RehabVisual: Adapting and Testing the Visuomotor Skills Stimulation Platform on Patients with Multiple Sclerosis

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Abstract: Multiple Sclerosis (MS), the most prevalent immune-mediated inflammatory demyelinating disease affecting the Central Nervous System (CNS), has an estimated global incidence of 2,8 million individuals. Although its symptomatology is highly varied and unpredictable, depending on the lesions' location in the CNS, visual impairments are among the most common manifestations. However, conventional methods for assessing and rehabilitating visuomotor competences are not sufficient to deliver objective assessments or personalized therapies. The current study addresses this gap by adapting and testing the RehabVisual platform's usability in MS patients. RehabVisual, developed in previous studies, aims to objectively assess visuomotor skills through an integrated low-cost eye tracking system, offering specific clinical intervention. Before clinical application, a normative base was established using 50 healthy individuals for later comparison. The experimental group comprised 25 MS patients with and without confirmed visuomotor alterations. The protocol involved viewing three visual stimuli for later calculation of the mean Euclidean distance between the gaze and stimulus positions using the eye tracker, for further assessment of the patients' performance in tracking the stimulus. The findings confirmed diagnosed visual impairments, along with their quantification and storage for monitoring and rehabilitation purposes, highlighting the platform's potential as an auxiliary tool for healthcare professionals.

1 INTRODUCTION

Multiple Sclerosis (MS) is the most prevalent immune-mediated inflammatory demyelinating disease affecting the Central Nervous System (CNS), with an estimated incidence of 2,8 million individuals worldwide (Walton et al., 2020).

Patients suffering from this chronic pathology may present a variety of symptoms depending on the location of the CNS lesions, making it difficult to predict the disease's course. Visual impairments are among the most common symptoms and are often the first manifestation of the disease, significantly altering the patients' quality of life. However, the evaluation of these competencies is typically based on the subjective observation of the physicians, since it is usually performed by the naked eye, resulting in overlooked impairments (Sheehy et al., 2018).

In this sense, it is clear that the clinical practice would benefit from the inclusion of objective and accurate methods to adequately monitor the oculomotor function throughout the evolution of the pathology to avoid neglecting possible pathological alterations. Previous studies have included eye tracking systems to achieve this outcome, namely a research carried out in 2020 (Sheehy et al., 2020), which 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 microsac-

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cades associated with greater neurological disability.

Additionally, these objective methods should also aid in the rehabilitation area, allowing the creation of rehabilitation plans tailored to the patients' needs, ensuring a higher quality of life and independence in daily tasks.

RehabVisual is a visuomotor skills stimulation web-based platform designed both to evaluate the oculomotor behaviour and to develop personalized intervention plans. It was originally developed in a partnership between students and professors of biomedical engineering of NOVA School of Science and Technology, and occupational therapists and physicians from the Service of Physical Medicine and Rehabilitation of the Hospital Dona Estefânia (Machado et al., 2018) to improve the methodology used in infants with developmental abnormalities. Subsequently, an eye tracking system was developed to integrate the platform and objectively quantify visual impairments (Dias et al., 2020). Currently, the platform has been adapted and tested in post-stroke patients (Ferreira et al., 2020) and the eye tracker has been improved and validated (Fonseca, 2022).

The present paper aims to describe the adaptations made to the RehabVisual platform for its application on individuals diagnosed with MS, along with a comparison between the patients and a control group of individuals without associated pathology. The entire process was undertaken in collaboration with the Hospital Garcia de Orta (HGO), both the platform's alterations and the clinical application.

2 MATERIALS AND METHODS

The current chapter addresses the instruments used and expanded in this work, the RehabVisual platform and its integrated eye tracking system, in Section 2.1, along with the data acquisition methodology in Section 2.2.

2.1 Instruments

2.1.1 RehabVisual Platform

RehabVisual was designed using different programming languages, such as HTML, PHP, JS, CSS to create the web application, and SQL to create the database (Machado et al., 2018). Also, it allows four different profiles with distinct permissions within the platform: administrator, physician/technician, occupational therapist and caregiver.

The platform has two sections: assessment and intervention. The first one consists of a database to record all the relevant clinical information of the patient, namely their clinical record and ophthalmological, behavioral, neuropsychological and functional assessments, facilitating a long-term monitoring. The intervention program presents a variety of protocols with different stimuli according to the visuomotor skills status, allowing the selection of a more adequate set of stimuli for a specific patient.

The current study focused on the confirmation and monitoring of diagnosed visual alterations, namely in the functional assessment of MS patients, so the intervention program was not altered nor approached.

Regarding the specificities of the studied pathology, it was added a new database entry for the neuropsychology assessment, typically carried out in MS patients to evaluate their executive system. Also, the functional assessment was altered to include the experimental protocol employed in the current study, explained in Section 2.2.2.

2.1.2 Eye Tracking System

The eye tracking system was created using Matlab software and operates offline, only requiring prior recording of the participant's face during stimulus observation. Figure 1 summarizes the eye tracker's semi-automated workflow.
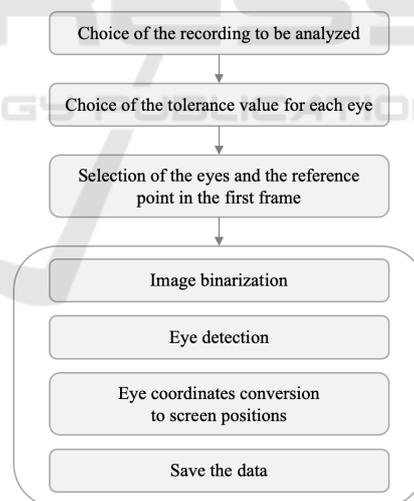

Figure 1: Eye tracking system operation summary.

The system needs a manual input of the video to be analysed, the tolerance value for each eye, and the position of the eyes and a reference point. These tolerance values are the input argument for the image segmentation technique used in the image binarization process (performed with the Matlab command `grayconnected()`). After the abovementioned steps that require user interaction, the system automatically analyses the whole video, processing every frame.

The eye detection is obtained by the `imfindcircles()` function, which finds black circles with a radius ranging from 80% to 120% of the first found circle's radius. The image coordinates of both irises and the reference point are saved in matrices and converted into screen positions in pixels following a calibration.

With the pixel coordinates of the subject's gaze and of the stimulus, it is possible to correlate these to metrics and calculate the distance between them. The program automatically presents the mean Euclidean distance between the gaze and the stimulus positions for the chosen video and respective stimulus, which is a metric that showed a promising result in the validation of this system (Fonseca, 2022). Additionally, it also generates graphs depicting the overlay of the stimulus positions with the gaze's direction of each eye (both in pixels) as a function of the video frame number. These graphs are separated between vertical and horizontal directions and can be used to assess a subject's performance in following the visual stimulus presented.

2.2 Data Acquisition

Data acquisition was carried out in two separate samples, forming a control group and an experimental group. The Ethics Committees of the HGO and the NOVA School of Science and Technology reviewed the present protocol and allowed its execution in their facilities, for the construction of the experimental and control groups, respectively.

Section 2.2.1 presents a characterization of both groups. The experimental protocol is detailed in Section 2.2.2.

2.2.1 Samples Characterization

Control Group. Two inclusion criteria were defined for the selection of the control group: minimum age of 18 years old and absence of known pathology that could affect ocular movements in any way. Additionally, all subjects were asked to remove their glasses to prevent interference with the detection of the eyes by the eye tracker. Nonetheless, it was ensured that the stimulus recognition was not affected in order to allow an accurate stimulus tracking by the participant.

Data collection was carried out in a sample of 50 volunteers, among whom 38 (76%) were female and 12 (24%) were male. Ages ranged from 19 to 63 years old (mean $30,3 \pm 13,3$ years), while the female population presented a mean value of 32,7 years of age with a standard deviation of 14,4 years and the male

cohort presented a mean value of 22,5 years of age with a standard deviation of 1,6.

Additionally, all participants willingly agreed to collaborate in the study, providing their free consent before initializing any experiment.

Multiple Sclerosis Group. Regarding the experimental group, the inclusion criteria defined were having a diagnostic of MS and not having a relapse in more than six months. Similarly to the control group, the participants were asked to remove their glasses due to the same reasons explained earlier. The study population involved 25 participants, 18 females (72%) and 7 males (28%). Ages ranged from 19 to 63 years old (mean $41,8 \pm 11,7$ years), with a mean value of 41,2 years of age for the female cohort and a standard deviation of 11,5 years, whereas the male population had a mean value of 43,3 years of age and a standard deviation of 12,9 years.

It was also taken into consideration the MS subtype of each patient and whether they had a diagnosis of internuclear ophthalmoplegia, optic neuropathy, or executive alterations, which are common symptoms related to MS and may affect the patient's performance in following a visual stimulus. The most common subtype presented was Relapsing-remitting Multiple Sclerosis, accounting for 22 (88%) of the participants, while the other 3 (12%) were diagnosed with Secondary Progressive Multiple Sclerosis. Regarding the neurological symptoms, 9 patients (36%) had already been diagnosed with internuclear ophthalmoplegia, 9 patients (36%) with optic neuropathy, and 12 (48%) with executive alterations.

Before initializing the experimental protocol, all participants were fully informed about the aim of the study and its procedures, and all provided free informed consent.

2.2.2 Experimental Protocol

All participants from both groups were asked to visualize three videos containing different visual stimuli with increasing complexity, while resting their head on a support, and an external camera recorded their face. The subjects were instructed to follow the stimulus solely with their eyes, keeping their head immobile throughout the entire videos. The recording of the participants' face must include a clear image of their eyes, uncovered and aligned with the screen. Furthermore, the lighting conditions should be favorable, minimizing reflections or shadows on the subjects' ocular surfaces, and this video should be recorded at approximately 30 frames per second, since recording at a lower frame rate could result in the loss of relevant movement information. Lastly, it is essential that

their head is rest and immobile, ensuring that the only present movements are the eyes'.

Experimental Setup. The experimental setup is shown in Figure 2 (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 2 (on the right), was used to immobilize the head, as the subject was instructed to rest their chin and forehead during the acquisition.

Figure 2: Experimental setup (on the left) and head rest (on the right).

The monitor and the camera were positioned at approximately 20 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.

The camera used was a Logitech C920 HD PRO Webcam, which offers a 78° 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.

Stimuli. Three different stimuli were elaborated in collaboration with the Neurology Service of the HGO and were shown during the experimental protocol. The stimulus itself was the same, comprised by a black circle with a red center (Figure 3, on the left), differing only in the trajectory followed. Additionally, all three videos started with a calibration sequence of 15 seconds, equivalent to 450 frames, creating a correspondence between the maximum and minimum amplitude of the eyes and the screen edges.

Considering the scheme represented in Figure 3 (on the right), the calibration procedure followed the sequence B-D-H-F, after an initial fixed position for 3 s at the first location and with a fixation on each of the marked locations of 1 s.
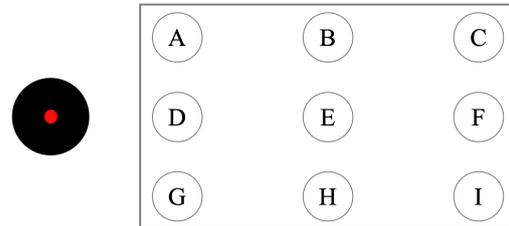

Figure 3: Stimulus (on the left) and possible locations of the stimuli's paths (on the right).

The first video has a duration of 28 s, in which the stimulus moves to location E, where it remains stationary for 10 s until the end, following the calibration abovementioned. This stimulus was chosen to ascertain the presence of nystagmus, by investigating the capability of maintaining a steady gaze at a fixed point.

The second video aimed to assess if the subject could achieve a smooth pursuit of the stimulus, which could translate into the presence (or absence) of saccadic intrusions. Accordingly, in this 40 s video, the stimulus describes the path E-B-H-E-D-F after the calibration, comprising vertical and horizontal movements with 1 s fixations at each marked location.

Lastly, the third video comprehends a trajectory along the screen corners, as well as an intermittent movement at the end, resulting in a duration of 1 minute and 40 seconds, in order to assess the subject's visual filed and visual perception. The initial continuous movement corresponds to the path E-B-H-I-A-G-C with a fixation of 1 s in each location following the calibration. Subsequently, the stimulus fades and reappears in another area, where it remains stationary for 3 s, describing the unpredictable sequence E-A-I-D-F-B-G-C-H.

3 RESULTS AND DISCUSSION

3.1 Control Group

After applying the experimental protocol to the control group, the mean Euclidean distance between the stimulus and the gaze positions was calculated for the first two videos and for each subject in order to establish a reference value for further comparison with the experimental group. The third video was analysed separately. Table 1 summarizes the results obtained.

Table 1: Descriptive statistics of the mean Euclidean distance between the stimulus and the gaze positions (in pixels) for the first two videos and for both eyes of the control group.

Mean Euclidean distances (pixels)	1st Video		2nd Video	
	Right	Left	Right	Left
Maximum	125	119	137	149
Minimun	49	44	53	61
Mean	84	89	109	116

As it was expected, in general the obtained values are greater for the second video. This result may be related to the participants' performance, as well as to the eye detecting system. A longer video demands a longer attention span and can lead to visual fatigue, therefore resulting in a more imprecise tracking. On the other hand, a longer time interval implies a higher chance of situations where the eye is not correctly detected, namely due to blinking or momentary changes in brightness, and a higher chance of the subject moving their head. Moreover, an initial imprecise calibration results in more inaccurate values in a longer video, thus leading to higher mean Euclidean distances.

Following the same methodology of the study that validated the eye tracking system (Fonseca, 2022), it was established a threshold value for each stimulus according to the approximate maximum value. Therefore, mean Euclidean distances above 130 pixels and 150 pixels, for the first and second stimulus respectively, were indicators of difficulties in tracking the stimulus. The three figures below depict the graphs generated by the eye tracking system for the three stimuli of one healthy participant's left eye.

Figure 4 shows the graphs representing the movements of the first stimulus (red) and the left eye (green) tracking it. The graphs are separated in the two directions, horizontal (top) and vertical (bottom), and both measure screen positions in pixels as a function of the video's frame number. As the stimulus remains static at the end of the video, there is a horizontal line in both graphs representing the unchanged coordinates.

Accordingly, Figure 5 depicts the graphs representing the movements of the second stimulus (red) and the left eye (green) following it, for the horizontal (top) and vertical (bottom) directions. During the vertical movements, the graph corresponding to the movement in the x axis shows 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 graph that corresponds to the
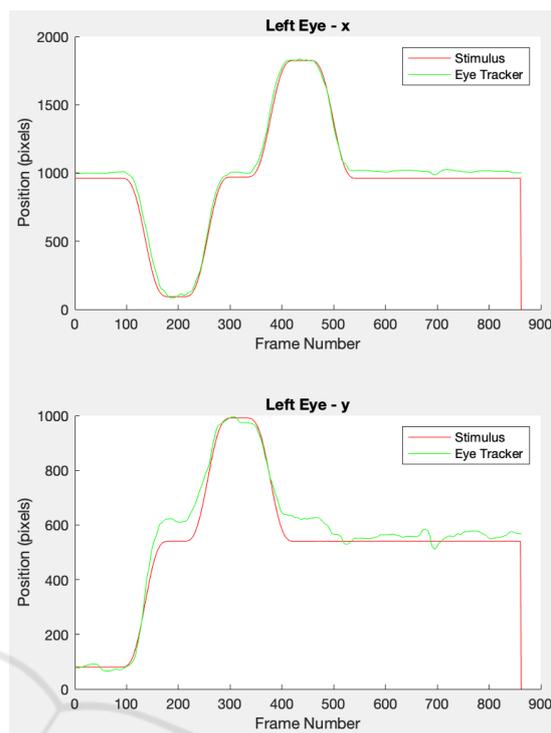

Figure 4: Coordinates in pixels of the first stimulus (red) and the gaze (green) as a function of the frame number for the left eye.

movements in the vertical direction.

Lastly, the graphs in Figure 6 detail the movement of the third stimulus (red) and of the left eye (green) tracking it. In this case, the stimulus fades and appears in another location to produce an intermittent movement, which is evident by the abrupt changes in both graphs representing each direction, horizontal (top) and vertical (bottom).

Analysing the generated graphs, and taking into consideration that the graphs for the right eye are identical, the curves representing the participant's gaze are noisier than the curves representing the stimulus. Yet, all the transitions and fixations are correctly identified. Another outcome is that the y coordinate estimation of the eye movement seems less accurate than the horizontal coordinate, for the three stimuli. Said discrepancy might be caused by differences in eyelid opening during vertical movements, which do not occur during horizontal ones.

3.2 Multiple Sclerosis Group

In accordance with the previous subsection, Table 2 represents the results obtained for the experimental group of MS patients.

Upon initial examination, we can confirm that, on average, the values are higher for this group of indi-
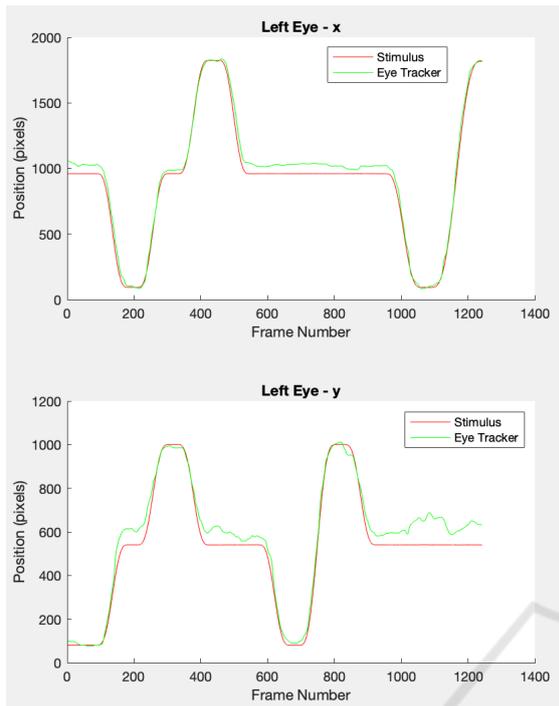
Figure 5: Coordinates in pixels of the second stimulus (red) and the gaze (green) as a function of the frame number for the left eye.
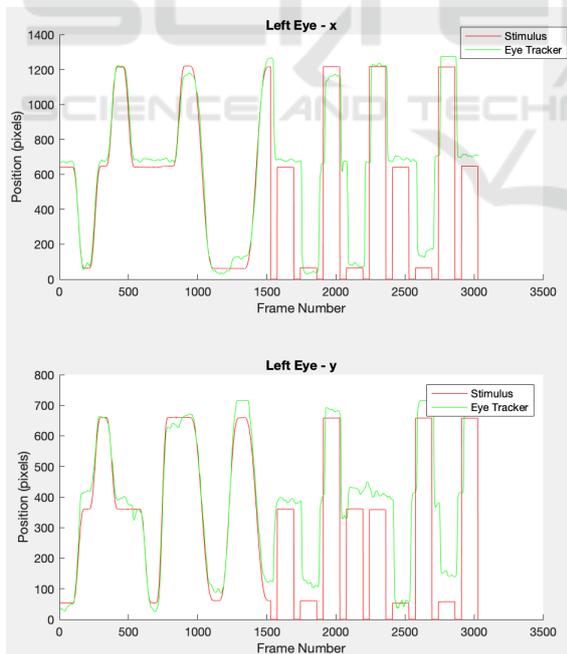
Table 2: Descriptive statistics of the mean Euclidean distance between the stimulus and the gaze positions (in pixels) for the first two videos and for both eyes of the experimental group.

Mean Euclidean distances (pixels)	1st Video		2nd Video	
	Right	Left	Right	Left
Maximum	336	346	367	457
Minimun	58	48	81	72
Mean	113	128	159	171

sample includes patients with diagnosed visual impairments. Furthermore, during the acquisition, some patients were unable to keep their head still and track the stimulus only with eye movements, resulting in a relatively mobile reference point and, consequently, in disparate results. This limitation may be linked to the presence of executive impairments, which can affect, for example, the ability to maintain focus and follow instructions.

As mentioned above, the first stimulus was used 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 diagnostic of visuomotor alterations, which can be seen in the following figures.

Figure 7 represents the right eye movements of patient 15 while visualizing the first stimulus. This patient is a female diagnosed with Relapsing-remitting Multiple Sclerosis and executive alterations. The mean Euclidean distances between the stimulus and the gaze positions were 159 ± 96 pixels for the right eye and 134 ± 113 pixels for the left eye.

As this patient has no diagnosed visual alterations, it was expected that the graphs would show a smooth pursuit of the stimulus. Yet, by the presence of several peaks, it is clear that the patient was not able to follow the stimulus's continuous movement. Also, in the highlighted area, it is possible to see a higher slope in the green line, suggesting that the patient anticipated the movement and had to adjust their gaze.

Regarding the second stimulus, its aim 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. Patient 5 had already been diagnosed with internuclear ophthalmoplegia and executive alterations, so the presence of abnormal eye movements were predicted. The graphs generated by
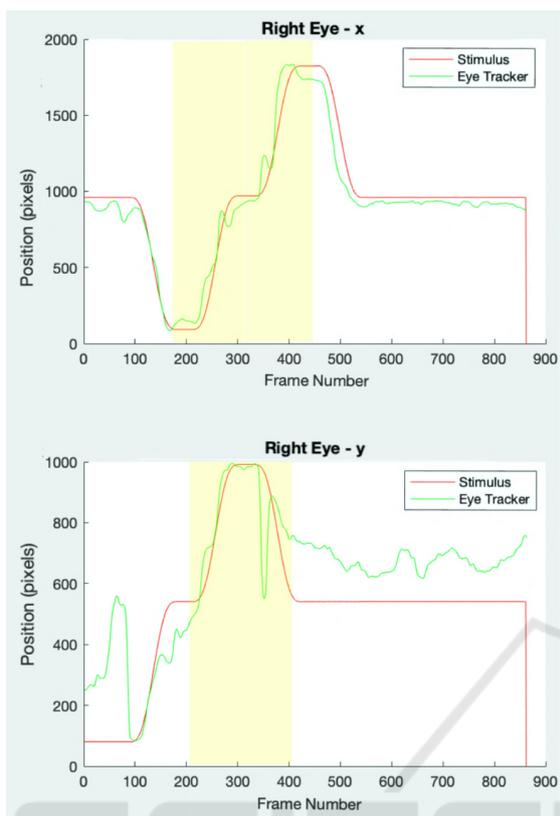

Figure 6: Coordinates in pixels of the third stimulus (red) and the gaze (green) as a function of the frame number for the left eye.

viduals than for the group constituted by healthy individuals, which was undoubtedly expected since this

Figure 7: Coordinates in pixels of the first stimulus (red) and the right eye's gaze (green) of patient 15 as a function of the frame number, with the x positions on the top and the y positions on the bottom.

the eye tracking system corresponding to the visualization of the second video by patient 5 are presented in Figure 8. In this case, the mean Euclidean distances between the stimulus and the left eye's gaze positions were 153 ± 161 pixels for the right eye and 157 ± 144 pixels for the left eye.

As can be observed, 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). Similarly to the first case, this indicates that the patient anticipated the movement, resulting in a discontinuous motion and having to later adjust the gaze to properly follow the stimulus's movement. The same phenomenon occurs at approximately frame 980, during a horizontal movement from the middle of the screen to the left.

The third stimulus aimed to assess the patients' field of vision, as well as their visual attention. In MS, the visual field may be affected due to the inflammation of the optic nerve (optic neuritis). However, at the time of the acquisition, none of the patients was in this situation, and as a result none of them exhibited a
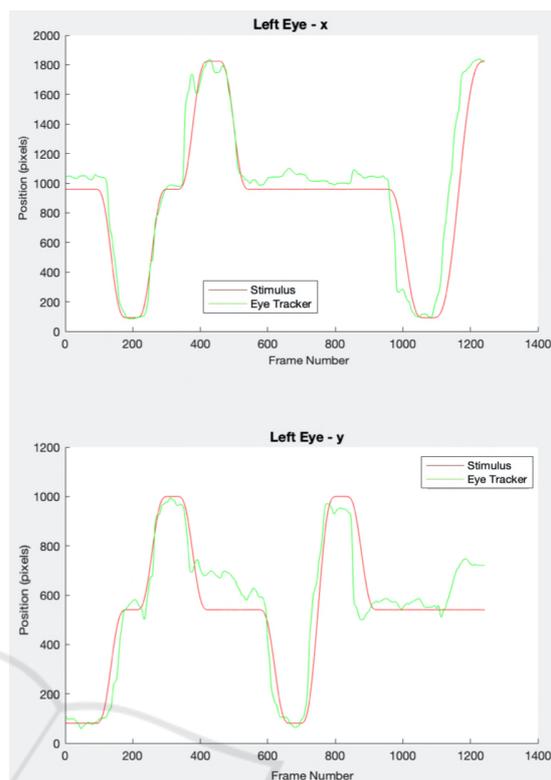

Figure 8: Coordinates in pixels of the second stimulus (red) and the left eye's gaze (green) of patient 5 as a function of the frame number, with the x positions on the top and the y positions on the bottom.

loss of the visual field. Therefore, no new results were anticipated when compared 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. However, it is important to integrate a stimulus to assess these competences in future studies as well, as they are usually affected in individuals with MS.

4 CONCLUSIONS AND FUTURE WORK

The main objective of the present study was to expand and adapt the RehabVisual platform to MS and test its usability on patients diagnosed with this pathology, following its adaptation and expansion for this population as a continuation of previous work.

To achieve this goal, the experimental protocol was performed in 50 healthy volunteers (control group) to establish normative values for further comparison and 25 MS patients from the HGO (exper-

imental group). Subsequently, the mean Euclidean distances between the gaze and the stimulus positions were calculated and it was evident that the values, in general, were higher for the experimental group, as it was expected.

The results obtained show that it is possible to record and save a quantification of the visual impairments, as the eye tracking system was able to confirm diagnosed visual alterations. This platform enables an easier monitoring of the disease's progress, along with a possible auxiliary tool for the rehabilitation planning. In this sense, it is evident that MS patients may benefit from the use of the RehabVisual platform.

Although the results obtained are promising, there are some limitations that were encountered and should be addressed in future studies. Regarding the eye tracking system itself, there were some errors demonstrated in the eye detection, leading to inaccurate values, thus the system's general performance should continue to be improved. Additionally, the computational time needed to process the data was greater than desired, taking approximately 5 minutes to process a video of 29 seconds (with around 600 frames). On another note, the metric used for assessment (mean Euclidean distance between the stimulus and the gaze positions) was not always a good indicator of difficulties in tracking the stimulus, since it is a mean value. In this regard, analysing Euclidean distances in specific positions should be interesting and could bring satisfactory results.

Also regarding future work, it is important to conduct a usability test in order to evaluate the platform's performance in the hands of healthcare professionals, as well as to assess areas for improvement. Additionally, as the present work did not focus on the rehabilitation area, it would be interesting to use the platform to choose individualized rehabilitation programs in future studies and test its results and relevance.

The present study offers a summary of the methodologies and results obtained, intending to highlight the potential of the RehabVisual platform, as mentioned earlier. Furthermore, RehabVisual allows for systematic and standardized monitoring of patients with visuomotor impairments over time. Additionally, it facilitates the identification the intervention methodologies' impact, allowing necessary adaptations to address the specific needs of each patient when required.

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