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Effective Visual Field Rehabilitation in Homonymous Hemianopia by Attaching Binocular Prisms to Lenses

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Abstract

Purpose: To study if rehabilitation and partial recovery of the visual field is possible in the context of complete homonymous hemianopia (CHH). It is also important to determine whether or not the acquisition of pointing accuracy strategies by these patients leads to improvement in their everyday performance.

Methods: All the patients had neuro-ophthalmologic symptoms with sector field loss characteristic of CHH. We tested the effectiveness of a visual rehabilitation treatment for CHH, consisting in attaching prism strips to both lenses of the patient's glasses. We designed an experiment in which participants had to point to a target located at a particular distance and in a particular direction in the visual field, using a 'device pointer' fixed to a king-size protractor.

Results: Results from an ANOVA revealed that patients improved their ability to locate objects in space after three months of the treatment, that is, by means of practice and adaptation.

Conclusion: The partial recovery of the lost visual field can be explained by two alternative hypotheses: one is based on brain neuroplasticity and the other on perceptual learning and attentional filtering of two overlapping images.

Keywords: homonymous hemianopia, visual rehabilitation, visual psychophysics, hemianopic prisms, loss of visual field.

Introduction

Patients with normal visual acuity and complete homonymous hemianopia (CHH) present spatial orientation difficulties that negatively impact on their quality of life. They can lose the ability to dress themselves, may ignore routes that are familiar, stumble when walking alone, collide with obstacles, and find it all but impossible to read or work with a computer. In short, they lose personal autonomy. Paradoxically, it is common for patients in the early stages of this neurological condition to be unaware of these symptoms.[1] Consequently, a key question that needs to be addressed by the visual sciences concerns the extent to which some degree of rehabilitation or partial recovery of the lost field of vision (FoV) can be achieved. Specialists[2-3] in visual rehabilitation for hemianopia are also interested in whether or not the acquisition of compensatory oculomotor strategies by these patients could lead to improved performance in their everyday activities.

Hemianopia is often classified based on the location of the FoV that has been lost.[4] Complete homonymous hemianopia can be defined as absolute or partial loss of vision in the right or left FoV of both eyes.[5] It occurs as a result of structural pathological processes that affect retrochiasmatic visual pathways, and it can be caused by a variety of lesions and indifferent topographies.[5-7]

There is a small body of scientific literature[8,9,10,11] reviewing the factors associated with the epidemiology, aetiology, clinical presentation and course of hemianopias. Regarding aetiology, hemianopic defects are among the most common disorders after strokes. Rossi et al [12]reported that in the USA there were about 10million cases of head injuries annually, 20% of which were associated with brain injuries, and that a third of patients who survived a stroke had complete or incomplete homonymous hemianopia (HH).

In the UK, Pambakian and Kennard[2] estimated that approximately one third of patients who survived a stroke had complete or incomplete HH, with 40% of HH cases being caused by injuries in theoccipitallobe, 30% in the parietal lobe, 25% in the temporal lobe, and 5% in the optic tract and lateral geniculate nucleus.

Given the prevalence of hemianopia resulting from stroke and the increasing longevity of the population, research on the treatment of hemianopia must be regarded as a priority. A number of studies[8,12-13] have reported that the use of prisms (usually Fresnel prisms) can be an effective treatment for HH. Palomar-Petit[14] described how the central field could be restored by placing small prism strips on to the spectacle lenses (on the side with hemianopia) of patients. Gotlieb et al[15] proposed the use of a monocular sector prism that was affixed to the side of the lens corresponding to the lost visual field (VF). He noted that when the patient's eyes were in the primary position of gaze or directed outside the hemianopic hand, the monocular prism had no effect on the FoV. However, when the gaze was directed into the prism, confusion or perception of two different objects in the same location occurred. He interpreted that confusion would arise due to the appearance and visibility of an object which would be invisible without the prism. He also noted that diplopia occurred with the expansion of the resulting FoV, which could be very disorienting and unpleasant for the patient. These drawbacks could explain the limited success of this technique.

Gottlieb et al.[15] examined the use of 15-diopter plastic press-on Fresnel prisms as a means of recovering the FoV in 18 patients with stroke and homonymous hemianopia or unilateral visual neglect, comparing the performance of these patients with that of 21 controls. After four weeks the prism-treated group performed significantly better than controls on several tasks requiring hand-eye coordination. The authors concluded that the treatment with 15-diopter Fresnel prisms improves visual perception test scores, but not the performance on the Barthel ADL test[16], in stroke patients with homonymous hemianopia or unilateral visual neglect.

Gottlieb et al.,[15] Zihl[17] and also Kasten et al.[18]suggested that regular training of the blind FoV using visual stimuli similar to those used in a computer-controlled perimetry test could facilitate recovery of the FoV next to the midline and provide an expansion of the FoV.

Pambakian and Kennard[2] addressed the issue of whether it was possible to restore visual function in patients with CHH. They emphasized the importance of several rehabilitation treatments, such as psychophysical techniques, for improving care in the blind half of the FoV. They also suggested the possibility of using optical aids, hemianopic mirrors and prisms, as well as cognitive techniques for improving eye movements. They concluded that research on rehabilitation of patients with brain damage and functional impairment was a very difficult and laborious task. In addition, they acknowledged that the effectiveness of such treatments was not properly detailed, since there was insufficient research and most published studies suffered from some methodological flaw.

In a comprehensive review, Peli[19] classified the effects of the instruments used in the rehabilitation of hemianopia into two groups: those relocating the FoV and those producing expansion. He argues that the expansion effect of the FoV is preferred because the simultaneous FoV is wider and allows the patient to control the environment at all times, thus enabling safer mobility. However, relocation only changes the position of the lost FoV, or its relative position with regard to the midline. This author also holds that the FoV changes when viewed through binocular sectors. Since the patient does not see objects in that part of the FoV he or she is less likely to fixate, and therefore a voluntary eye movement is required. Peli[19] points out that in addition to these limitations, patients have an optical loss of FoV in the centre of the FoV caused by the binocular sectorial prism. Peli[20] has also developed a method consisting in a monocular sectorial prism fit on the eye with the side of the defect and limited to the top or bottom FoV, or covering both peripheral FoV. This prism has to be placed across the entire width of the lens in order to be effective in all lateral positions of gaze. The prism expands the FoV by promoting peripheral diplopia, producing optically peripheral exotropia, while maintaining bifoveal alignment. Peli[19] stated that this expansion of the FoV can be measured with standard binocular perimetry because it is effective in all positions of gaze, including the primary position. He uses 40-diopter Fresnel prisms, which give a spread of approximately 20° around the midline. However, since the prism only affects the peripheral vision, one could use another prism of greater power.

O'Neill et al[21] proposed the use of monocular prisms on the side of the complete hemianopia, with bases at the default address. In this way a peripheral exotropia is produced, which achieves the expansion of the FoV. With regard to the success of the rehabilitation process, Palomar-Mascaró et al.[22-23] emphasized the importance of ascertaining the prismatic power, as well as the need to ensure the correct position when attaching the binocular prism to the lens.

The aim of the present study was to evaluate the efficacy of a visual rehabilitation treatment with binocular prisms for CHH, by means of performance in a task of visual precision in spatial localization, measured with a 'device pointer' adapted to a king-size protractor.

Methods

Participants

Twenty patients (6 female, 14 male), ranging in age from 18 to 63 years, and 15 controls (6 female, 9 male), aged between 31 and 66 years, participated in the study.

The inclusion criteria for the group of patients with CHH were 1) diagnosis of CHH from more than one year, assessed by Dicon's computerized perimetry (Paradigm Medical) and confirmed neurologically by CT or MRI; 2) 6/6 visual acuity (VA); and 3) no previous treatment aimed at visual rehabilitation. Exclusion criteria for this group were1) anosognosia for the hemianopia and evidence of mental disorder or serious physical impairment, and2) normal or corrected VA below6/6.

The inclusion criteria for the control group were 1) 6/6 normal or corrected VA,2) no FoV defects, verified by computerized perimetry, and 3) no anomaly of binocular vision. Exclusion criteria for this group were1) less than 20/20 VA and 2) low willingness to participate.

Presbyopic participants wore the appropriate addition for 40 cm working distance.

Participants provided written informed consent after the nature of the study had been explained to them. The Declaration of Helsinki tenets of 1975 (as revised in October in 2008) were followed throughout the study, which received approval from the Ethics Committee of the University of Barcelona.

Stimuli and Apparatus

The stimulus was a point of 5 mm in diameter which could be placed in each of five directions in the visual field (-60º, -30º,0º, +30º and +60º). The experimenter located this target point at the eye level in a particular randomized angular location next to a protractor fitted with a bar. It was designed to measure precision in location of the visual direction of the target point (see Fig.1).

Fig1. *Pointer perimeter device consisting in a protractor fitted with a bar, thus enabling the experimenter to measure precision in the task of locating target points placed in different directions in the visual field.*

Treatment description: Palomar vertically attached prism.

The overall goal of vision rehabilitation is to reduce the effects of visual disability resulting from hemianopia. The treatment makes use of Palomar binocular sectorial prisms that are attached vertically to the patient's glasses, with the bases of the prism oriented towards the anopic area (see Fig. 2). This accessory facilitates access to the patient's lost FoV, helping him/her with spatial orientation.[23] The power of the attached prisms was determined in order to ensure their appropriateness for both, distance and near vision. The prisms had 20-25 diopters for far visual distance and 15-20 diopters for near vision, and were attached to the centre of the glass lenses in vertical strips. The bases of the prism were oriented toward the side of the homonymous hemianopic defect. Depending on the homogeneity of the loss to central FoV, the prisms were usually shifted between 1mm and 5.5 mm from the centre to the hemianopic side. To check participants' efficacy we used a computerized perimeter and presented the stimulus in a range around 30º eccentricity.

Fig2. *Top view (left panel) and front (right panel) of the spectacles of a patient with right homonymous hemianopia, showing the 20-diopter Palomar attached prisms, whose bases are oriented towards the right.*

The patient simultaneously receives images from the FoV of the left and right eyes, projected onto the functional hemiretinas. Images corresponding to the FoV of the non-functional hemiretina were then captured through the prisms (Fig. 3). Upon receiving these two different overlapped images, it is likely that the patient will have to sequentially process these images. Consequently, the visual system must perform a reconstruction of the visual space subtended for each eye, combining (merging) both reconstructed spaces. Thus, using the campimeter (perimeter) it is possible to assess the restored central FoV by comparing the spatial localization accuracy under both conditions, that is, executed with or without the aid of the attached prisms (Fig. 4). In this way, any beneficial effects of treatment can be quantified.

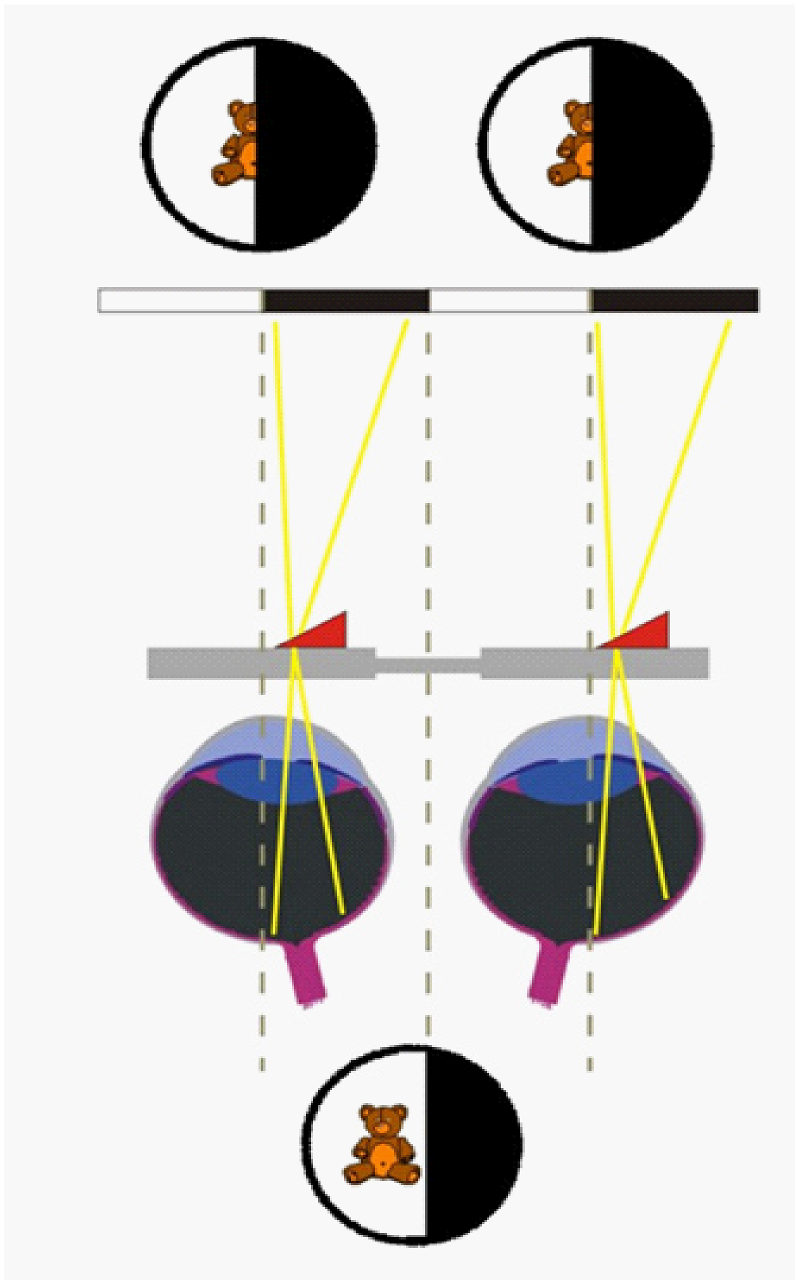

Fig3. *Diagram illustrating the functioning of the attached prisms in the case of a patient with right CHH.*

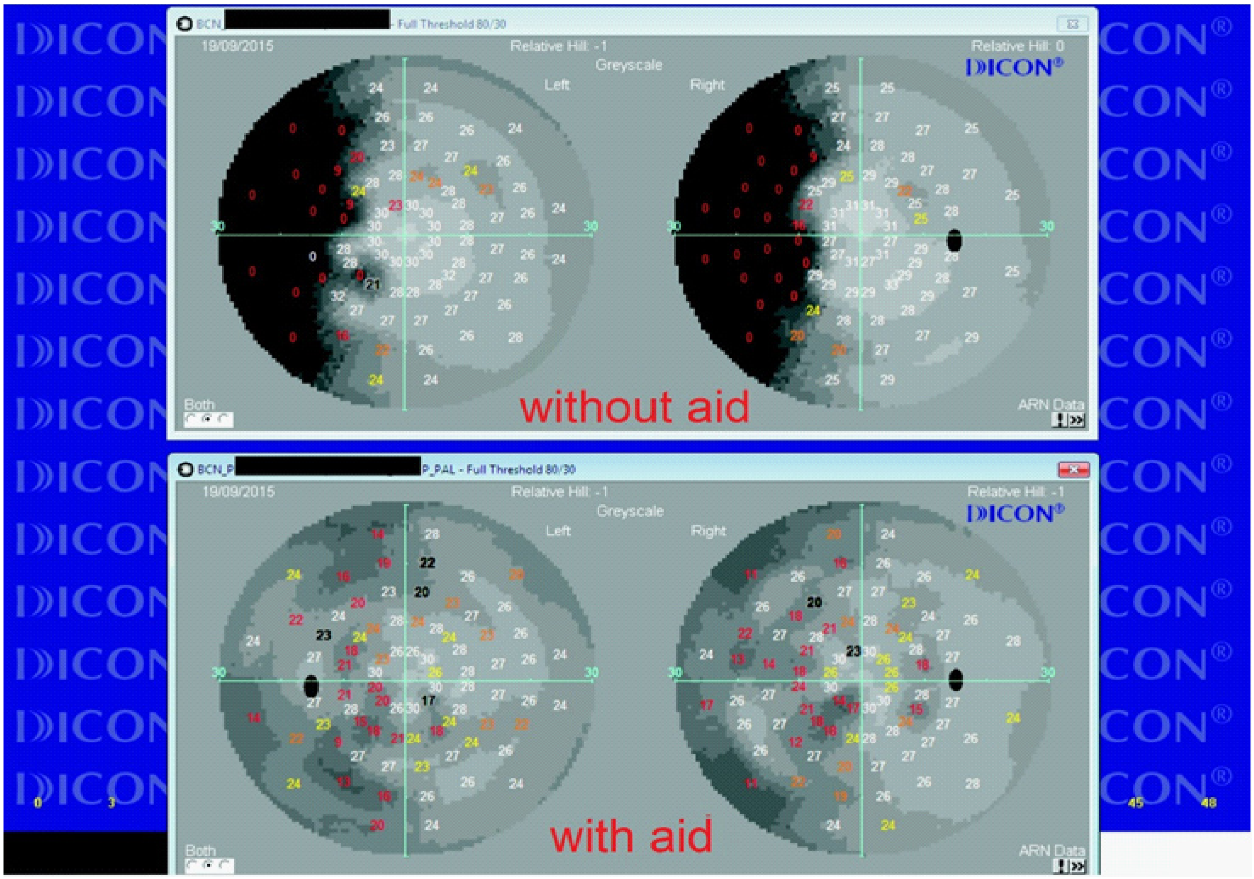

Fig4. *Visual field with and without prisms*

Procedure

The participants were tested for precision in the localization of a single point placed at a constant distance (30 cm in radius) for five visual directions in their visual field. The visual direction in which the patient was facing directly ahead was taken as 0º, while directions involving a deviation of ±30º and ±60º to the left or right were also presented in random order. Obviously, patients with homonymous hemianopia in the left visual field will show difficulties locating target points in the left visual field, while those with homonymous hemianopia in the right visual field will show difficulties locating target points in the right visual field.

The participants were instructed to rotate a bar until it was pointing towards the target point as precisely as possible. The rotation (visual direction) of the bar was recorded by fixing it to a protractor (see Figure 1). Thus, we used a magnitude production psychophysical method. Five trials (repetitions) were conducted using the pointing-bar task for each visual direction. These 25 trials were performed using the prisms under three visual conditions [two under monocular vision (LE and RE) and one under binocular vision]. In addition, the participants were tested at three time points: a) at baseline (first session), b) after a month, and c) after three months.

Therefore, each participant performed a total of 225 pointing trials per session (5 Repetitions × 5 Directions × 3 Visual conditions × 3 Time points). Each participant took around 40 minutes to complete the 225 trials/session. Thus, the total duration of the tests across the three sessions was around 120 minutes.

Results

First, the pointing errors (deviation or difference in rotation) were calculated for each trial in the group of patients with hemianopia. The means of the errors were then used to conduct a mixed factorial ANOVA with Direction (-60º, -30º,0º, +30º and +60º), Visual Condition (Left Eye, Right Eye and Binocular) and Time (baseline, 1 month, 3 months) as repeated measures, and Hemianopia as the between-subjects factor. The Greenhouse-Geisser correction for non-sphericity was applied when necessary and is indicated by the adjusted degrees of freedom.

The results from the 5 x 2 x 3 x 3 (Direction x Hemianopia x Condition x Time) ANOVA showed that the main effects of Direction [F(2.097, 37.75)= 42.468; p < .001; η2p= .702; pow= 1.0] and Hemianopia[F(1,18)= 12.830; p < .001; η2p= .536; pow= .991] were statistically significant. The main effects of Condition and Time were not significant. Errors increased in line with the deviation in the frontal line (visual direction) (see Fig 5). However, errors also depended on the lateralization of the hemianopia (to the left or to the right). Thus, patients with left hemianopia made greater errors (-.643º)in the left visual field, and vice-versa, that is, patients with right hemianopia made greater errors (+.451) in the right visual field.

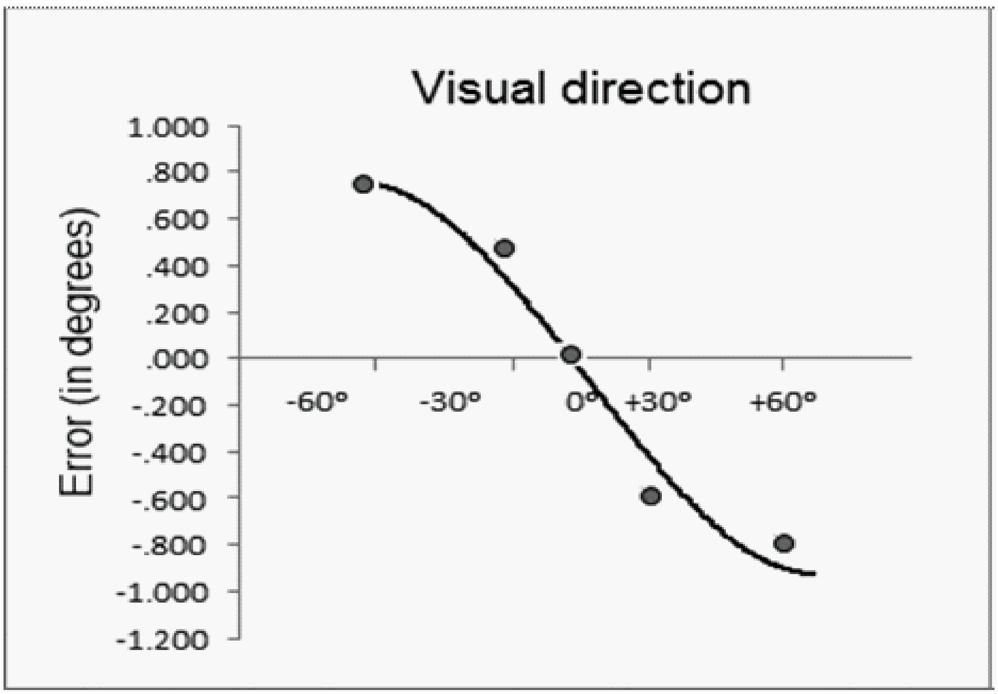

Fig5. *Mean of the errors in the pointing task according to visual direction and the best fit function.*

The two-way interactions of Direction x Hemianopia [F(2.097, 37.75)= 6.934; p < .001; η^2p= .278; pow= .992] and Direction x Time[F(3.34,60.117)= 47.302; p < .001; η^2p= .724; pow= 1.0] were significant. Simple effects analysis revealed that errors at baseline and at one month were significantly greater for directions contra lateral to the hemianopic retina, whereas they were null for the ipsilateral retina (Fig. 6) and any differences were not significant. In addition, the error in these directions decreased significantly with time, such that the results obtained at three months showed that the error was almost null (Fig. 6) and any differences were not significant.

The two-way interaction Hemianopia x Time was also significant [F(1.14, 20.52)= 24.584; p < .001; η^2p= .577; pow= .990]. Errors corresponding to the left hemianopia and those caused by damage in the right hemisphere both decrea sed significantly as time passed.

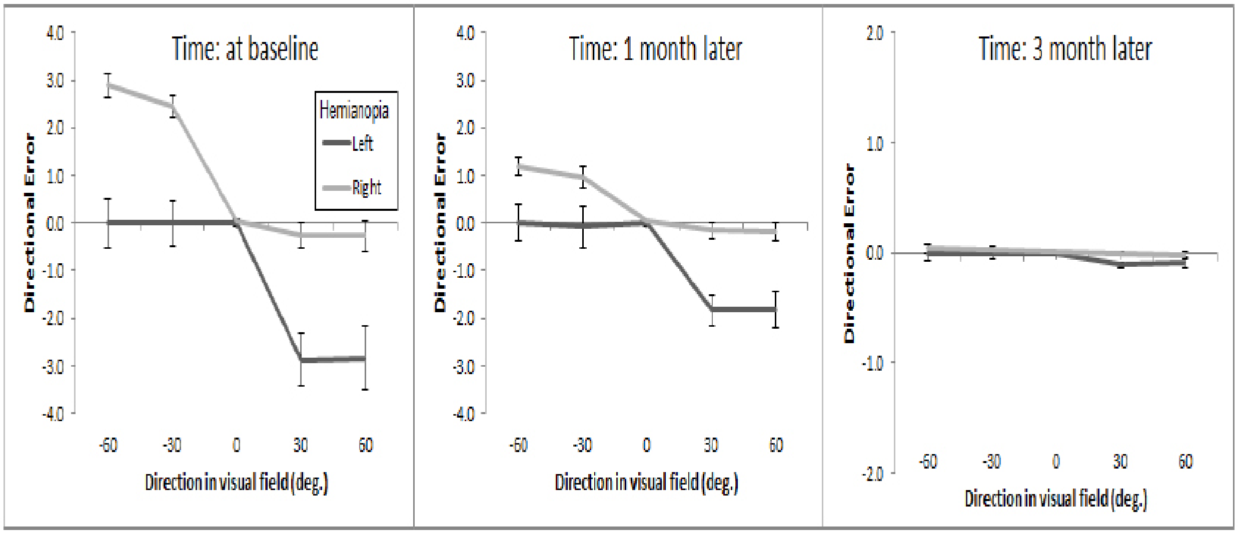

Fig6. *Mean of the errors in the pointing task for each type of hemianopia as a function of the visual direction and according to time. Bars indicate the standard error of the mean (95% confidence level).*

Finally, the three-way Direction x Hemianopia x Time interaction was also significant [$F(3.34, 60.117)= 8.378$; $p < .001$; $\eta^2 p= .318$; pow= .994], suggesting that for participants with hemianopia, errors occurred when the stimulus was located to the contra lateral side in the visual field with respect to the hemianopia. Compared with the 0º visual direction these errors were larger for ±30º ($p < .03$) and even greater for ±60º ($p < .03$). However, these effects diminished as time elapsed, with errors disappearing after three months of the treatment involving prisms attached to the patient's glasses. Figure 6 shows the mean errors in the pointing task corresponding to each type of hemianopia as a function of the visual direction, and with each panel showing the results for a particular time. Taken together, these results indicate that participants with hemianopia improved their performance in the pointing task that required them to locate target points (stimuli) in the affected region of the visual field, and that this improvement was achieved in about three months of treatment with the prisms attached to their glasses.

The pointing errors (deviation or difference in rotation) were also calculated for each trial in the Control group (people without hemianopia). The means of the errors were then used to perform a mixed factorial ANOVA with Direction (-60º, -30º,0º, +30º and +60º), Condition (Left Eye, Right Eye and Binocular) and Time (baseline, 1 month, 3 months) as factors. Direction, Condition and Time were taken as repeated measures. The results from the 5 x 3 x 3 (Direction x Condition x Time) ANOVA showed that none of the main effects was significant. Moreover, neither the two-way interactions nor the three-way interaction were significant. Therefore, no significant differences in pointing task errors were observed.

Errors made by the two groups (patients and controls) for each visual direction in the last session (after three months of treatment), but only in the binocular visual condition, were then compared by a two-way mixed ANOVA: 2 (Groups) x 5 (Directions), with Group as the between-subjects variable and Direction as the within-subject variable. The results showed again that none of the main effects for Group ($p < .812$) or Direction ($p < .186$) was significant. The two-way Group x Direction interaction was like wise not significant ($p < .187$). Therefore, no significant differences in pointing task errors were observed between the two groups after the treatment (i.e. at three months).

Discussion

A major problem that urgently needs to be addressed by the visual sciences concerns the extent to which rehabilitation and partial restoration of the FoV is possible in patients with CHH. It is also important to determine whether or not the acquisition of compensatory oculomotor strategies by these patients leads to improvement in their performance and normal functioning. The overall goal of the present rehabilitation treatment for homonymous hemianopia was to reduce disability resulting from the loss of FoV, to increase patients' confidence and to facilitate reintegration into their social and professional lives by restoring autonomy. The aim of the study was to investigate the efficacy of this treatment, in which prisms are attached to the lenses of a patient's glasses for a period of three months.[21-22]

To test the efficacy of the treatment we designed an experiment in which participants had to locate a number of points presented sequentially in random order. The points were located at a particular distance and in a particular direction in the visual field, and patients were asked to indicate their position using a 'device pointer' attached to a protractor. The analysis showed that patients had monocularly recovered the lost FoV. Specifically, they improved their ability to locate objects in space by using the attached prisms, that is, through practice and spatial visual adaptation (perceptual learning in eye-hand coordination, etc.). The most remarkable result was that three of the patients, who had presented homonymous hemianopia for more than five years, achieved a recovery of between 5 and 8 degrees around the central FoV through use of the attached prisms. In these cases, the prism was attached between 1 and 2 mm towards the side with a loss of FoV. This recovery was evaluated clinically by computerized perimetry.

Location tasks have been used to assess the cortically blind hemifield. For example, Zihl and von Cramon[24] tested localization in the cortically blind fields of their patients and found that performance improved with practice when pointing[25] or when saccadic responses were required.[17,24,26] In the context of perceptual learning it is interesting that the practice effect transferred to stimuli of lower contrast in the patient tested by.[25]

Our results raise the question of how (i.e. through what monocular mechanisms) such spatial reconstruction may occur. There are two possible scenarios that could explain the results. One explanatory hypothesis is based on the recovery of perception corresponding to the central-part FoV of the lost half-retina. This hypothesis assumes that cerebral neuro plasticity processes are induced in the patient, and that this enables recovery of alternative visual processing pathways. One obvious way to test this idea would be to obtain neuro imaging recordings of brain regions involved in processing the target location when it is localized in positions corresponding to the lost FoV. Indeed, by using fMRI (functional magnetic resonance imaging) or PET (positron emission tomography) to record images before and after treatment, and during execution of the task, it would be possible to confirm or rule out any neural activity in the visual pathways in the brain. An alternative and more plausible explanation involves spatial reconstruction of the visual scene. This reconstruction would operate monocularly and would produce some recovery in the FoV, which could be explained by the action of a selective attentional filter that would be temporarily applied to each of the two super imposed images that the attached prisms send to the healthy hemi retina. As a result of treatment (prism strips attached to the patient's glasses)[22-23], two overlapping images are projected onto the subject's retina. One of them corresponds to the individual's usual field of registration, while the other overlaps the first, due to the displacement of the image caused by the prisms and the corresponding visual field damage. This is why, when starting treatment, patients reported experiencing spatial displacement in the restored half-field, but did not report any diplopia or confusion. After a process of sensory adaptation, patients must learn to pay attention separately and sequentially to each of these two images. In our case, the improved performance of patients in the location task (using a device pointer) suggests that this enhancement is not due to an oculomotor use of compensatory strategies. Rather it can be attributed to some degree of learning resulting from selective access to each of the two images projected onto healthy hemi retina and further processing of these images, thereby allowing reconstruction of the frontal visual space. We believe that the gain in amplitude of the lost FoV occurred because the patient had the opportunity to practice in relation to the visual (attentional) selection among the two overlapping — although separable — images. Attentive processing is initially voluntary and subsequently becomes automatic. The increased ability to separate the two superimposed images on one retina, after a period of adaptation and practice, allows patients to reconstruct an image with greater horizontal extension, integrating the two overlapping images.

This perceptual grouping has previously been demonstrated with images of binocular rivalry by Kovács and colleagues.[27] They used pairs of dissimilar images with confused patterns, breaking the coherency of conventional stimuli and replacing them by complementary patchworks of intermingled rival images. In this way they showed that the brain unscrambles the pieces of the patchwork arriving from different eyes to obtain coherent perception. Indeed, pattern coherency in itself can lead to perceptual alternations, and the patchworks are reassembled into coherent forms by most observers. Although the role of retinal disparity and diplopia has been considered for a long time (e.g., Mitchell[28,] and Howard and Roger[29]) very little attention has been paid to 'overlapped images' in research papers. One exception is the study by Pepperell and Ruschkowski[30] in which they tested whether the inclusion of double images in two-dimensional pictures could enhance the illusion of three-dimensional space. They concluded that double images could be added to the list of depth cues available to the list of pictorial depth cues.

To conclude, the results of the present study shed some light on the principles underlying the recovery of the visual field in patients affected by CHH. We propose that the main mechanism supporting this rehabilitation is one involving attention and automatic processing of images in the retina. Further research is now required to demonstrate the ability to dissociate automatically two images that are overlapped in the retina.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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