the stimulus, as it was proposed. This can be concluded based on the cases mentioned in Section 6.3.1 (patient 19, Figure 6.2) and Section 6.3.2 (patient 23, Figure 6.4). In this sense, a correlation was not found between the clinical data and the results obtained that encompasses all the patients. This hypothesis was only adequate for patients who are not diagnosed with visual alterations, which presented mean Euclidean distances below the established threshold.

To address this gap, the graphs were also taken into consideration and a new metric was explored. For these cases, the length of the graph line representing the gaze position on the x-axis was calculated and compared to the one representing the stimulus position on the same axis. This metric demonstrated that even if the mean Euclidean distance between the gaze and the stimulus positions falls within the established values, the length of the graph line will be considerably higher if there are disruptions in eye movements.

The thresholds of 130 pixels and 150 pixels for the first and second videos respectively were chosen based on the values obtained from the normative base participants (see Chapter 5). However, these values depend on various factors that may have negatively influenced the discrepancy between both samples. These factors may be related to the volunteers themselves, namely their ability to follow the stimulus only with the eyes or even the physiology of their eyes. On the other hand, it may be related to environmental conditions, as the acquisition for the two groups occurred in different locations, leading to varying lighting conditions and, consequently, different performances of the eye tracking system. These factors contribute to the inaccuracy of the mean Euclidean distance in detailing if the patients were able to follow the stimulus with or without difficulties.

Through the graphs generated by the eye tracker, it is possible to record the eye movements of patients and quantify them, preventing potential impairments from being overlooked. Furthermore, by implementing the eye tracker into the RehabVisual platform, it will be possible to extend the analysis to multiple stimuli included in the platform, which could serve as a valuable tool for assessing patients throughout therapy sessions and to assist in the design of rehabilitation plans.

7

Conclusions and Future Work

This chapter concludes this dissertation by reviewing its main findings and contributions to biomedical research. Additionally, a reflection on this work's limitations is presented, as well suggestions for improvement as perspectives for future work.

7.1 Conclusions

In the present dissertation, the potential of the RehabVisual platform for patients diagnosed with Multiple Sclerosis (MS) has been demonstrated. Initially developed to assist healthcare professionals in visuomotor rehabilitation for children with developmental delay and applied to post-Stroke patients, this tool was adapted to include MS patients. Beyond its objective to serve as an auxiliary tool for diagnosing visuomotor impairments, it is also intended to aid in the rehabilitation area, allowing for standardized yet individualized monitoring of patients' progress throughout therapeutic interventions.

In this regard, adjustments were first made to the platform, considering the feedback from the usability test conducted after the platform's application with post-Stroke patients in the previous dissertation, as well as the experience of Dr. Irene Mendes, a highly experienced neurologist in the MS area at Hospital Garcia de Orta (HGO). Taking into account the visual dysfunctions commonly found in MS patients, the visual stimuli that were going to be shown during the data acquisition were also selected at this stage.

Subsequently, the experimental procedure was applied to a group of 50 individuals without associated pathology to build a normative base. This process allowed for the establishment of a reference value for the previously chosen and validated metric that assesses if an individual was able to follow the stimulus without difficulties, the mean Euclidean distance between the gaze and stimulus positions. During this process, some limitations in the eye tracking system were identified and attempts were made to address them by making certain modifications to the Matlab code in order to achieve more reliable results.

Following this, the protocol was repeated in a population of 25 MS patients. The results obtained made it possible to identify and confirm the expected visuomotor alterations. However, when the values were compared with the ones obtained from the control group,

they were not a good predictor for the presence of visual impairments. In this sense, another metric was explored, the length of the graph line representing gaze position as a function of the frame number, yielding favorable results allied with the mean Euclidean distance.

In conclusion, it can be stated that this dissertation successfully achieved its proposed objective. Enhanced by the eye tracker, RehabVisual emerges as an important and innovative tool for the future of clinical practice in visuomotor rehabilitation, aiding in both diagnosis and treatment of these skills. Nevertheless, there are some limitations and room for improvements in the developed system, which will be addressed in the following section.

7.2 Limitations and Future Work

In the previous dissertation [13], improvements and new implementations were gathered through a usability test conducted with the team from the Physical Medicine and Rehabilitation Service at the HGO. During that test, the application of the RehabVisual platform on other neurological conditions, particularly on patients with MS, was suggested. This led to the present dissertation, which yielded favorable results. Accordingly, conducting another usability test to gather feedback from healthcare professionals and additional suggestions for improvement would be beneficial.

As seen in Chapter 6, there is a limitation related to the metric used (mean Euclidean distance between gaze and stimulus positions), as several patients exhibited visual alterations while still falling within the established normal values based on the normative base. This result may be attributed to environmental conditions, so it would be important in the future to ensure that both the control and the experimental groups are subjected to similar conditions. Furthermore, improving the performance of the eye tracker is essential since the alterations made did not yield satisfactory results for all participants. An interesting suggestion would be to visualize the results of the two codes used in an application, utilizing a software like Matlab's GUIDE, to be able to choose the one that best suits the situation.

As mentioned in the characterization of the experimental group's sample (Section 6.1), two patients were not included in the analysis because they were unable to properly support their heads on the designated support. Therefore, the experimental setup may be unsuitable for individuals with more severe motor impairments, and this aspect needs to be taken into consideration when the study population may present such conditions.

In the future, the goal is for RehabVisual to be used in the rehabilitation of visuomotor skills, providing an objective and standardized assessment of the patients' progress, as well as offering individualized and effective treatment tailored to the specific needs of each individual. In this sense, it is crucial to continue investing in this platform and collaborate closely with healthcare professionals to further innovate and enhance its capabilities.

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A

Manual de Utilizador da Plataforma RehabVisual: Esclerose Múltipla

This appendix contains a Portuguese user guide for the RehabVisual platform applied to patients with Multiple Sclerosis, considering all the menus and functionalities of interest.

A.1 Página Principal

A Figura A.1 retrata a página principal da plataforma, antes do início da sessão, onde é possível aceder a informações relevantes acerca do presente projeto.

Figure A.1: Página principal da plataforma, antes do *login*.

Os botões "Competências Visuomotoras" e "O Projeto", disponíveis no canto superior direito, levam, respetivamente, a uma explicação das competências visuomotoras (Figura A.2) e à informação geral sobre o projeto e a equipa que o desenvolveu (Figura A.3). Na secção "Contactos", é possível encontrar toda a informação de contacto, bem como enviar uma mensagem instantânea, através do email, para a equipa (Figura A.4).

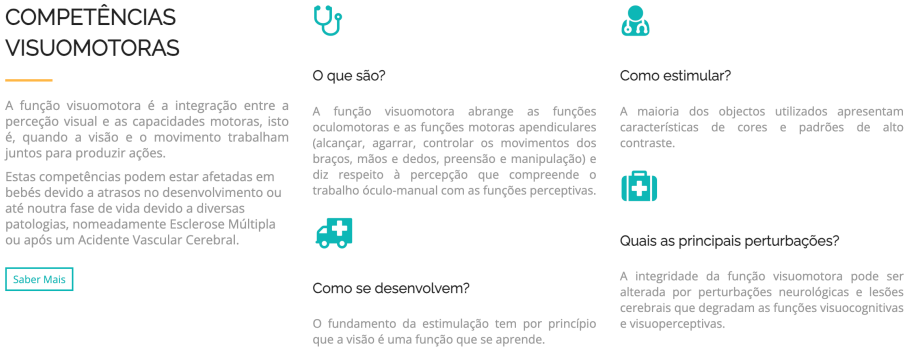

Figure A.2: Secção informativa sobre as Competências Visuomotoras.

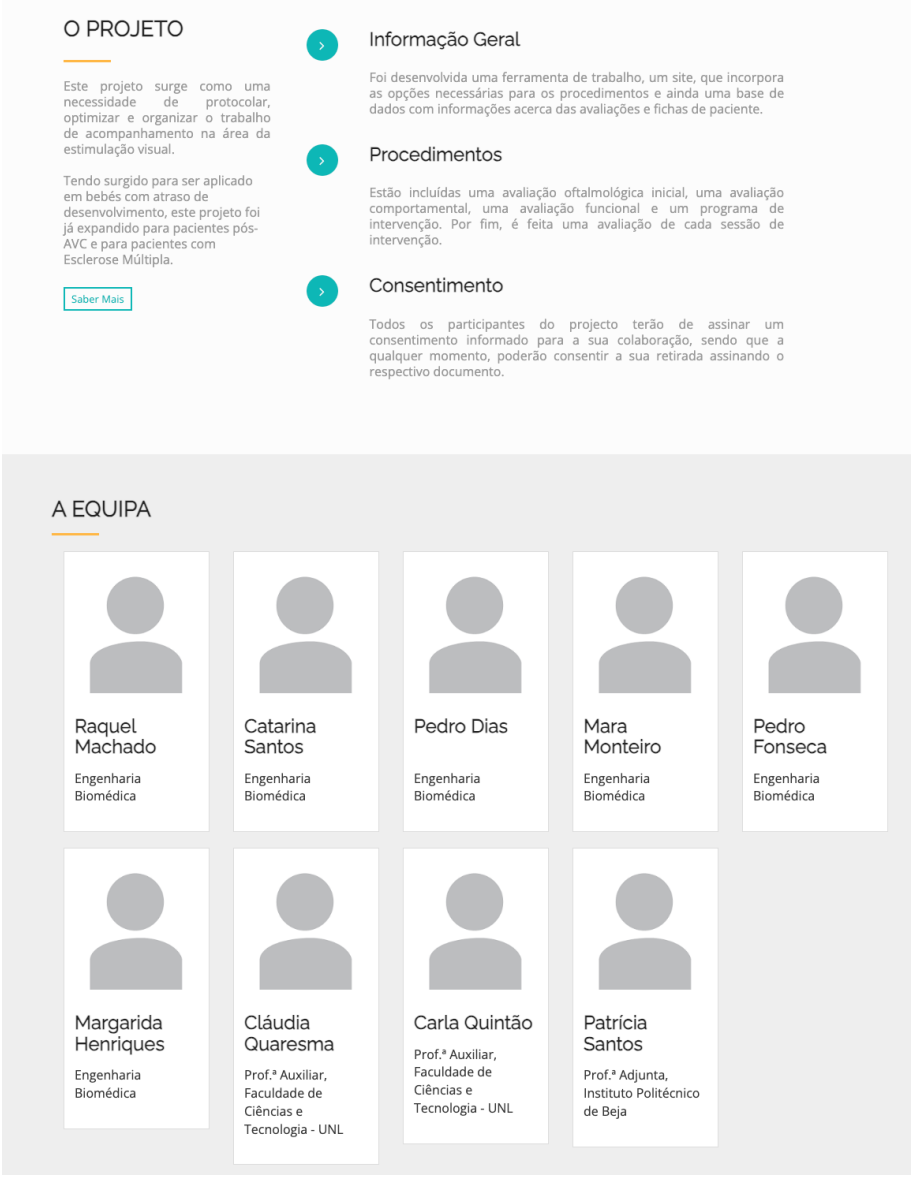

Figure A.3: Secção informativa sobre O Projeto.

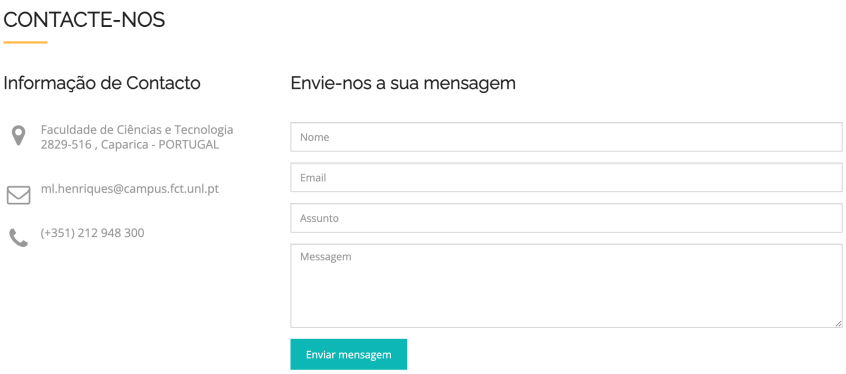

Figure A.4: Formulário de contacto disponível na página principal da plataforma.

Através do botão "Entrar" (Figura A.1), é possível iniciar a sessão na plataforma introduzindo os respetivos dados de acesso - nome de utilizador e palavra-passe - na janela *pop-up* (ver Figura A.5). Caso o utilizador esteja registado, o *login* é efetuado com sucesso e o site redireciona-o para a página seguinte. Se as credenciais de acesso estiverem incorretas, aparecerá uma mensagem de erro, tal como se pode ver na Figura A.6.

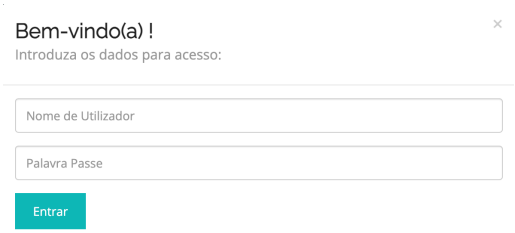

Figure A.5: Janela *pop-up* para iniciar sessão.

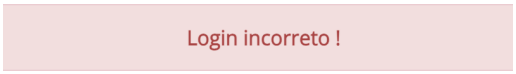

Figure A.6: Mensagem de erro após falha no início da sessão.

A.2 Página Inicial

Após o início de sessão, o utilizador é redirecionado para a página inicial da plataforma, ilustrada na Figura A.7. No centro estão apresentados os menus informativos "Gerir Utilizadores", "Gerir Fichas", "Gerir Avaliações" e "Plano de Intervenção", cujo objetivo é apenas auxiliar os utilizadores na escolha do menu que procuram.

No lado esquerdo encontra-se a barra de menus, através da qual é possível aceder às diferentes funcionalidades. As opções disponíveis variam com o tipo de utilizador, consoante explicado na Secção A.3.

No canto superior direito estão disponíveis as ferramentas do utilizador (Figura A.9, sendo possível consultar o perfil do utilizador, aceder às definições do perfil e terminar sessão, voltando à Página Principal detalhada na Secção A.1. Na segunda opção é possível editar as informações do perfil, nomeadamente o nome, o contacto telefónico, o email e a palavra-passe, como apresentado na Figura A.9, e na primeira opção é possível consultar estas informações.

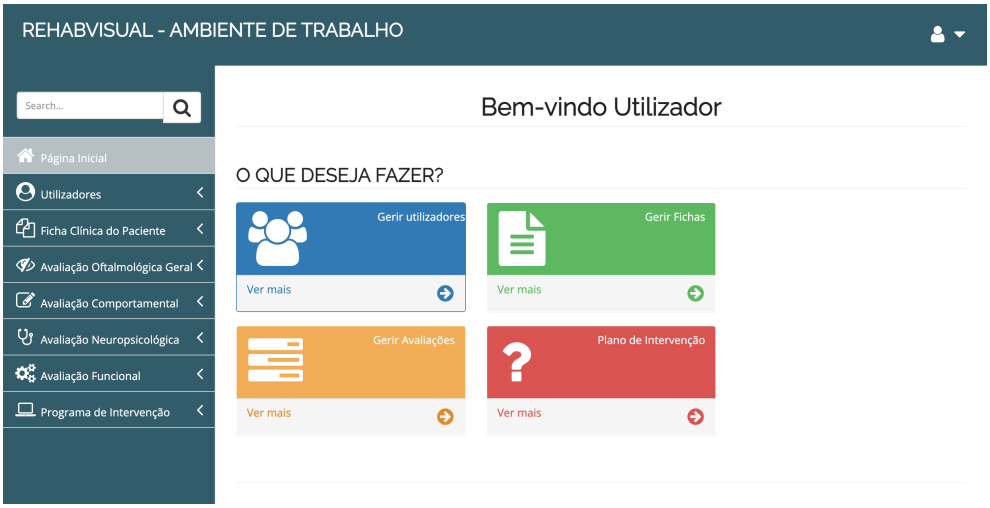

Figure A.7: Página inicial do ambiente de trabalho da plataforma RehabVisual.

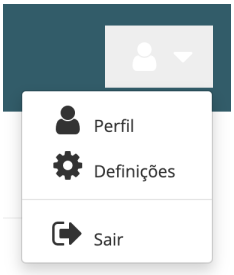

Figure A.8: Ferramentas do utilizador.

A.3 Utilizadores

A plataforma RehabVisual permite cinco tipos de utilizadores diferentes: administrador, médico, técnico, terapeuta ocupacional e prestador de cuidados. Estes utilizadores são diferenciados pelas suas permissões distintas, que podem ser consultadas na Tabela A.1.

No menu "Utilizadores", acessível através da barra de menus, é possível gerir os utilizadores registados na plataforma, permitindo-se adicionar, consultar e eliminar, sempre dependendo das restrições mencionadas acima.

Para adicionar um novo utilizador, é necessário selecionar o separador "Utilizadores - Adicionar" e preencher o formulário ilustrado na Figura A.10, selecionando "Registar" no final. Apenas um utilizador já registado poderá registar novos utilizadores. Para além disso, um administrador poderá adicionar qualquer tipo de utilizador, enquanto os restantes apenas poderão adicionar prestadores de cuidados.

No menu "Utilizadores - Consultar" (Figura A.11) encontra-se uma tabela com os dados dos utilizadores já registados e, consoante as permissões já referidas, existem as opções de editar (botão "Editar") ou eliminar (botão "Apagar") os dados. Neste separador é também possível aceder diretamente à página de registo de utilizadores através do botão "Adicionar Utilizador".

Esta tabela, bem como todas as outras que se encontram na plataforma, permite a

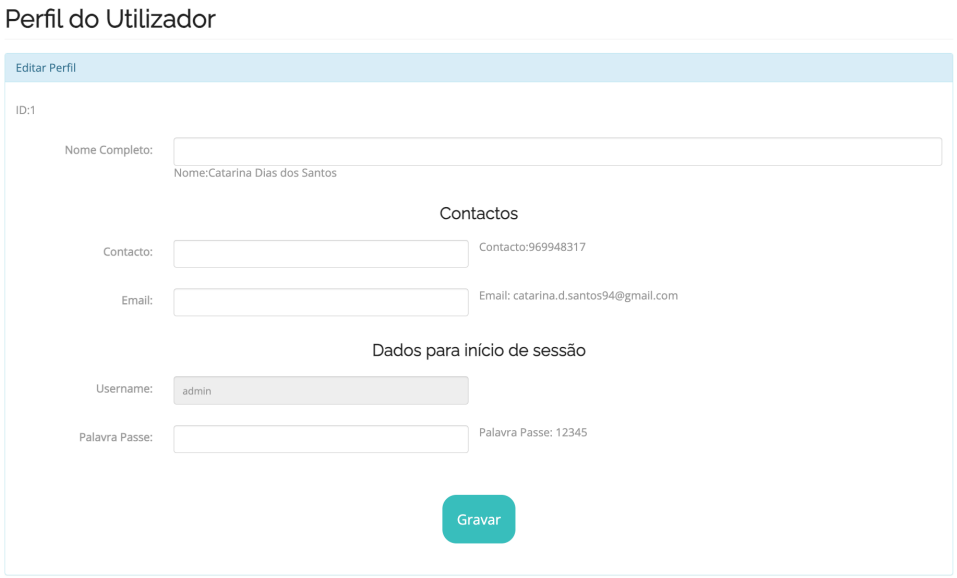

Figure A.9: Página das definições do perfil de utilizador.

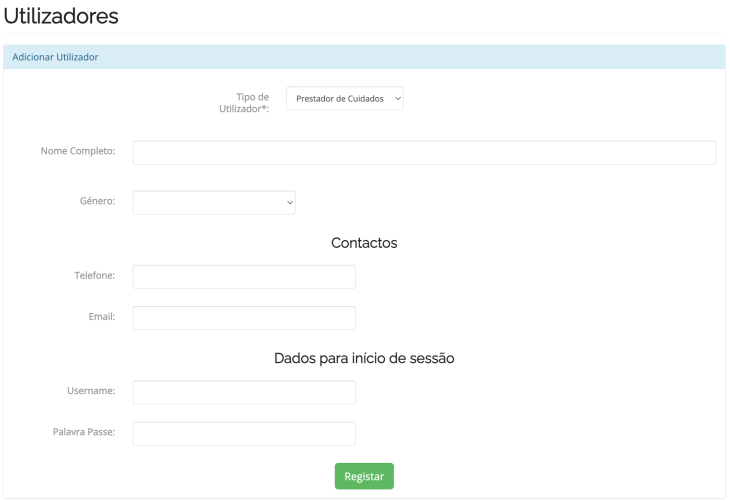

Figure A.10: Formulário para registo de novo utilizador.

ordenação dos vários campos por ordem alfabética e por ordem crescente/decrescente de valores numéricos. Para além disso, é possível utilizar o campo de pesquisa e selecionar o número de entradas a mostrar por cada página.

A.4 Ficha Clínica do Paciente

O menu "Ficha Clínica do Paciente" permite adicionar uma ficha clínica à plataforma, bem como consultar, editar e remover, dependendo do tipo de utilizador (de acordo com a Tabela A.1).

Para adicionar um paciente à plataforma, o utilizador deve aceder ao separador

Table A.1: Permissões de acesso dos utilizadores da RehabVisual (adaptado de [13]).

	Administrator	Physician/Technician	Occupational Therapist	Caregiver
Main Page				
Consult information on:				
Visuomotor skills	X	X	X	X
The project	X	X	X	X
Users				
Add	X	X	X	
Consult	X	X	X	
Edit	X	X	X	
Remove	X	X	X	
Medical Record				
Add	X	X	X	
Consult	X	X	X	
Edit	X	X	X	
Remove	X	X	X	
General Ophthalmological Assessment				
Add	X	X		
Consult	X	X	X	
Edit	X	X		
Remove	X	X		
Neuropsychological Assessment				
Add	X	X		
Consult	X	X	X	
Edit	X	X		
Remove	X	X		
Functional Assessment				
Add	X		X	
Consult	X	X	X	
Edit	X		X	
Remove	X		X	
Intervention Program				
Start session	X		X	
View session	X	X	X	
Edit session	X		X	
View created programs	X	X	X	
View sample programs	X	X	X	X

"Ficha Clínica do Paciente – Adicionar"e selecionar a patologia "Esclerose Múltipla" (ver Figura A.12). Posteriormente, deve preencher o formulário da Ficha Clínica, ilustrado na Figura A.13, clicando em "Registar" no final. O utilizador tem a opção de anexar até três ficheiros que considere relevantes na secção "Ficheiros".

Se o utilizador quiser consultar, editar ou remover uma ficha clínica deve aceder ao separador "Ficha Clínica do Paciente – Consultar". Após seleção da patologia de interesse, encontrará uma tabela com as informações de cada paciente cuja ficha clínica já foi inserida na plataforma, como ilustra a Figura A.14. Através dos botões do lado direito "Editar", "Consultar" e "Apagar" é possível alterar, ver ou remover, respetivamente, a ficha clínica do paciente em questão. O botão "Adicionar Ficha do Paciente" presente no topo da página permite aceder diretamente ao formulário da Figura A.13.

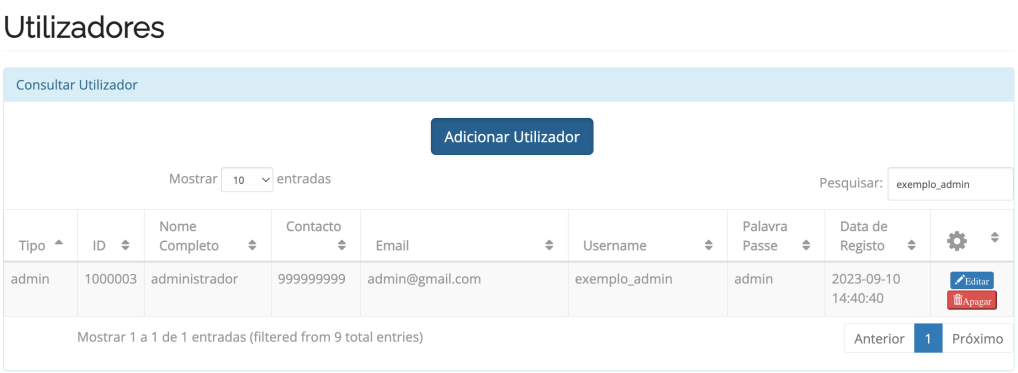

Figure A.11: Tabela dos utilizadores registados na plataforma.

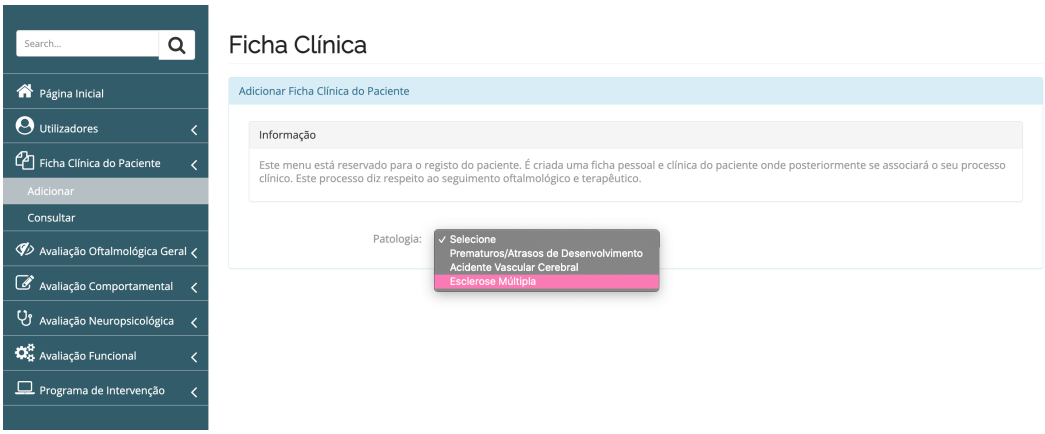

Figure A.12: Página para iniciar o registo do novo paciente.

A.5 Avaliação Oftalmológica Geral

O menu "Avaliação Oftalmológica Geral" permite adicionar uma avaliação oftalmológica, associando-a a um paciente específico, bem como consultar, editar e remover as avaliações já existentes, dependendo do tipo de utilizador (de acordo com a Tabela A.1).

Para iniciar o registo de uma nova avaliação é necessário selecionar o separador "Avaliação Oftalmológica Geral – Adicionar"e selecionar a patologia "Esclerose Múltipla", à semelhança do menu anterior. Aqui, é apresentada uma tabela (ver Figura A.15) de todos os pacientes com Esclerose Múltipla. Ao clicar no botão do lado direito da tabela ("Avaliação Oftalmológica"), o utilizador é redirecionado para o formulário da avaliação oftalmológica, ilustrado na Figura A.16, que será associada ao respetivo paciente. Para registar os dados, terá de preencher os campos apresentados e selecionar "Adicionar Avaliação" no final.

No separador "Avaliação Oftalmológica Geral - Consultar", o utilizador poderá alterar, ver e eliminar as avaliações oftalmológicas disponíveis, clicando nos botões "Editar", "Consultar" e "Apagar", respetivamente (ver Figura A.17).

A.6 Avaliação Neuropsicológica

O menu "Avaliação Neuropsicológica" é destinado apenas aos pacientes de Esclerose Múltipla, pelo que o utilizador não tem que selecionar a patologia. No entanto, o funcionamento é semelhante ao anterior, diferenciando-se apenas no formulário da avaliação, apresentado na Figura A.18. O utilizador deve preencher os campos e submeter a avaliação, que ficará associada ao respetivo paciente, clicando no botão "Adicionar Avaliação" no final.

Para editar, consultar e eliminar avaliações já existentes, o utilizador deve aceder ao separador "Avaliação Neuropsicológica - Consultar", à semelhança do menu explicado na secção anterior.

A.7 Avaliação Funcional

O menu "Avaliação Funcional" está também dividido em dois separadores - "Adicionar" e "Consultar" - sendo necessário escolher a patologia "Esclerose Múltipla" em ambos.

Após a escolha da patologia no separador "Avaliação Funcional – Adicionar", é apresentada uma tabela com os pacientes, à semelhança dos menus explicados anteriormente. Após a seleção do paciente, clicando no botão "Avaliação Funcional" do lado direito, o utilizador é redirecionado para a primeira página da avaliação, presente na Figura A.19. Nesta página encontra informação acerca da avaliação funcional, bem como o procedimento que deve ser seguido para a realizar. Os botões "Início" e "Fim" iniciam e terminam, respetivamente, a gravação tanto do paciente como do estímulo que vai visualizar. Os botões seguintes iniciam os três vídeos, respetivamente, que incluem a avaliação funcional.

Para registar uma nova avaliação, o utilizador deve clicar no botão "Avaliação Funcional →" no canto inferior direito da página. Aqui, o utilizador poderá inserir a data da avaliação em questão, observações e os gráficos obtidos através do *eye tracker* (ver Figura A.20).

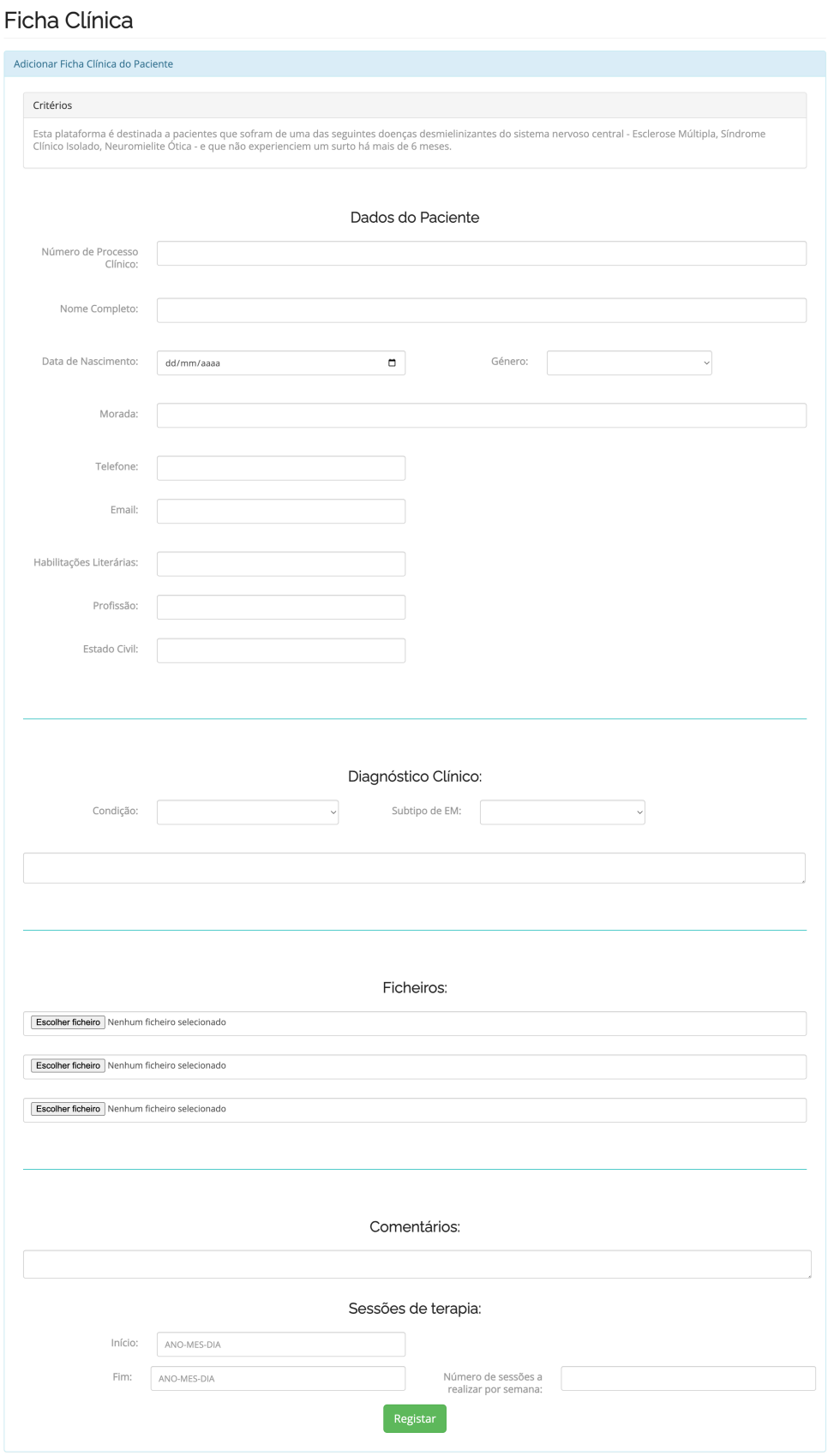

Figure A.13: Formulário para registar a ficha clínica de um paciente com Esclerose Múltipla.

Figure A.14: Tabela para editar, consultar ou apagar fichas clínicas dos pacientes.

Figure A.15: Tabela para adicionar avaliação oftalmológica geral.

Figure A.16: Formulário para registar a avaliação oftalmológica geral de um paciente com Esclerose Múltipla.

Figure A.17: Tabela para editar, consultar ou apagar avaliações oftalmológicas gerais dos pacientes.

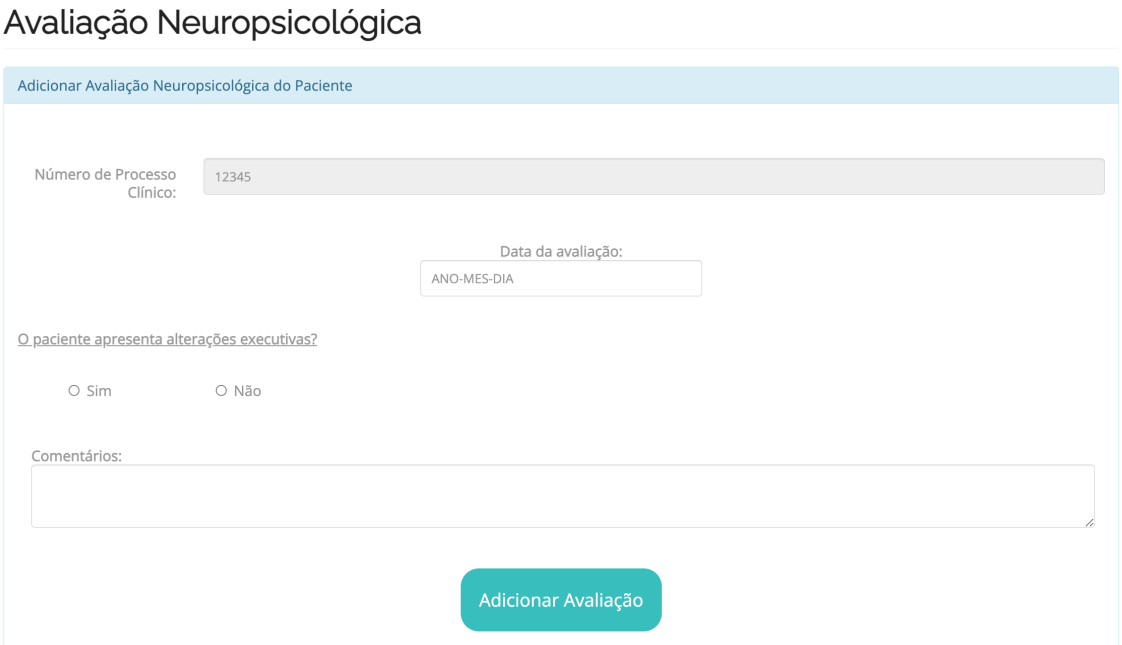

Figure A.18: Formulário para registar a avaliação neuropsicológica de um paciente com Esclerose Múltipla.

Figure A.19: Primeira página da avaliação funcional.

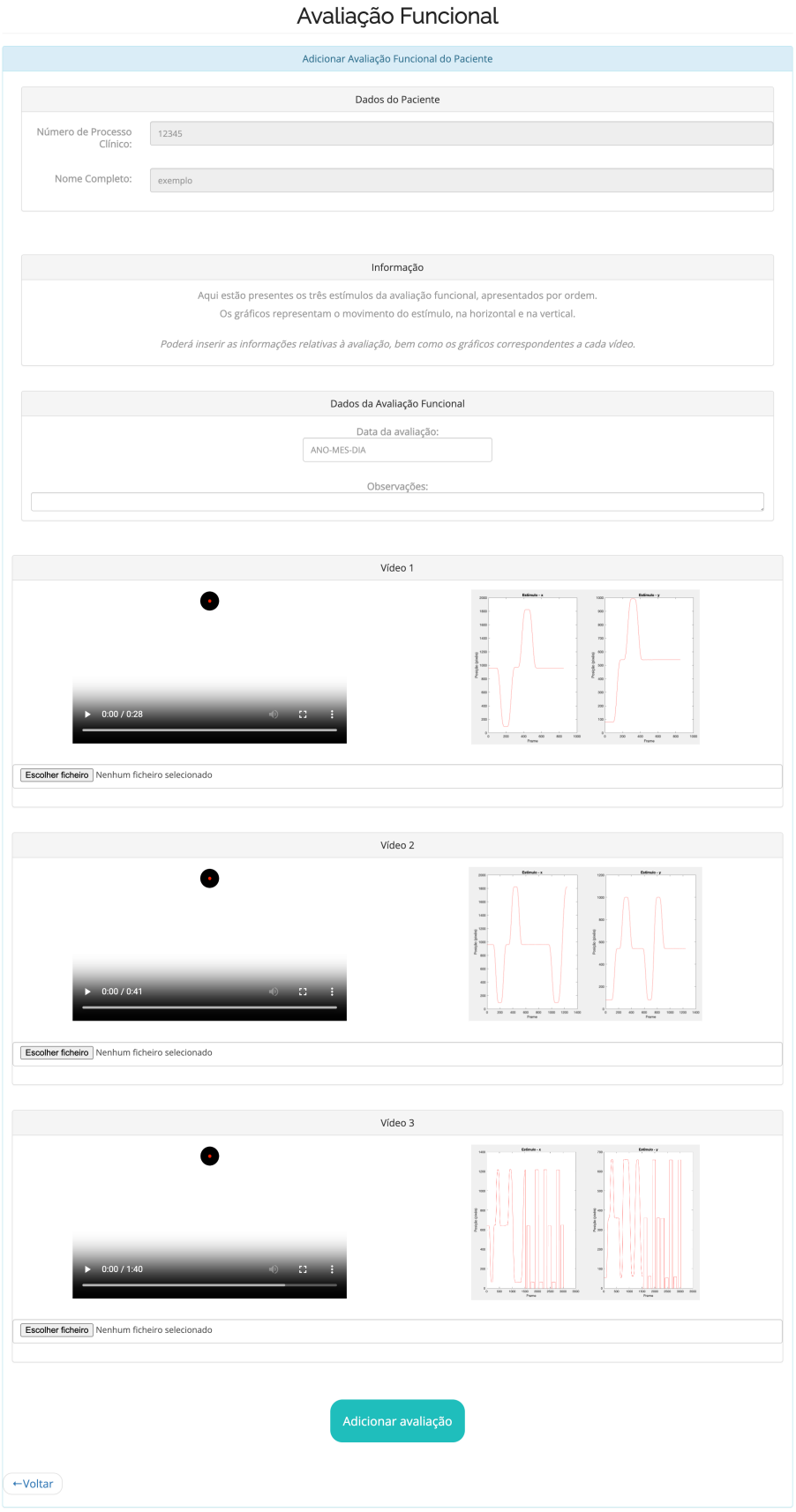

Figure A.20: Segunda página da avaliação funcional.

B

Informed Consent (Normative Base)

In this appendix, the Portuguese informed consent provided by the participants of the control group is presented.

Consentimento Informado

Eu, _____, declaro que me foi transmitido pela estudante Margarida Henriques, de forma inteligível e adequada, o objetivo da presente dissertação de mestrado, bem como o procedimento inerente à participação neste estudo.

Declaro que concordo em realizar o protocolo experimental explicado, autorizando a captação de imagem para posterior análise de movimentos oculares.

Declaro que não sofro de qualquer patologia que possa afetar de alguma forma os meus movimentos oculares (pós-AVC, diabetes, estrabismo, cataratas, etc.).

Por fim, declaro que, embora tenha concordado previamente em participar no presente estudo, poderei a qualquer momento durante o ensaio exigir a suspensão do mesmo e não permitir a utilização dos meus dados.

_____

Assinatura do voluntário

_____

Data (dd/mm/aaaa)

C

Informed Consent (MS Patients)

In this appendix, it is presented the Portuguese informed consent that was signed by the patients who participated in the experimental group. Its preparation took into consideration the regulations established by the HGO.

CONSENTIMENTO INFORMADO PARA PARTICIPAÇÃO NO ESTUDO

"RehabVisual: Adaptação e Validação da Plataforma de Estimulação de Competências Visuomotoras em Pacientes com Esclerose Múltipla"

Introdução

Por indicação do seu médico assistente, Irene Mendes.

Objetivos

O presente estudo tem como objetivo aplicar a plataforma de estimulação visuomotora já desenvolvida, RehabVisual, em pacientes diagnosticados com Esclerose Múltipla e validar a sua usabilidade enquanto elemento auxiliar de diagnóstico e reabilitação visuomotora.

Potenciais Benefícios

Os principais benefícios deste estudo passam pela quantificação das dificuldades visuomotoras dos pacientes, permitindo o foco em tratamentos individualizados de reabilitação específicos às respetivas necessidades.

Potenciais Riscos

O presente estudo não apresenta potenciais riscos, uma vez que a recolha de dados é simples e de curta duração.

Funções do Doente

1. Preenchimento de um questionário para caracterização da amostra;
2. Visualização de três vídeos contendo um estímulo visual:
    a. Manter a cabeça imóvel, pousando o queixo na queixeira e apoiando a testa no suporte cinzento;
    b. Deverá tentar seguir o estímulo visual com o olhar, focando-se no seu centro.

Os três vídeos têm, respetivamente, 29 segundos, 41 segundos e 1 minuto e 40 segundos, aumentando a complexidade dos movimentos e havendo um intervalo entre cada um.

Compensações Financeiras

Não existem compensações financeiras diretas pela participação no presente estudo.

Participação no Estudo

A participação no estudo é voluntária. A recusa em participar não tem repercussão no habitual seguimento do doente.

O consentimento para participação no estudo pode ser retirado em qualquer altura sem repercussão no habitual seguimento do doente.

Confirmo que expliquei à pessoa abaixo indicada, de forma adequada e inteligível, os procedimentos necessários ao ato referido neste documento. Respondi a todas as questões que me foram colocadas e assegurei-me de que houve um período de reflexão suficiente para a tomada da decisão. Também garante que, em caso de recusa, não haverá quaisquer consequências.

Nome do investigador/profissional de saúde: Irene Mendes

Telefone: ……..

Email: ……..

Assinatura: …….

Data: …… /…… /…..

Declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas pela pessoa que acima assina. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências. Desta forma, declaro que aceito participar neste estudo, e que tomo a minha decisão de forma inteiramente livre, e permito a utilização dos dados que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação e nas garantias de confidencialidade e anonimato que me são dadas pela investigadora.

Nome legível da pessoa que consente:

……

Telefone/telemóvel: ……..

Email (caso possua): ……..

Assinatura: ……

Data: …… /…… /……