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Visual training and emotional state of people with retinitis pigmentosa

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Abstract—The purpose of the study was to improve the visual functioning of people with restriction in contrast sensitivity (CS), such as retinitis pigmentosa (RP), by means of a visual training program. Twenty-six volunteers with RP participated, distributed in two groups: 15 who made up the experimental group (who received the training program) and 11 who participated as a control group (without training). Participants were evaluated before beginning training, on completion, and 3 mo following completion for CS with the Pelli-Robson Contrast Sensitivity (P&R) test, visual functioning with the Visual Function Questionnaire (VFQ), and in emotional state with the Beck Depression Inventory (BDI). The training program is based on software that generates luminous stimuli of varying duration and intensity and registers the stimuli perceived by the subject. The outcomes showed significant differences posttraining in the experimental group in depression ($F_{1,14} = 5.42$; $p < 0.04$), VFQ ($Z = –2.27$; $p < 0.02$), and P&R in the right eye ($Z = –1.99$; $p < 0.046$) and left eye ($Z = –2.30$; $p < 0.02$) but not in binocular ($Z = –0.96$; $p < 0.34$). The outcomes showed that the experimental group made significant progress in all variables and these effects remained after 3 mo, which suggests that the program could be a helpful addition to RP rehabilitation and help mitigate the damage.

Key words: adults, contrast sensitivity, depression, emotional state, rehabilitation, retinal degenerative diseases, retinitis pigmentosa, visual functioning, visual performance, visual training.

INTRODUCTION

The degree of autonomy in personal and social performance is assessed by efficiency in carrying out various daily tasks. In conducting these activities, people with low vision, such as those with retinitis pigmentosa (RP), can have serious difficulties, which may adversely affect their social and personal welfare.

RP belongs to a group of degenerative diseases of the retina characterized by a progressive loss of vision that can lead to blindness. This disorder specifically implies night blindness, peripheral restrictions and/or scotomas (scattered spots in which vision is absent or deficient) in the visual field (VF) [1–3], frequent reduction of visual acuity (VA) [1–4], and alterations in contrast sensitivity (CS) [5–6], showing a significant reduction of CS in a wide range of spatial frequencies. These symptoms affect daily visual functioning, lifestyle, and social development and influence the emotional state [7–8], as well as the visual-perceptual state [9]; therefore, paying attention to these aspects is fundamental in our study.

Abbreviations: BDI = Beck Depression Inventory, CS = contrast sensitivity, HMD = head-mounted display, MMSE = Mini-Mental State Examination, P&R = Pelli-Robson Contrast Sensitivity, RP = retinitis pigmentosa, SD = standard deviation, VA = visual acuity, VF = visual field, VFQ = Visual Function Questionnaire.

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Until now, there have been no medical solutions or pharmacological treatments for this pathology or for other degenerative visual problems.

Contrast Sensitivity

One of the parameters used to assess visual functioning, which significantly influences the performance of daily living activities, is CS [10–12], the ability to discriminate between shades of gray [13]. Assessment of CS is useful for evaluating the effects of some visual deficits because a person may have good VA but diminished CS and therefore may experience some difficulties in certain real-life situations [6–11]. This is the case of some people with RP.

Improvements in CS can be obtained in subjects with normal vision by training them with challenging tasks that involve vision [14]. This training is of great interest to people with RP since the loss of CS is one of the main difficulties faced [15] and significantly affects their ability to carry out daily living tasks [11].

Visual Functioning and Retinitis Pigmentosa

Various studies have indicated that differences in visual functioning in daily living activities are significant among people with visual impairments such as RP; therefore, their functional performance is considered in their assessment [11,16–18]. It has even been stressed that the outcomes of this assessment are as valuable and complete as the data provided by ophthalmological tests [11–18]. Procedures to evaluate visual functioning include lists or self-report tools used in the tasks in order to record easily observable behaviors. These behaviors make it possible to study visual functioning in daily living activities by measuring visual and psychosocial aspects. Other studies have shown that daily visual functioning can be affected by negative emotional states such as depression [11–18], although depression is also affected by daily living activities.

Emotional State and Retinitis Pigmentosa

Numerous authors have noted that adults who develop visual restriction have a greater risk of depression [18–21]. Furthermore, depression constitutes a major source of functional disability, and the consequences in adults also affect visual rehabilitation [22–23]. A previous research study showed that emotional adjustment worsens over time [24].

Depression in people with RP is frequent [7,11,18]. The prevalence has been estimated at 25.7 percent (while in the general population it amounts to 10%). Nemshick et al. showed that the period of greatest crisis or stress occurs during or immediately following diagnosis [25], and López-Justicia et al. recommended evaluating the depression variable just after the diagnosis of the disease and again over time [7].

Visual Stimulation and Retinitis Pigmentosa

Some years ago, procedures for assessment and for perceptual and visual training began to be applied to adults with visual deficiencies (including RP) in order to improve their visual functioning and performance in certain situations of everyday life [16–17]. These studies concluded that practice and training could improve the functional use of residual vision, although it was also observed that people who were more actively involved in training made better use of their residual vision [16]. Thus, both practice and motivation seem to be decisive factors in improving the use of residual vision.

Visual stimulation and training are highly relevant in interventions with people affected by low vision, even when the level of remaining vision is very low. This type of training has been proven to be effective in enhancing their quality of life regardless of the patient's age [26–27]. The aim of visual stimulation and visual training is to train affected people in using their visual functions so that they achieve both a quantitative and a qualitative enhancement in social functioning [26–27]. Likewise, visual stimulation and training allow affected people to use their remaining VA ability [28]; this aspect should not be disregarded, because it has been confirmed that a large number of RP-affected individuals maintain some VA to the end of their lives, even if it is minimal [29]. This fact is undoubtedly valuable for planning education and rehabilitation activities [30].

On the other hand, methods for training the visual system in people with VF deficit have been developed using computer programs to stimulate, through luminous points, the edge of the region of the VF situated between a visually intact area and a damaged area [31], resulting in a significant increase in visual function. For a long time, it was believed that these problems could not be treated since it was thought that vision required a high degree of neuronal organization produced during the early stages of life. Nevertheless, despite this specific period for organization, a considerable degree of plasticity has been documented in the adult visual system damaged by a lesion: a reorganization of the neuron receptive field occurs following lesions

in the retina or cortex, with cortical neurons with receptive fields associated with the damaged area of the retina acquiring new fields in adjacent areas [32]. Some of the criticisms of these procedures have pointed out that the increase in VF produced could be explained by movement of the eyes toward the affected area in an attempt to compensate for the deficit in VF [33–34].

Purpose of Study

The final purpose of this study was to improve the CS of people with limited CS, such as those with RP, by means of a visual training program.

Assuming as a starting hypothesis that it is possible to improve the CS of people with difficulties in this function, we have applied a training program based on the stimulation of VF with different levels of contrast and using covert direction of attention. It is known that covert attention, or orientation of the attention toward visual stimuli that appear in areas other than the fixation point, improves the response of the visual system [35]. We also hypothesized that visual training would lead to an improvement both in functional vision in daily living activities (specifically CS) and in emotional state.

METHODS

Participants

A meeting was organized for people with RP, members of the RP Association of Andalusia (who participated in research coordinated by two of the authors), to inform them about the objectives of the study and the activities involved. A sample of 26 volunteers with RP was then selected from all those who agreed to participate and who fulfilled the inclusion criteria: having bilateral VF loss ranging between 5° and 40° (binocular), having VA ranging between 20/20 (0.0 logMAR unit) and 20/200 (1.0 logMAR unit) in the better eye, and presenting no cognitive impairment (score greater than 24 measured with Mini-Mental State Examination [MMSE]). These participants were asked to provide an ophthalmological report, including the diagnosis and the degree of VA and VF. Their VA was measured with Snellen acuity charts, and their monocular and binocular kinetic VF was measured with a Goldmann Perimeter (V4, III4, I4, II2). Later, they were randomly assigned (considering VA and VF) into two groups: 15 (13 women and 2 men) who made up the experimental group (who received the training program), and 11 (8 women and 3 men) who participated as a control group (without training program). There were no significant differences between the groups in VA (right eye: $\chi^2 = 2.36$, $p = 0.50$; left eye: $\chi^2 = 6.36$, $p = 0.10$; binocular: $\chi^2 = 6.36$, $p = 0.10$) or in VF ($\chi^2 = 11.46$, $p > 0.99$). The participants were evaluated before starting the training period (pre-), on completion (post-) and 3 mo following completion (post 3 mo). At each evaluation, participants completed the following tests: the Pelli-Robson Contrast Sensitivity (P&R) test, the Visual Function Questionnaire (VFQ), and the Beck Depression Inventory (BDI). VA was measured only before beginning training and on completion. The participants in the control group were informed that they could undertake the training program in a second phase of the study.

Table 1 shows the demographic characteristics of the participants by groups. Four had associated incipient cataracts, one had mild central macular edema in one eye, another had very incipient macular degeneration in one eye, and three had photopsia (sensation of seeing lights, sparks, or colors). The presence of ring scotomas or temporal islands was not included in the reports. Participants had been diagnosed between 2 and 57 yr before (mean = 14.58, standard deviation [SD] = 11.16). None of the participants

Table 1.
Demographic characteristics of participants by group.

Characteristic	Experimental Group	Control Group
Age (yr)		
Range	22–57	17–57
Mean ± SD	43.00 ± 10.55	36.64 ± 13.06
Sex		
Female	13	8
Male	2	3
VA (logMAR unit)		
RE Range	0.00–1.00	0.00–1.00
LE Range	0.30–1.00	0.30–1.00
VF		
Range	5.00–40.00	5.00–40.00
Mean ± SD	14.80 ± 9.49	17.73 ± 13.11
Associated Visual Pathologies		
Incipient Cataracts	2	—
Photopsia	2	1
Mild Central Macular Edema	1	—
Mild Macular Degeneration	1	—

LE = left eye, logMAR = logarithm of minimum angle of resolution, RE = right eye, VA = visual acuity, VF = visual field.

were receiving any type of treatment for depression at the time of the study. One participant had mild central macular edema in one eye.

Materials

Contrast Sensitivity

To evaluate CS, we used the P&R test. The P&R test, as indicated by Pelli et al. [36], consists of two printed optotype charts, 97 × 82 cm, with eight lines each showing a different sequence of letters (6 per line). All the letters are the same size and are arranged in groups whose contrast varies from high to low. Each group has three letters of the same contrast level, and the contrast is lower in the group on the right. The test can measure up to 16 different contrast values in steps of 0.15 log units, from 0.0 to 2.25.

Visual Functioning

The National Eye Institute VFQ (VFQ-25, version 2000) was used to obtain a measure of the individual visual functioning in everyday life [37]. This instrument is composed of 38 items that provide a general measure of the difficulties associated with vision in daily life in people with chronic eye diseases, as well as 11 subscales that evaluate emotional well-being and social functioning: general health and general vision, near vision, distance vision, driving, peripheral vision, color vision, ocular pain, specific visual limitations (role difficulties), dependency, social functioning, and mental health. The questionnaire measures, therefore, visual and psychosocial aspects that belong to visual functioning in everyday life. The answers to the items range between 1 and 5 points, depending on which best fits the respondent's situation. These scores are converted to a 0 to 100 scale, so higher scores mean better visual functioning. The questionnaire enabled us to obtain scores in each of the subscales (although in the present study we have omitted the results in the driving subscale because only one participant could do it) and an overall score.

We chose this scale because it is much used and cited in recent years and there are studies that underpin its utility in the population with RP [18]. The psychometric properties of the scale are robust (the reliability ranges between 0.71 and 0.85 and it has reliability equal to or greater than 0.70, in all the subscales) [37].

Depression

We used the BDI to evaluate depression [38]. The BDI is a self-applicable instrument validated for the Spanish population [39] to quantify symptoms of depression in normal and clinical populations. The BDI has an average reliability (alpha coefficient) of 0.86 [40]. The version used in this study was the abbreviated scale of 13 items, and there is a high correlation (0.96) between both forms [38]. In this version, the respondent must choose a sentence from four options, listed in order of severity. Each item is assessed with different options of answers from 0 to 3, giving a total possible score of 39 points. The following scores were taken into account: 0 to 4 = absence of depression, 5 to 7 = mild depression, 8 to 15 = moderate depression, and >15 = serious depression [41].

Training Program

The instruments for the training program consisted of a personal computer, a head-mounted display (HMD), and software that generates the training patterns and registers the responses of the user during each session. Visual stimuli consisted of bright spots of varying intensity, duration, and position generated within the VF of the HMD, first for each eye in monocular vision and then in binocular vision.

Using an HMD allowed us greater control over the illumination conditions, as well as helping to avoid any possible sources of distraction. The software included in the training program generated the visual stimuli on the HMD and registered the response of the participant when he or she perceived it and pressed a key. The visual field was divided into a regular grid of eight by eight areas or cells arranged into four quadrants of the screen, with the stimuli located at the center of the cells. Stimuli were shown in all the defined positions at three different levels of intensity, 1/3, 2/3, and 1, with 1 corresponding to the highest intensity. During each complete training stage (either monocular or binocular), the 64 defined areas were stimulated once with each of the three intensity levels in each position presented randomly (64 stimuli per intensity level).

During the whole training session, a fixation point remained in the center of the screen, where the participants had to direct his or her gaze at all times. Before presenting each new stimulus, the quadrant in which it was due to appear was pointed at by an arrow in the center of the visual field behind the fixation point. The arrow remained in this position for a random variable time

(400–600 ms) before the stimulus appeared. The stimulus was then displayed for 200 ms. In some randomly selected cases, the stimulus was not provided, with the intention of avoiding any tendency toward false positives. Once the stimulus disappeared, there was a variable period of time during which the participant had to press a computer key to register the event as soon as he or she saw it. The time for registering events was also chosen randomly within a range between 400 to 600 ms.

The use of variable temporal ranges both in the stage prior to the display of the stimulus and in the phase in which, if it is perceived, it is recorded was intended to create a different duration for different stimulation cycles; we hoped that this would avoid participants registering stimuli that they had not seen because they were simply following a repetitive periodic response to the stimuli.

With the information generated in each session, a complete and detailed analysis of the development of each participant can be carried out.

Procedure

The procedure followed for applying the P&R test consisted of all the participants in the study reading (in monocular and binocular vision) the letters located on the optotype, beginning with the top row and continuing until two of the three letters in the same group were read incorrectly.

The participants sat in front of the chart at a distance of 1 m with the center of the chart at eye level, avoiding reflections on the surface of the chart. All participants were assessed at the same location and under identical conditions, maintaining the illumination constant and consistent with that established by the authors. The illumination was measured, following the recommendation of the test instructions, using a Lumix DMC-L1 camera with a Leica D Vario-Elmarit 14–50mm f/2.8–3.5 lens (Panasonic; Kadoma, Japan), adjusted to 100 ASA, so that the illumination of the room corresponded to the combination of 1/15 s and aperture of f/5.6.

Next, following a break after the CS test, we proceeded to evaluate VFQ (VFQ-25, version 2000) [37] and depression. The evaluation was carried out by the same researcher, administered in the same laboratory with the same luminance levels. Approximately 2 h were required to conduct all the tests.

The training phase for each participant was planned for a period of 3 mo, with daily 15 min sessions in the participant's home and 1 d off per week. Each session was divided into three phases: two to train each eye separately and a third for binocular training. The software program and HMD were installed on the laptops of all participants so that they could carry out the training at home, without having to travel. In the beginning of each phase at every training session, the software repeated the instructions through a message displayed on the HMD and a recorded speech. These instructions consisted of keeping their gaze on the central fixation point and pressing the laptop keyboard every time a stimulus was perceived. At the end of the session, when the three phases were completed, a message was displayed showing a measure related to the performance of the session, computed using the number of stimuli at each intensity that the user perceived. For each session, a file was generated containing all the relevant information for a later analysis: perceived stimuli (their intensity and location) and a timestamp to control the training follow-up. We recommended that participants complete the training every day during the same time frame, at a time when they were calm and could concentrate and when other factors would not interfere.

The participants were instructed to keep their eyes on the fixation point and to avoid eye movements during the intervention, although this was not monitored in every training session. However, at the beginning of each of the three stages, participants were reminded of this instruction with a message displayed on the HMD and with a spoken message that they carry out the training task by keeping their eyes on the fixation point.

During the training period, the process was monitored by a telephone call every 15 d, registering the most notable aspects of the participants' experience. No procedures were applied to affect the emotional state.

RESULTS

Statistical Analyses

Pretraining Measures

Since the violation of the homogeneity of variance between the experimental group and control group can lead to biased results in the analyses of unequal sample sizes, the Kolmogorov-Smirnov test was performed in the depression variable in the experimental group ($p > 0.90$) and in the control group ($p > 0.66$). No significant differences were found between the two groups ($F = 1.99$, $p = 0.18$). It was also performed for differences

between groups in depression (F = 1.99; p = 0.18) and VFQ variables (χ^2 = 3.08, p > 0.99). The depression scores and VFQ scores at pretest did not differ between the experimental group and control group.

Table 2 shows the mean score and SD of both groups in depression, P&R test, and VFQ before beginning training, on its completion, and 3 mo following completion. VA only shows two measures, before beginning training and after finishing it.

Table 3 shows the mean score and SD of both groups in VFQ subscales in the three assessments.

Correlation Studies

Spearman correlation analysis between the two groups showed a negative and significant relationship between levels of depression and VFQ (ρ = –0.64, p < 0.01) in both the experimental group (ρ = –0.73, p < 0.01) and in the control group (ρ = –0.84, p < 0.001). No correlation was found between levels of depression and VA in the right eye (ρ = –0.25, p < 0.26), left eye (ρ = –0.12, p < 0.59), or binocular (ρ = –0.08, p < 0.97) or between levels of depression and CS in the right eye (ρ = –0.18, p < 0.42), left eye (ρ = –0.39, p < 0.09), or binocular (ρ = –0.17, p < 0.47).

Results of Depression Variable

Different linear models of repeated measurements (2 × 2: two groups × two levels of measurements: pretraining and posttraining) were carried out for the depression variable. The main effect of group ($F_{1,24}$ = 0.34, p < 0.57) and the two levels of measurements ($F_{1,24}$ = 0.01, p < 0.91) showed

Table 2.
Mean ± standard deviation scores in depression, visual acuity (VA), Pelli-Robson Contrast Sensitivity (P&R) test, and Visual Function Questionnaire (VFQ) of two groups.

Measure	Pre		Post		Post 3 mo	
	EG	CG	EG	CG	EG	CG
Depression	5.08 ± 4.54	2.56 ± 2.69	3.66 ± 3.89	4.11 ± 5.60	3.25 ± 4.09	4.66 ± 4.82
VA-RE	0.23 ± 0.59	0.21 ± 0.62	0.17 ± 0.55	0.21 ± 0.62	—	—
VA-LE	0.19 ± 0.59	0.20 ± 0.64	0.15 ± 0.60	0.20 ± 0.64	—	—
VA-B	0.19 ± 0.59	0.20 ± 0.64	0.15 ± 0.60	0.20 ± 0.64	—	—
P&R-RE	1.45 ± 0.47	1.53 ± 0.42	1.55 ± 0.46	1.53 ± 0.42	1.58 ± 0.52	1.53 ± 0.42
P&R-LE	1.49 ± 0.33	1.48 ± 0.45	1.57 ± 0.30	1.48 ± 0.45	1.65 ± 0.34	1.48 ± 0.45
P&R-B	1.69 ± 0.26	1.63 ± 0.44	1.73 ± 0.26	1.63 ± 0.44	1.74 ± 0.27	1.63 ± 0.44
VFQ	63.92 ± 15.64	60.64 ± 19.33	67.08 ± 16.01	61.53 ± 18.78	65.60 ± 18.11	61.48 ± 18.99

B = binocular, CG = control group, EG = experimental group, LE = left eye, RE = right eye.

Table 3.
Mean Visual Function Questionnaire subscale scores (mean ± standard deviation) in two groups.

Subscale	Pre		Post		Post 3 mo	
	EG	CG	EG	CG	EG	CG
General Health	68.66 ± 13.39	71.36 ± 22.42	69.83 ± 15.10	72.72 ± 20.44	71.83 ± 16.72	72.00 ± 20.73
General Vision	58.66 ± 15.75	54.54 ± 18.50	57.66 ± 17.71	55.00 ± 20.00	59.33 ± 16.24	54.72 ± 19.93
Ocular Pain	78.33 ± 21.37	76.13 ± 18.07	85.38 ± 16.63	80.07 ± 17.38	84.16 ± 19.17	79.80 ± 17.54
Near Activities	66.10 ± 23.03	59.84 ± 28.52	64.44 ± 23.82	61.66 ± 28.79	63.83 ± 25.05	61.49 ± 28.95
Distance Activities	57.77 ± 19.08	53.37 ± 22.50	55.55 ± 16.49	56.16 ± 22.11	56.10 ± 15.65	56.43 ± 22.22
Social Functioning	63.88 ± 19.83	62.05 ± 21.26	65.55 ± 24.16	62.66 ± 23.59	62.21 ± 23.11	62.57 ± 23.72
Mental Health	67.66 ± 23.05	60.45 ± 29.19	73.00 ± 22.89	65.45 ± 29.10	70.33 ± 23.25	65.45 ± 29.10
Role Difficulties	62.50 ± 19.33	50.00 ± 19.96	58.75 ± 20.16	47.45 ± 14.44	56.25 ± 21.65	47.45 ± 14.44
Dependency	72.50 ± 27.01	63.63 ± 29.02	80.41 ± 23.12	65.45 ± 31.74	71.66 ± 29.77	65.18 ± 31.75
Color Vision	75.00 ± 25.00	77.27 ± 26.11	78.33 ± 20.84	75.00 ± 27.38	80.00 ± 27.05	75.00 ± 27.38
Peripheral Vision	43.33 ± 22.09	36.36 ± 20.50	45.00 ± 16.90	36.36 ± 23.35	43.33 ± 19.97	36.18 ± 23.24

CG = control group, EG = experimental group.

no significant differences, but there was a significant interaction between the two variables ($F_{1,24} = 6.12$, $p < 0.02$). A new linear model of the effects of the two levels of measurements on the levels of groups showed significant differences in the experimental group ($F_{1,14} = 5.42$, $p < 0.04$) but not in the control group ($F_{1,10} = 1.89$, $p < 0.21$). This confirms an improvement in the participants of the experimental group in the depression variable.

In order to know if the improvement was maintained, a new analysis posttraining and post 3 mo (using the *t*-test) was carried out. Since a decrease in depression can be expected as a result of training, we used a one-sided test, that is, halving the *p*-values found in the two-side *t*-test. In the experimental group, no significant differences were found between posttraining and post 3 mo ($t = 0.62$, $p = 0.27$), but significant differences were found between pretraining and post 3 mo scores ($t = 2.30$, $p = 0.02$). No significant differences were found in the control group between posttraining and post 3 mo ($t = –1.64$, $p = 0.07$), but significant differences were found between pretraining and post 3 mo scores ($t = –2.22$, $p = 0.03$), confirming an increase in the depression variable, contrary to what was observed in the experimental group.

Results in Visual Function Questionnaire Variable

The Wilcoxon signed-rank test was used to compare the scores of the two groups in VFQ. The results of this test in pretraining and posttraining showed significant differences in the experimental group ($Z = –2.27$, $p < 0.02$), but not in the control group ($Z = –1.12$, $p < 0.26$). No significant differences were found in posttraining and post 3 mo measurements in the experimental group ($Z = –1.36$, $p < 0.17$), nor in the control group ($Z = –0.68$, $p < 0.50$).

Results in Pelli-Robson Contrast Sensory Test Variable

In the P&R test, Wilcoxon signed-rank test showed significant differences in pretraining and posttraining scores in the experimental group in the right eye ($Z = –1.99$, $p < 0.046$) and the left eye ($Z = –2.30$, $p < 0.02$), but not in binocular ($Z = –0.96$, $p < 0.34$). No significant differences were found in the control group in the right eye, left eye, and binocular ($Z = 1.00$, $p < 0.32$). In the posttraining and post 3 mo scores, no significant differences were found in the experimental group in the right eye score ($Z = –0.21$, $p < 0.83$), left eye ($Z = –1.49$, $p < 0.14$) and binocular ($Z = 0.01$, $p > 0.99$), although significant differences were found between pretraining and post 3 mo scores in the right eye ($Z = –2.68$, $p < 0.01$) and in the left eye ($Z = –2.30$, $p < 0.02$), but not in binocular ($Z = –0.72$, $p < 0.47$). In the control group, no significant differences were found between posttraining and post 3 mo scores, or between pretraining and post 3 mo scores.

Results in Visual Acuity Variable

In the VA evaluation posttraining, Wilcoxon signed-rank test showed no significant differences in the experimental group score in the right eye ($Z = –0.16$, $p < 0.11$), left eye ($Z = –0.92$, $p < 0.36$), and binocular ($Z = –0.18$, $p < 0.85$). No significant differences were found in the control group in the right eye, left eye, or binocular, maintaining the initial mean scores.

Results in Training Program

To assess the gain score for each trained contrast level (1/3, 2/3, and 1), the average number of stimuli perceived in the last seven training sessions as compared to the first seven sessions was calculated over a maximum of 64 shown stimuli, taking into account the stimuli perceived with each eye individually and in binocular. **Table 4** shows these numbers and the average gain score at each contrast level, which has been calculated individually for each participant with the following expression: $(b – a)/(64 – a)$, where b is the average number of stimuli perceived in the last seven sessions, and a the average of the first seven sessions.

The average gain score achieved by the group was 26 percent for low-contrast stimuli, 20 percent for medium-contrast, and 6 percent for high-contrast. These results enabled us to confirm that the participants undergoing training improved in the three contrast levels, but especially in the low-contrast stimuli, as can be seen from the percentage values and also from the increase in the average number of perceived stimuli. The average number of completed training sessions was 58.1 (74.5%).

Table 4.
Number of perceived stimuli (average of both eyes and binocular) at beginning and end of training program, and gain score.

Contrast Level	First Week	Last Week	Gain Score
1/3	23.87	31.76	0.26
2/3	33.37	37.41	0.20
1	36.85	39.32	0.06

DISCUSSION

The final aim of the present study was to improve the CS of people with restriction in contrast, such as those with RP, through the training of CS. The results obtained confirm an improvement in the participants of the experimental group in CS, depression, and visual functioning, associated with the training. No significant improvement was found in VA.

Contrast Sensitivity and Visual Acuity

Given the data obtained on CS, we can confirm positive progression for people who carried out the training program. That improvement was maintained 3 mo after the conclusion of the training. There was also an improvement in the three contrast levels, especially in the low-contrast stimuli. We believe that these results are very interesting because, as has been widely argued, improvements in CS may facilitate the performance of visual processing at different stages of the visual system [13]. It is important to highlight this because the loss of CS is one of the main difficulties faced by affected individuals and seriously affects their daily life [11]. A look at the scores obtained in the P&R test reveals an improvement in each eye separately and in binocular vision after training (**Table 2**). However, in the case of binocular vision the improvement is not significant. Perhaps a larger sample or completing a higher number of training sessions would have allowed us to detect improvement in binocular vision. Note that there are no changes between the two evaluations in the control group, with scores remaining at the initial levels.

These findings are partially consistent with findings of Fahle and Poggio [42], who reported improvements in VA and CS after visual training, proving that perceptual training, previously considered not applicable to the treatment of adults, is effective for the treatment of, for instance, amblyopia and presbyopia [13,43–44], although in this study we have found no significant differences in VA. It should be noted that a possible limitation of the study lies in the wide range of VA and VF. Although a smaller range would have been desirable, the groups were, at least, homogeneous as shown by the statistical tests carried out. Also, in accordance with Hahm et al. [18] and Szlyk et al. [11], the assessment of visual functioning was as valuable and complete as the data provided by ophthalmologic tests and the results of VFQ pretreatment showed no significant differences between the two groups.

Emotional State and Visual Functioning

The results of Spearman correlation analysis highlight that there is a negative and significant correlation between the level of depression and visual functioning, which is in line with the data found in the studies by Hahm et al. [18] and Szlyk et al. [11]. For this reason, it seems reasonable to conclude that an improvement in visual functioning favors the emotional state and quality of life. The results obtained in our study showed an improvement in both variables of those who participated in the training program compared with the control group. It should be noted that the initial level of depression was in the limit range of mild depression and we observed a decrease in the scores obtained after the training and post 3 mo. This result has to be borne in mind when compared with those of the control group, which showed a slight increase (also in post 3 mo evaluation) in an even lower range of mild depression.

In spite of the great variability and heterogeneity between the participants in both groups (as demonstrated by the high SDs) and the slightly higher initial score in VFQ score in the experimental group, an improvement was noted in the experimental group. Certainly, the data from our study do not allow us to confirm emphatically that the improvement was due to participation in the program; however, they seem to confirm that participating in the program benefitted both visual functioning and emotional well-being. This improvement cannot be ascribed to the implementation of any psychological procedure to reduce levels of depression, because no such procedure or treatment was applied. Instead, the improvement could be related to the mutual influence of emotional state and visual functioning, also observed in other studies. For example, Hahm et al. [18] and Szlyk et al. [11] have pointed out the negative influence of the emotional state on visual functioning, which reduces people's vision-related quality of life, while Grant et al. [22] also stressed that the psychological state may influence vision rehabilitation programs.

Possibly, the opportunity to participate in the experiment and to make improvements in their training sessions (once the training session was completed the participants received an overall evaluation of the use of the session calculated by the number of stimuli perceived at each intensity) had an effect on the improvement of their emotional

state. In this sense, it must be stressed that all participants were volunteers with a moderate level of involvement, especially those in the experimental group (as evidenced by the regular and normal development of training for 74.5% training sessions). This may explain the favorable changes found, corroborating the results obtained in previous studies that demonstrate that practice and motivation seem to determine improvement [16]. Possibly, as stated by Herse [45], the simplest intervention may prove highly effective in enhancing quality of life and personal well-being.

Limitations

Although the results obtained seem encouraging, we are aware that they should be considered with caution because of the small sample size. Additional studies with larger samples will be needed to confirm our findings. Another limitation is the voluntary nature of participation in the study, which may explain, at least in part, the moderate degree of motivation.

Although the participants were instructed to keep their eyes on the fixation point and to avoid eye movements during the intervention, it would be desirable to control this factor. This task would be easier to carry out with the help of an eye-tracker if the training were carried out with a conventional monitor instead of the HMD we used. Nevertheless, we consider that the use of the HMD not only allows training to be less affected by the conditions of ambient illumination, but also decreases the effect of possible distractions that divert the attention, and therefore less effort is required to maintain the fixation point during the training session.

CONCLUSIONS

The results obtained seem encouraging since they highlight an improvement in CS, visual functioning, and emotional state of people with a degenerative retinal disease for which there is currently no treatment and the development and prognosis are not favorable. Although we did not find studies that analyze training to improve CS in people with RP that would have enabled us to compare our results, we believe that initiatives such as this can contribute to better functional and emotional well-being of this population.

For this reason, we think that the training program applied is a helpful addition to RP rehabilitation and that the findings of our study have important implications in planning interventions with people with RP. We should not forget the repercussions that visual impairments such as RP have on the emotional state and daily activities of those who are affected [7,11,18]. Hence, training to improve visual functioning may favor their personal, social, and professional integration.

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