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Virtual Interactive Environment for Low-Cost Treatment of Mechanical Strabismus and Amblyopia

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Abstract: This study presents a technique that uses an interactive virtual environment for the rehabilitation treatment of patients with mechanical strabismus and/or amblyopia who have lost eye movement. The relevant part of this treatment is the act of forcing the two eyes to cooperate with each other by increasing the level of adaptation of the brain and allowing the weak eye to see again. Accordingly, the game enables both eyes to work together, providing the patient with better visual comfort and life quality. In addition, the virtual environment is attractive and has the ability to overcome specific challenges with real-time feedback, coinciding with ideal approaches for use in ocular rehabilitation. The entire game was developed with free software and the 3D environment, which is made from low-cost virtual reality glasses, as well as Google Cardboard which uses a smartphone for the display of the game. The method presented was tested in 41 male and female patients, aged 8 to 39 years, and resulted in the success of 40 patients. The method proved to be feasible and accessible as a tool for the treatment of amblyopia and strabismus. The project was registered in the Brazil platform and approved by the ethics committee of the State University of Piaui—UESPI, with the CAAE identification code: 37802114.8.0000.5209.

Keywords: strabismus; virtual reality; rehabilitation

1. Introduction

In the field of ophthalmology, it is almost unanimous that strabismus is classified as one of the most difficult problems. The application aspect relates to the subtleties and skills required by the exams, as well as the diagnostic, therapeutic, clinical and surgical techniques in the care of strabismus. In fact, the diagnosis of oculomotor imbalances and related visual dysfunctions depends on a complex and diverse set of exams, from which the simple selection of appropriate ones in each case already requires training and experience.

The requirement for detail in the diagnosis of strabismus does not allow for the study of these details that involves a series of tests that lead to this diagnosis. This has generated a belief that the presence of one or more orthoptists for the treatment of strabismus is essential, and therefore. The reason for this is that in several areas of knowledge, there are incentives and investments for automation, as well as an increase in accuracy in performing tasks and diagnoses.

By exploring this stagnation with the development of technologies that help in strabismus treatment, this work presents a technique of strabismus treatment with the creation of a virtual environment that is used as a tool for the exercise of the ocular muscles, which is pleasantly viewed by the patient.

The general objective is to rehabilitate strabismus caused by muscle eye problems in people with amblyopia using exercises designed in virtual environments. The specific objectives are as follows: to rehabilitate children in an attractive way, since traditional methods are dull, and to rehabilitate adults without the need for surgery. Accordingly, the method is not invasive. Furthermore, there will be an improvement in individuals' postures, since this can be adjusted by body adaptation to the eye problem.

2. Strabismus

Strabismus is an eye disorder that causes misalignment and loss of parallelism between the eyes, caused by a dysfunction in at least one of the six muscles responsible for the movement of each eye, where one eye may be in its normal position and the affected eye may be directed to any other axis (up, down, in or out) [1]. The six muscles in each eye responsible for movement must function symmetrically and with equal application of forces in their movement. As two muscles move the eye sideways, the other four move it up or down. When there is no similar application of forces through these muscles for proper alignment between the eyes, strabismus may occur [2].

Strabismus occurs in children and adults, with greater recurrence in the first group, and it may be of hereditary origin. However, a specific cause is not known for the occurrence of ocular deviation leading to strabismus [2]. In adults, problems related to nervous order, endocrinology or caused by physical trauma, may be related to strabismus [3].

The brain controls the eye muscles. This explains why children with cerebral palsy, Down Syndrome, hydrocephalus and brain tumors develop strabismus. When the eyesight of one eye is altered due to a cataract or other injury, the eye usually becomes sidelined [4].

The following may be signs of strabismus: double vision, visual scuffing, visual blurring, head bending for observation, closing one eye in brightness and constant blinking. If strabismus is suspected, ophthalmologic examination is required to determine its cause, and treatment starts immediately [4].

There are several ways to classify strabismus. One of them is related to the deviation of the eyeball, which can be classified as esotropia or convergent deviation (deviation of the eyes inwards). This one is the most common and was chosen as the focus of this work. Another classification is divergent exotropia or deviation (deviation of the eyes outward). This happens more when the patient looks away or in situations of lack of attention and fatigue [1]. There are also vertical deviations [5].

As for the permanence in time, strabismus is, in most cases, permanent, but there are cases in which it is intermittent or even latent. There is a classification of this disease, which is not absolute, distinguishing four clinical forms of strabismus. These are infantile, secondary, acquired and microestrabism [6].

The first one mentioned (infantile) is one in which development begins in the first six months of the child's life and is related to cyanosis. The secondary one results from a primary sensory deficit or from a result of surgical intervention, branching into two others, which are sensory esotropia and consecutive esotropia. The acquired one appears at a more advanced age compared to the infantile one. This one, in turn, has four distinct forms: the accommodative strabismus which is related to the adaptive power of the eye; the non-accommodating strabismus; the acute strabismus which develops suddenly and without any apparent reason; and mechanical strabismus which is related to the mechanical restriction of some extraocular muscles. Finally, there is microestraism which occurs when the degree of deviation is less than 10 dioptres [6], which can be measured by prisms [7].

The most common type of strabismus is manifested in the form of squinting eyes and is almost always accompanied by a lazy eye or amblyopia.

3. Amblyopia

Amblyopia is characterized by decreased vision of one eye or both eyes and is occasionally caused by the deprivation of vision or abnormal binocular interaction. Neither of these causes can be detected by physical examination of the eye and, in some cases, the condition is reversible with therapeutic measures [4].

The process of developing the central nervous system leads to better vision. However, the immature visual system becomes vulnerable to the harmful effects of sensory input, and inequality generates suppression of an image to prevent the formation of a blurred image [8]. Amblyopia is often caused by abnormalities in the visual system that make it difficult to form clear images in the retina during the post-natal period.

Ocular examination may reveal the origin of pathologies as precursors of physical amblyopia and, in some cases, physical defects of the optic nerve may lead to additional loss of vision called relative amblyopia [4,9].

Strabismus and anisometropia are the most frequent causes of amblyopia. The age limit for the recovery of amblyopia has been discussed. It is considered, from a practical point of view, irreversible after 8 years of age [10]. The curve of sensitivity for development and treatment is shown in Figure 1.

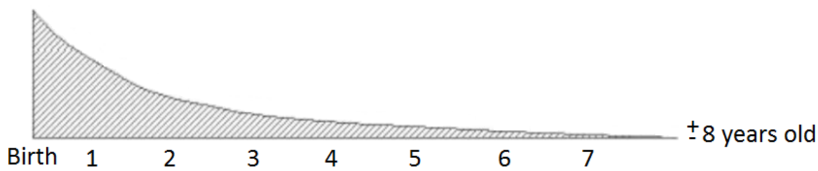

Figure 1. Sensitivity curve for development and treatment.

Strabismic amblyopia, a condition in which amblyopia is associated with strabismus, begins with macular suppression. Hence, it occurs when the fovea of the eyelid eye is eliminated. This occurs because the fovea of the deviated eye has straight correspondence with the medial region of the fixating eye, and this causes effects such as diplopia and confusion of images.

It has been reported in the literature that adults with strabismic amblyopia have little chance of recovery. It is also said that amblyopia is not treatable beyond 10 years of age, because the visual system has already developed and would already have a fixed function. However, now, it is clear that the adult human visual cortex has a significant degree of plasticity [11]. This makes the recovery of cortical function in adulthood an attainable goal [11,12].

One of the objectives of this research is to develop a virtual environment for the treatment of a person at any stage of life.

4. Strabismus Treatment

The first measure to be taken to treat strabismus is to see if there is amblyopia, the priority treatment is to find a cure for amblyopia, and only after that does the treatment focus on ocular deviation.According to Costenbader, the treatment for esotropia, whether surgical or not, has, as its final objective, three results: (1) improvement of vision in each eye; (2) better binocular alignment with harmonious movements; and (3) safe binocular vision [13].

4.1. Strabismus Surgical Treatment

The clinical treatment of strabismus, in general, attempts to correct the positions, lengths and tensions of the outer eye muscles for the eye so that their responses become adequate. Surgical treatment arose in the mid-eighteenth century in a very rudimentary form. It was started by John Taylor, who adopted a technique called strabotomy or neurotomy. It consisted of the section of the muscle causing strabismus. It did not obtain very satisfactory results and soon fell into oblivion by the doctors of the time [14]. In 1839 in Berlin, a new technique called myotomy, developed by Dieffenbach, appeared. This consisted of totally sectioning the hyperfunctioning muscle, and with that, the eyestrain returned to its normal aesthetic form. However, with the passage of time, complications appeared. In the majority of cases, a secondary strabismus appeared, which ended up rendering this kind of surgery impossible [14].

With the improvement of studies on the ocular anatomy realized by Bonet in 1841, it became possible to better dissect the muscles by locating their insertions. From this, a new surgical technique, tenotomy, emerged in which the tendon was sectioned, instead of the muscle, as was done in myotomy. In spite of a good initial presentation, with the passage of time, the appearance of divergent strabismus occurred [14].

More than a decade later, in 1855, for the first time in England, Chritchet performed a surgery called muscular advancement. This surgery consisted of increasing the strength of the operated muscle to advance the insertion of the strabismus muscle. Over a short period of time, the problems related to this surgery arose because the advance only favored small deviations. To overcome this difficulty, the muscle was resected and then advanced, thus creating the muscular resection surgery used in the surgical corrections of strabismus. Nevertheless, the outcome of the advancement was unsatisfactory at large angles. Bilateral surgery of both lateral strata then began [15].

4.2. Non-Surgical Treatment for Strabismus

Historically, non-surgical treatment, initiated by Paulus of Aegina in the seventh century BC, focused on strabismus and used a mask, as shown in Figure 6. This was used as a treatment involving the concept of a forced forward look [16]. In 1722, Saint-Yves refuted against the use of masks, claiming that only the good eye looked through the hole, and the eclipse eye continued with the deviation behind it. In 1838, Charles Wheatstone developed the mirror stereoscope, the predecessor of the synophorus [17]. The use of miotics and pletopic also describe non-surgical treatment performed without the use of this apparatus. This was described above.

4.2.1. Miotics

In 1896, Javal reported the use of this method based on his experiences in the Manual of Strabismus. The use of miotics in strabismus is based on the spasm of the peripheral housing caused by the drug [18]. Since the days of Javal, the treatment of strabismus with miotics had fallen into oblivion until 1949, when Abraham published his preliminary reports entitled “The use of miotics in the treatment of convergent strabismus and anisometropia” [19]. In his conclusions, he stated that miotics may be a substitute for glasses for very young patients who cannot make use of these and that the treatment is particularly suitable for patients with intermittent strabismus.

4.2.2. Pleoptica

Pleoptica is an ocular exercise technique that aims to re-educate, rehabilitate and improve visual acuity and the ability to see objects clearly. This treatment attempts to overcome the obstacles of amblyopia and eccentric fixation [13].

4.2.3. Video Games

Current research has been directed at treating the eye that presents amblyopia through a video game because of its dynamism. The principle of this concept is game research as a tool to improve vision and visual attention in adults with normal vision. Achtman, Green and Bavelier [20] stated that adult brain plasticity is often difficult to obtain, but they consider the playing video games as a way of inducing general improvements in vision. Bavelier et al. [21] reviewed training environments using video game action and showed that they were able to actually foster brain and learning plasticity, because learning is usually quite specific to the exact task used during training, a limiting factor for practical applications such as rehabilitation, workforce training or education. Green and Bavelier [22] also stated that video game action may improve the ability to learn new visual tasks, and Green, Li and Bavelier, [23] documented that playing video games enhances basic visual skills, such as agglomeration acuity and contrast sensitivity.

Another example of increased visual abilities was shown by the experimental design by Li et al. [24]. The first ocular activities of 20 s used occlusion, and the next 40 s used video game therapy. The conclusion was that the improvement shown could not be explained simply by the eye occlusion technique. The limits and time course of visual plasticity induced by the video game experience were quantified. The observed visual acuity recovery was at least five times faster than would be expected from the single technique of occlusion in infantile amblyopia. Later Li, Ngo, and Levi [25] observed that after 40 s of video game play, there was a reduction in the blinking action of the eye. Hussain et al. [26] developed a video game with adaptive contrast for the treatment of 20 people with amblyopia and obtained excellent results.

There has also been research from the binocular point of view, in which neural signals of the amblyopic eye are suppressed in the cortex by the dominant eye. Research conducted by Baker, Meese and Hess [27] are related with support of the contrast in vision above the threshold. However, their research only involved eight people. Bi et al. [28] performed studies in monkeys that showed robust binocular suppression in both cortical areas, and the magnitude was correlated with the degree of amblyopia. Ding, Klein, and Levi [29] investigated binocular combination above the threshold in humans with abnormal binocular visual experience in childhood. Ding and Levi [30] performed research in humans with amblyopia regarding asymmetry in binocular vision with the purpose of developing new models and methods to rebalance this asymmetric binocular vision, as well as manipulating the contrast and brightness in both eyes. Hess, Thompson, and Baker [31] provided an overview of recent studies investigating the structure, measurement and treatment of binocular vision. Maehara et al. [32] investigated the manner in which suppression influences the relative perception of supralimilar contrast and luminance between the eyes of a person under conditions of visualization with dichoptic treatment.

Seen from this perspective, an alternative approach is to treat amblyopia by reducing suppression. Hess and her colleagues used video games to train adults with amblyopia and documented significant improvements in visual acuity and stereopsis. Some research by Hess, Mansouri, and Thompson and Hess, et al. [31,33] showed that long periods of visualization under conditions of artificial stimuli, during which information from the two eyes was combined, led to the reinforcement of binocular vision. In such cases, there was improvement in the monocular acuity of the amblyopic eye. Furthermore, there was a reduction, suppression and strengthening of binocular fusion. Li et al. [34] performed studies on adults with amblyopia who did not respond to eye occlusion therapy, demonstrating thatthe relief of amblyopic eye suppression through the presentation of dichoptic stimulus induces higher levels of plasticity than the forced use of the amblyopic eye alone. To et al. [35] developed a prototype for the treatment of amblyopia which the user can perform at home and which is of interest in current treatment of childhood amblyopia. They further stated that improvement in visual function can be achieved in amblyopic adults.

In Gargantini's article, [36] a virtual environment was developed with rift glasses only for the treatment of amblyopia. However, there were some drawbacks: it was unpopular, it was not well accepted by the young patients, and sometimes, it disturbed the residual fusion between the eyes.

Thus, it is observed that there has been much recent research on the use of a virtual environment for the exclusive treatment of amblyopia. It has already been proven that video games help the motor activity of the eye and develop brain plasticity. However, a technique to treat one of the origins of amblyopia, which in most cases is generated by strabismus, has not been described. The vergence of the eye is not observed when placing the patient in a game. Such activities may lead to a dangerous practices, as can be seen in the results of reference [28], which showed with animal studies that amblyopia and strabismus can be induced in orthoptic sessions. The tool used was the prism. In addition, an exercise sequence for rehabilitation has also not been observed.

5. Interactive Virtual Environment for the Treatment of Mechanical Structure and Ambliopia

The use of technology is increasingly becoming an important tool in rehabilitation. This has been well received and has shown satisfactory results [12,34,37]. It was based on this interaction that a method was sought to reduce the disorders caused by these eye diseases.

Virtual reality games were developed in which normal information was combined between the eyes in order to reduce the suppression by stimuli of different contrasts in each eye. The use of this type of noninvasive technique has the purpose of stimulating the brain, aimed at the temporary alteration of the balance of excitation and inhibition in the visual cortex, modulating the mechanisms responsible for the plasticity of the brain and causing the eyelid to recover its movement [38].

5.1. Virtual Reality and Google Cardboard

Real-time interactive graphical computing enables developers of computer equipment to create devices that allow a degree of immersion that is capable of introducing the user into situations that are happening in a computing environment. From this, the notion was generated of what nowadays refers to virtual reality as an interface between the user and the machine using a series of devices that simultaneously stimulate the human senses, expanding the user experience with the computational system [39,40].

Virtual reality has been gaining considerable space in the study of data output interfaces for computational purposes. It is mainly used in games. For user and machine interactions to occur satisfactorily, a range of equipment that is based on stereoscopic division of the image into the presentation of the virtual environment can be used. In this study, the tool used to treat convergent strabismus and amblyopia was Google Cardboard.

Google Cardboard

Google Cardboard is a Head-Mounted Display (HMD) built with low-cost materials, such as cardboard, biconvex lenses and a magnetic button. The Cardboard allows an individual to attach a smartphone to the front to view three-dimensional images, as seen in Figure 2 [41].

This device is used for the stereoscopic visualization of three-dimensional images through smartphones that have Android operating systems to immerse the user into a simulated virtual environment.

With the use of simple materials in its composition in terms of price, Google Cardboard is different from other virtual reality devices. It can also be manufactured by the user, since it is mostly made with cardboard, and all the processing of images and presentation of stereoscopic images is performed by the smartphone coupled to the front of the Cardboard.

The Cardboard's main objective is to allow access to the concept of virtual reality, and its practical application occurs in a simple and intuitive way by creating a functional and independent prototype [41].

Figure 2. Google Cardboard device used in three-dimensional image visualization [41].

The Cardboard is built with materials that cost a maximum of US$ 40.00 and this is possible by using low cost materials such as cardboard in the main frame and biconvex lenses for the correction of any distortions in the stereoscopic image presented in the application. Besides the lenses, Google Cardboard has a magnetic button that changes the intensity of the surrounding magnetic field. This variation in magnetic field strength can be detected by the smartphone through the magnetometer. By varying the intensity of the local magnetic field generated by the magnetic button and detected by the magnetometer of the smartphone, it is possible to select and control the actions of the mobile application that is responsible for the presentation of the stereoscopic images [42].

There are other goggles for viewing virtual environments, such as Oculus Rift, Project Morpheus and Gear VR. However, the problem with these devices, especially Oculus Rift, is the high cost of their construction. There is a product that is not in its final version and therefore, is not available in the market, apart from for developers [43]. However, there is equipment, such as Altergaze and Archos VR, which have a price and functionality similar to those of Google Cardboard, which qualify them as virtual reality glasses and consequently, allow them to be applied optionally in the treatment proposed in this work for the correction of strabismus and amblyopia. These, in addition to their low cost, have the advantage that they can be used practically everywhere because they require little physical space in terms of equipment.

5.2. The Games Developed for the Treatment

The virtual environment designed in Google Cardboard is characterized by three activities: the setting for immersion of the patient in the treatment and development of an elongation prior to the action activity, action activities for the stimulation of the musculature and relaxation, consisting of a final stretch. The games used in the study were Tetris, Runner, Pong and Relax, accompanied by metrics to measure performance with gamification elements, such as scores based on performance in the game and rankings with better scores. The punctuation of the patient was obtained as a method of attraction and to maintain the patient's self-esteem. Based on this sequence, it was observed that the virtual environment is destined to rehabilitate only muscular problems. It was also observed that there have been no previous studies that have explored the physiotherapy of the ocular muscles and their benefits [44].

The time taken to perform the daily activity activity was only thirty minutes, as it becomes a tiring exercise if done for periods longer than this. In addition, very long durations can cause dizziness and nausea in patients, which can lead to difficulties in the treatment and removal of the patient [45].

The system aims to generate a stereoscopic view; hence, the image display is in two halves that occupy the same dimensions of the display of the smartphone. These halves present distinct horizontal positions, which, when exposed to a certain distance from the eye (determined by the Cardboard carcass), generate the impression to the user that there is only one image with depth. Then, the virtual reality impression becomes evident. The image is distorted and slightly oval, and this distortion is corrected by the biconvex lenses present in Google Cardboard [46].

The game is shown to the patient with slightly different images for each eye. The main point is to get the eyes to work cooperatively by enlarging the level of adaptation of the brain to the exercise, applying stimuli to the weak eye so that the brain learns to discern the images and consequently, offering binocular vision. This exercise is achieved with some objects that are shown to the eye being treated.

The characteristics of the activities and scenarios developed to be used in the virtual environment include the following:

- Easy-to-handle activities to reach all ages, especially those of advanced age who have difficulty assimilating commands and understanding activities.
- Colorful activities to stimulate visual activity and attract attention.
- Activities that include a score regarding patient time and which are challenging for the patient to try to overcome each section.
- Educational activities without the use of scenarios that may deviate from the characteristics of the patient, especially in regard to age group.

The data collection instrument is online and can be accessed via the Internet, allowing the user to perform rehabilitation with pre-established activities. Users entering the virtual environment present an identification (code) that, during the course of the activities, is used to form their own database, automatically registering their metrics.

The process of visual rehabilitation of the strabismus promote a postural improvement due to postural habits resulting from deviations in the eye. There is a lower risk index in the rehabilitation of strabismus because it is a non-invasive method. This is because the patient does not undergo surgery, is not exposed to surgical and post-surgical infections, does not require hospitalization and does not undergo cuts. Furthermore, the technique does not cause necrosis.

However, the use of HMD can provide mild nausea, motion sickness and headaches due to the technology of virtual reality glasses. No matter how advanced it is, the technology has not yet overcome the obstacle of unease to some users, which occurs in these situations due to the differences between the movement perceived by the eyes and the movement perceived by the body. There is a delay between the movement of the head in virtual reality, and when the image in front of the user's eyes changes, there is a mismatch between the sensed movements (with the inner ears) and the observed image (with the eyes). In real life, this delay is zero, and the sensory and motor systems are tightly coupled. In summary, if there is movement in the individual's vision without movement in the vestibular system, a set of organs that regulates balance, the user will feel discomfort [47]. However, recent studies have suggested that the use of a virtual nose projected on the screen where the virtual environment is visualized can help to reduce the level of nausea. However, these studies still do not clarify the reason for the auxiliary resource in the reduction of the visual side effects of virtual environments [48].

6. Methodology

This research was exploratory and experimental and used a virtual environment for the rehabilitation treatment of patients with strabismus and/or amblyopia who have lost eye movement. The relevant part of it is the act of forcing the two eyes to cooperate with each other by increasing the level of adaptation of the brain and allowing the weak eye to see again, allowing the patient to have better visual comfort and quality of life. In addition, the virtual environment is attractive and has the ability to overcome specific challenges and real-time feedback, coinciding with ideal approaches to be used in ocular rehabilitation.

The study population was composed of randomly chosen patients, and the activities performed did not distinguish between sex.

There was a concern in the research team about designing a virtual environment that would be attractive to all age groups. For example, the eyes of a child of 8 to 12 years are attracted to dynamic and colorful virtual environments and theoretically present better performance compared to people aged over 40 years. This last class presents slower eye movement, with slightly compromised structures due to wear over time.

The exclusion criterion was intended for patients with strabismus whose deficiency was due to sensory deficiency and who did not have parental permission if they were underage.

The research was conducted after approval of the ethics committee. Strabismus individuals were composed of 41 randomly selected patients. The activity was performed in a reserved room, with only the patient and the participating health professional being present.

All the research was done by an experienced professional who was quite renowned in the area. The evaluation form used was the same one used by the clinic in order to facilitate the services of the professional.

The possible risks of this research were mild nausea, nausea and headaches due to the use of 3D glasses. To minimize these risks, professionals were trained and equipment was tested before use.

At each meeting with the professional, the patient performed three activities: relaxation, to immerse the patient in the treatment; action activities to stimulate the musculature; and metrics to measure performance. These exercises included half an hour of play in each consultation between 2 to 3 times a week for approximately 2 months, depending on what the professional recommended. These exercises consisted of sitting in a chair, putting on the special glasses and selection of three different sets by the physiotherapist to start the treatment.

6.1. Description of the Virtual Environment

The virtual environment was initially accessed with the software configuration to choose the resolution (512 × 384, 640 × 400, 640 × 480, 800 × 600, 1024 × 768, 1280 × 600, 1280 × 720, 1280 × 768, 1360 × 768, 1366 × 768) and graphic quality (fastest, fast, simple, good, beautiful, fantastic), as shown in Figure 3.

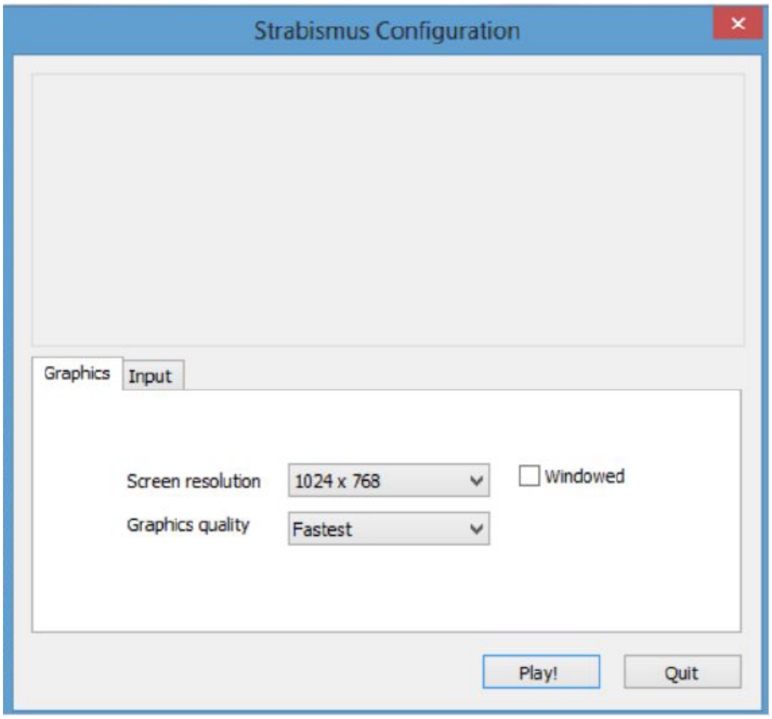

Figure 3. Choice of the resolution in the application used in the treatment described in this work.

The next step was to set up the identification of the patient. The activities were recorded in the database to analyze the evolution of the patient.

However, to meet the different degrees of convergent strabismus and amblyopia, the system was developed to choose the degree of vergence for each eye. The importance of this system is that after being able to rehabilitate the eye that has left the suppressed vision of the image, the professional can allow it to return to the proper position, reducing the vergence and training the muscles. The scenario that enables this function is shown in Figure 4.

Figure 4. Activity scenario.

6.2. Adaptation of the Virtual Environment

The main objective of having an ambience was to pass the central vision of the activity that is unknown to the patient, with the intention of decreasing the predictability of the activity which could cause a possible decrease in the response of the brain to the exercise. In the other activities, only changes in scenery occurred. It was during this period that the logic of the system, the patient's first contact, was understood. All patients needed to understand exactly how the activity operated, for example, handling the equipment correctly, so that they could perform actions accordingly and follow the activity without any doubt about the man–machine interface. This phase was of extreme importance because it refers to the stretching of the ocular muscles.

Stretches are exercises designed to increase muscle flexibility, which promotes stretching of the muscle fibers without causing damage or injury, making them increase in length, and preparing the muscle to exercise. Stretching is used to increase the mobility of soft tissues by promoting an increase in the length of structures that have had adaptive shortening. Its main effect is an increase in the movement amplitude, that is, an increase in the static flexibility [49]. In addition, this activity presents other functions, such as the reduction of the error at each beginning of the section, since the patient takes time to adapt. The eye cannot receive a very high activity load at the beginning of the section, and this becomes a process. A demonstration of the setting scenario can be observed in Figure 5.

6.3. Virtual Environmental Activity

In this section, the patient was induced to make movements in the eyeballs by exercising the muscles according to their performance and by making progress along the developed activities.

Positive adaptations were induced, such as muscular strengthening, improvement in concentration, balance and ocular motor coordination, and consequently, a gradual/excellent/optimal recovery of the movement dynamics. A demonstration of the scenario of the activity can be observed in Figures 6 and 7.

Figure 5. Atmosphere scenario.

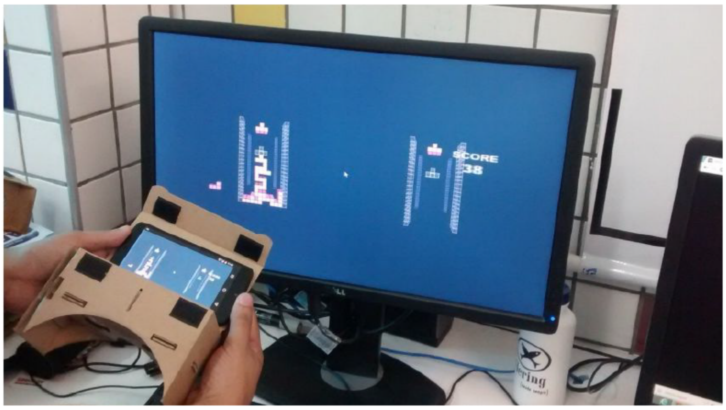

Figure 6. Activity scenario.

Figure 7. Activity scenario.

In this way, it is sought to force the activity of the eye that has been suppressed over time and in a second step to perform activities for the eye to direct the ideal position.

6.4. Relaxation of the Virtual Environment

The last activity of the patient was related to relaxation, which is a stretching activity. The practice of stretching after exercise is aimed at avoiding muscle shortening due to the strong and successive muscle contractions involved in the training [50]. The muscles tend to shorten when they spend a lot of time standing or when they get stiff when the body performs a very exhausting physical activity, losing its elasticity. Stretching is nothing more than a series of exercises that have the function of returning the muscles to their natural size or relaxing them. In addition, stretching improves blood circulation and motor coordination. During relaxation, the extent to which the patient is observed by some values on the screen by the volunteer himself, also leads to the acquisition of information in a more complete database of each patient. An illustration is shown in Figure 8. In the upper part, the missed points are shown, and these indicate the number of balls that the person has passed. The combo points indicate the points that the person is making in the match. In the lower part, the total points indicate the record of the volunteer. The green rectangle indicates the plane in which the ball is moving.

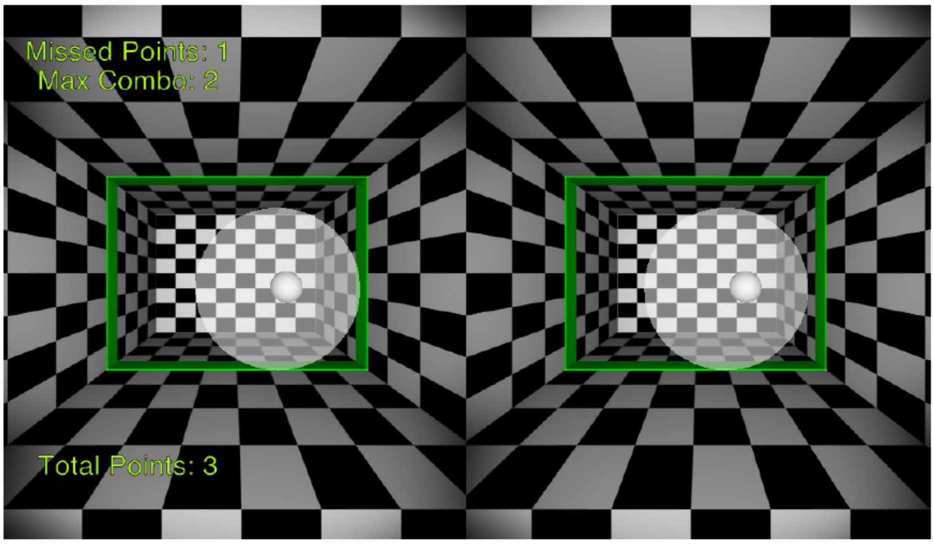

Figure 8. Relaxation scenario.

The practice of stretching at the end of the physical effort is aimed at avoiding muscle shortening due to the strong and successive muscular contractions involved in the training.

7. Results

After the sessions, the results obtained and are posted in Table 1. The table shows each patient, identified by a number, their age ranging from 8 to 39 years, the number of sessions and the success of the treatment.

Of the 41 persons who performed the tests, 39 of them obtained satisfactory results in their rehabilitation, that is, the treatment was effective in 98%. In 95% of cases, success was observed with a maximum of 10 sessions. In the remainder, a maximum of 20 sessions was required.

One negative result was observed in a patient who did not follow the professional's instructions—he was a child who participated in the treatment, referred by his parents and was not committed. The number of sessions stipulated as standard was 10. However, two patients presented difficulties and were assigned 10 more sessions by the professional. Two patients recovered quickly.

It was noted that age is not a barrier to treatment as accepted by ophthalmologists and idealized by Helveston in 1989 [51].

After the non-invasive treatment, it was observed that strabismus and amblyopia did not return, and this was the desired outcome.

It was observed that the score presented in the game made it interesting to follow the patient's emotional state during the activities and served as an overcoming attraction. Scores increased over time due to user adaptation.

Table 1. Treatment Results.

Patient	Age	Sex	No. of Sessions	Success
1	8	M	10	Yes
2	18	F	10	Yes
3	12	F	10	Yes
4	19	F	10	Yes
5	16	F	10	Yes
6	16	F	10	Yes
7	9	F	10	Yes
8	27	M	10	Yes
9	32	F	10	Yes
10	24	F	10	Yes
11	20	F	10	Yes
12	14	F	10	Yes
13	35	F	10	Yes
14	8	F	10	Yes
15	8	F	10	Yes
16	36	F	10	Yes
17	18	F	20	Yes
18	09	F	10	No
19	24	M	10	Yes
20	18	F	10	Yes
21	8	F	20	Yes
22	6	F	6	Yes
23	13	F	10	Yes
24	20	M	10	Yes
25	32	F	10	Yes
26	14	M	10	Yes
27	21	F	10	Yes
28	17	F	10	Yes
29	33	F	10	Yes
30	8	F	10	Yes
31	18	F	10	Yes
32	22	F	6	Yes
33	16	M	10	Yes
34	18	F	10	Yes
35	12	F	10	Yes
36	16	M	10	Yes
37	27	M	10	Yes
38	8	F	10	Yes
39	21	F	10	Yes
40	27	F	10	Yes
41	39	F	10	Yes

8. Discussion

Statistical evaluation of the visual gain with respect to adherence showed that 22% were people aged less than or equal to ten years old, 44% were people aged between ten and twenty years, and 34% were people aged over the age of twenty.

In this division, we note that individuals aged older than eight years of age can undergo training and that those older than ten years have the maturity to carry out the treatment. Patients who did not obtain positive results did not carry out the activities as requested by the professional. This shows that there is a positive correlation between doing the treatment properly and gaining visual acuity.

It can be observed that 80% of participants were female only 20% were male. This difference is the result of the culture in which the treatment was applied, in which the female audience has greater vanity and social demand for better aesthetics.

Many factors determine adherence to treatment, such as age, level of understanding of the problem by the parents, initial visual acuity and speed of acuity gain, and all of these points should be considered in regard to positive results with treatment.

As a difficulty to carry out the research was the acceptance of the family as a new method, the choice of games that was attractive to perform sections, simple to use and fast learning. Initially it would be prepared different games for different age groups, but could affect the results.

Compared with orthoptic treatments that include proper occlusion of the good eye as a critical factor for the good development of vision, in this method, occlusion of the eye with a buffer does not occur. However, the formation of a complementary image that forces the eye muscles to perform specific activities, occurs.

The fact that the treatment is not surgical has two positive points: it is not invasive and it allows ocular rehabilitation. Because it is not invasive, there are fewer risks in the treatment—reduced problems with infection, surgical powder and possible return of the deficiency. The eye is able to rehabilitate after treatment, while surgery does not rehabilitate the activities of the muscles. The treatment discussed in this article restores muscle action and thus far, prevents the return of the disease.

Regarding the evaluation of the time of treatment taken to obtain the rehabilitation, improvements were shown in a short period of time. The treatment obtained positive results in 93% of the cases in ten sections or less, obtaining rehabilitation.

9. Conclusions

From testing the method proposed in this study in patients with strabismus and amblyopia caused by eye muscle problems, it appears to be a functional, effective and accessible alternative to the traditional methods of treatment.

An important aspect of this project is the developmental and treatment sensitivity curve that is currently accepted as true. In addition, it is expected that this project will eliminate the corporal deviations married by strabismus and amblyopia at all ages. Another relevant aspect is the fact that the proposed treatment is affordable, allowing for its application in financially disadvantaged regions.

This method of rehabilitation of strabismus has a lower risk index because it is a noninvasive method. The index is reduced because the method does not expose the patient to surgical tools, does not expose to surgical and surgical infections, does not require hospitalization, does not involve cuts and does not cause necrosis.

For future work, we suggest that patients with these eye diseases should perform part of the activities in a virtual environment in their residences without removal of the accompaniment of the professional. The development of new attractive games that can reach a larger part of the population will also be encouraged.

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