Original article

Binocular vision in glaucoma

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ABSTRACT

Objective: To describe the possible impairment of binocular vision in primary open angle glaucoma (POAG) patients.
Method: A cross-sectional study was conducted on 58 glaucoma patients, 76 ocular hypertensives and 82 normal subjects. They were examined with a battery of binocular tests consisting of the measurement of phoria angles, amplitudes of fusion (AF), near point of convergence (NPC) assessment, an evaluation of suppression (Worth test), stereoacuity according to Titmus, and TNO tests.
Results: The patients with glaucoma showed significantly increased phoria angles, especially in near vision, compared with the ocular hypertensives and controls (p = 0.000). AF were reduced mainly in near distances compared to hypertensives and controls (p = 0.000). The NPC of glaucoma was higher than the other two groups (p = 0.000). No differences were found in the near-distance suppression test between the three groups (p = 0.682), but there were differences in the distance vision of patients with glaucoma compared to hypertensives (OR = 3.867, 95% CI; 1.260–11.862; p = 0.008) and controls (OR = 5.831, 95% CI; 2.229–15.252; p = 0.000). The stereoacuity of patients with glaucoma was reduced in both tests (p = 0.001).
Conclusions: POAG is mostly associated with, an increased exophoria in near vision, a decreased AF in near vision, a far-distance NPC, central suppression in far-vision, and a loss of stereoacuity. These changes do not seem to appear early as they were not observed in hypertensive patients versus controls.

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La visión binocular en el glaucoma

RESUMEN

Objetivo: Describir posibles alteraciones de la visión binocular en sujetos afectados de glaucoma primario de ángulo abierto (GPA). Método: Estudio de diseño transversal. Se incluyó a 58 sujetos glaucomatosos, 76 hipertensivos oculares y 82 controles. En estos pacientes se estudiaron los ángulos de foria, las amplitudes de fusión (AF) en visión lejana y cercana, el punto próximo de convergencia (PPC), la supresión cercana y lejana mediante el test de Worth y la estereoeagudez según los tests de Titmus y TNO.

Palabras clave:
Visión binocular
Glaucoma
Fusión
Convergencia
Supresión
Estereopsis

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Introduction

Chronic open angle glaucoma (POAG) is a relatively frequent ocular disease affecting 2% of the adult population over 40. In addition, this prevalence increases with age. Glaucoma continues to be one of the main causes of blindness in the world, including highly industrialized countries. It is a chronic and initially asymptomatic disease that causes irreversible vision loss in a slowly progressive manner. It has been observed that from not very advanced stages of the disease patients experience limitations in daily activities related to vision, involving a significant reduction in their quality of life.

Generally, POAG affects both eyes either symmetrically or asymmetrically. It is assumed that glaucoma damage in each eye hinders sensory integration of monocular visual stimuli and this involves the deterioration of binocular vision. Even though onset is very gradual, this loss of binocularity could contribute to explain the physical limitations observed in patients due to its negative impact on visual performance.

This paper studies the possible binocular vision alterations in POAG subjects.

Subjects, materials and methods

The study was designed as cross-sectional. All subjects included in the study were in the Health Area 9 of the Community of Madrid and were selected consecutively by order of appearance in the period comprised between March 2006 and December 2010. Each subject signed an informed consent in order to participate in the study.

Overall, 216 subjects were recruited of which 58 were classified as glaucoma patients, 76 as ocular hypertensive (OHT group) and 82 non-glaucoma or hypertensive subjects (control group). The glaucoma group included patients with clinic and diagnostic of uni- or bilateral POAG with reliable campimetry and a mean deviation (MD) better than −12 dB in the worst eye and with intraocular asymmetries under 6 dB. The subjects fulfilling one or more of the following criteria were excluded: non-glaucoma optic neuropathy history, amblyopia, strabismus in childhood or acquired in adulthood, presence of opacities, recent intraocular surgery (under 2 months), corneal refractive surgery and existence of large refractive defects or anisometropia. The control group included subjects with intraocular pressure (IOP) under 21 mmHg, without hypotensor treatment in the absence of acquired papillary damage and without campimetric deterioration. The inclusion criteria for the control group were also applied to the OHT group with the exception of IOP which should be 21 mmHg or over without hypotensor treatment.

All selected subjects underwent a complete ophthalmological assessment, with visual acuity assessed in the logMAR scale, spherical equivalent, central corneal pachimetry in microns (µm) and IOP. In addition, they underwent campimetry with the 24-2 algorithm of the Humphrey II 740 field analyzer (Humphrey Instruments, Dublin, USA) and a specific assessment of binocular vision comprising: (a) horizontal phoria angles (HFA) in near and far vision by means of the red lens test and prism bar; (b) fusion amplitude (FA) in near and far vision, measuring the fusion rupture point in divergence and convergence with prism bar; (c) near convergence point (NCP) measured in centimeters, utilizing a morphoscopic steadily as fixing object; (d) sensory suppression determined with the Worth light test in far and near vision; (e) stereoacuity evaluation by means of Titmus test (Stereo Optical Co. Inc., Chicago, IL, USA) and TNO test (Laméris Tech, Nieuwegein, Holland).

Statistical analysis

A descriptive analysis was performed, verifying quantitative variables against normal values by means of the Kolmogorov–Smirnov (K–S) test. For paired variables (right and left eye), such as logMAR VA, spherical equivalent, central corneal pachimetry and MD, the mean value was taken as the study variables. The ANOVA variance analysis was applied for simultaneously comparing the mean quantitative variables of the 3 groups, while in the case of non-normal distributions the Kruskal–Wallis nonparametric test was applied. For quantitative variables comparisons the Chi square test was utilized.

A p value under 0.05 was taken as statistically significant. The statistical analysis was carried out with the SPSS Statistics software version 15.0 (SPSS Inc., Chicago, IL, USA) for Windows.
**Results**

No differences were found in visual acuity, age, spherical equivalent or sex distribution of the 3 studied groups ($p>0.05$) (Table 1). However, differences were found in the central corneal pachymetry and MD. For these variables, differences were found between glaucoma and hypertensive subjects ($p<0.05$), and between glaucoma and control subjects ($p<0.05$), but not between hypertensive and control subjects ($p>0.05$).

In near and far vision, HFA subjects were higher in the glaucoma group as against the HTO and control groups ($p=0.000$) (Table 2). Comparing the hypertensive and the control group, no significant differences were observed in the near and far phoria angles ($p=0.950$ and $p=0.652$, respectively), but significant differences were found between the glaucoma and hypertensive groups ($p=0.000$ and $p=0.000$, respectively), and the glaucoma and control groups ($p=0.000$ and $p=0.000$).

FA was diminished in glaucoma subjects (above all the near FA) against hypertensive and control subjects (Table 2). Comparing the groups in pairs, no differences were found only between the OHT and the control groups ($p=0.704$ and $p=0.853$ near and far FA, respectively). No differences were found in the rupture point in divergence between the 3 groups in near vision ($p=0.703$) as well as in far vision ($p=0.063$). However, differences were found for the rupture point in near convergence ($p=0.000$) and in far convergence ($p=0.025$) (Table 3). Once again it was observed that said differences were verified between glaucoma and hypertensive subjects and between glaucoma and control subjects, but not between hypertensive and control subjects.

NCP was statistically different in the 3 groups ($p=0.000$) and much higher in glaucoma subjects (Table 2), although differences between hypertensive and control subjects were not observed ($p=0.824$).

In what concerns near vision suppression (Worth test) no statistically significant differences were found between the 3 studied groups ($p=0.682$). But said differences were found in far vision suppression ($p=0.000$). According to the far vision Worth test there were no differences between the HTO and control groups (Chi square $p=0.522$), whereas differences were found between the glaucoma and HTO groups (OR = 3.867; CI 95%, 1.260–11.862; $p=0.008$), and glaucoma and control groups (OR = 5.831; CI 95%, 2229–15,252; $p=0.000$) (Table 4).

According to the Titmus test, glaucoma subjects exhibited stereoaucity of 180.54 ± 77.45” whereas hypertensive subjects exhibited 46.52 ± 7.51” and control subjects 46.56 ± 7.25. None of the 3 distributions was normal according to the K-S test ($p<0.05$). Said stereoaucity values were different from the statistical viewpoint ($p=0.000$). The stereoaucity of the glaucoma group was statistically different to that of the hypertensive.

### Table 1 – Mean ± standard deviation of demographic and evaluation variables.

<table>
<thead>
<tr>
<th>Glaucoma</th>
<th>Hypertensive</th>
<th>Controls</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>67.16 ± 9.53</td>
<td>63.75 ± 8.58</td>
<td>64.38 ± 8.06</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>42.9/57.1</td>
<td>32.89/67.10</td>
<td>32.93/67.07</td>
</tr>
<tr>
<td>Pachymetry (µm)</td>
<td>528.30 ± 35.90</td>
<td>558.52 ± 32.56</td>
<td>557.95 ± 30.97</td>
</tr>
<tr>
<td>VA logMAR</td>
<td>0.010 ± 0.027</td>
<td>0.002 ± 0.009</td>
<td>1.004 ± 0.013</td>
</tr>
<tr>
<td>SE</td>
<td>−0.02 ± 1.56</td>
<td>0.60 ± 1.05</td>
<td>0.60 ± 1.19</td>
</tr>
<tr>
<td>MD</td>
<td>−6.57 ± 2.39</td>
<td>−1.63 ± 1.42</td>
<td>−1.59 ± 1.30</td>
</tr>
</tbody>
</table>

MD, mean deviation; SE, spherical equivalent; µm, micron; M/F, male/female.

### Table 2 – Mean ± standard deviation of binocular vision variables.

<table>
<thead>
<tr>
<th>Glaucoma</th>
<th>Hypertensive</th>
<th>Controls</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near phoria angle (Δ)</td>
<td>−3.02 ± 1.80</td>
<td>−1.39 ± 1.37</td>
<td>−1.24 ± 1.93</td>
</tr>
<tr>
<td>Far phoria angle (Δ)</td>
<td>−1.06 ± 0.92</td>
<td>−0.17 ± 0.72</td>
<td>−0.42 ± 0.92</td>
</tr>
<tr>
<td>Near fusion amplitude (Δ)</td>
<td>32.16 ± 5.47</td>
<td>36.87 ± 6.29</td>
<td>38.20 ± 6.92</td>
</tr>
<tr>
<td>Far fusion amplitude (Δ)</td>
<td>13.05 ± 2.86</td>
<td>15.39 ± 3.33</td>
<td>15.78 ± 3.47</td>
</tr>
<tr>
<td>NCP (cm)</td>
<td>7.56 ± 2.24</td>
<td>5.96 ± 1.02</td>
<td>6.24 ± 1.47</td>
</tr>
</tbody>
</table>

NCP, near convergence point; Δ, prismatic dipters.

### Table 3 – Mean ± standard deviation of rupture points in divergence and convergence in near and far vision.

<table>
<thead>
<tr>
<th>Glaucoma</th>
<th>Hypertensive</th>
<th>Controls</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near fusion amplitude (Δ)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RP divergence</td>
<td>RP convergence</td>
<td>RP divergence</td>
<td>RP convergence</td>
</tr>
<tr>
<td>−10.82 ± 3.04</td>
<td>20.33 ± 6.64</td>
<td>−6.67 ± 2.08</td>
<td>6.37 ± 2.09</td>
</tr>
<tr>
<td>−11.39 ± 2.29</td>
<td>25.48 ± 5.66</td>
<td>−6.43 ± 2.25</td>
<td>8.52 ± 2.97</td>
</tr>
<tr>
<td>−11.11 ± 2.85</td>
<td>27.09 ± 5.52</td>
<td>−7.02 ± 2.43</td>
<td>8.44 ± 2.48</td>
</tr>
</tbody>
</table>

RP, rupture point; Δ, prismatic dipters.
Very few studies have been published about binocular vision and glaucoma.6–12 In this study glaucoma subjects were more exophoric, mainly in near vision. The phoria position arises in the presence of a stimulus for fixation but in the absence of binocular fusion. Under these conditions, the relative position of the visual axes (passive gaze position) mainly depends on the tonic convergence in far vision and accommodative and proximal convergence in near vision. The phoria position can also be influenced by age. It has been observed that with the passage of time individuals become more exophoric in near vision and less in far vision, to the extreme of becoming endophoric.13 On the other hand, the influence of other factors has been verified, including muscle and ligament elasticity, refractive imbalance and sensory suppression of one eye.13 Glaucoma could produce a tendency toward exophoria due to a sensory suppression mechanism derived from progressive and asymmetric visual function deterioration. In this study it was not possible to demonstrate the influence of age because no differences between the HTO and control groups were observed.

The FA were diminished for the glaucoma group both for near and far vision. The normal fusion range in near vision for adults ranges between 16° internal base to 30° external base; in far vision from 8° internal base to 16 external base.14 The divergence fusion rupture points, both in far and near vision of the glaucoma group were not significantly different to those of the HTO and control groups. However, the convergence fusion rupture point of glaucoma subjects was below that of the other 2 groups, mainly for near vision. Diminished FA of glaucoma patients could be due to weakening of positive fusion convergence as the rupture point in convergence is further away. In addition, these patients would require greater positive fusion demand due to being more exophoric in near vision.

NCP is considered to be normal when under 7.5 cm.15 The NCP of glaucoma subjects was over the normal value and statistically different to the values of the HTO and control groups. The differences between NCP and lower FA could be due to weakened fusion convergence caused by glaucoma. The peripheral visual field depression which is typical of the disease could cause a weakening of fusion vergences with the diminished overall convergence capacity. Burian16 emphasized the importance of the unequal stimulation of the peripheral retina for the production of fusion vergences.

No differences were observed between the 3 groups in Worth test suppression in near vision. However, differences were detected between the groups for far vision suppression. Greater suppression was observed in the glaucoma group vis-à-vis the HTO and control groups. The existence of greater exophoria in the context of glaucoma as well as lower fusional vergence reserve13 could cause some type of central suppression as an offsetting mechanism. This central suppression was best evidenced in the far vision Worth test. The Worth lights test for near vision assesses central suppression but the angle underlying the test is comparatively much bigger than that of far vision, for which reason small central suppression scotomae would go unnoticed with this test.13

In what concerns stereopsis, significant differences were found when comparing the 3 study groups both for the Titmus and the TNO tests. Bassi and Galanis6 found statistically

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**Table 4 - Suppression percentages in near and far Worth tests.**

<table>
<thead>
<tr>
<th></th>
<th>Glaucoma</th>
<th>Hypertense</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near Worth test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No suppression (%)</td>
<td>85.90</td>
<td>86.84</td>
<td>92.68</td>
</tr>
<tr>
<td>Suppression (%)</td>
<td>14.10</td>
<td>13.15</td>
<td>7.32</td>
</tr>
<tr>
<td>Far Worth test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No suppression (%)</td>
<td>48.20</td>
<td>77.63</td>
<td>84.15</td>
</tr>
<tr>
<td>Suppression (%)</td>
<td>51.80</td>
<td>22.37</td>
<td>15.85</td>
</tr>
</tbody>
</table>

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**Table 5 - Frequency and percentages of stereopsis under or equal to 60° and above 60° for TNO test.**

<table>
<thead>
<tr>
<th>TNO Test</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤60</td>
<td>18</td>
<td>31.03</td>
</tr>
<tr>
<td>&gt;60</td>
<td>40</td>
<td>68.96</td>
</tr>
<tr>
<td>≤60</td>
<td>54</td>
<td>71.05</td>
</tr>
<tr>
<td>&gt;60</td>
<td>22</td>
<td>28.95</td>
</tr>
<tr>
<td>≤60</td>
<td>64</td>
<td>78.05</td>
</tr>
<tr>
<td>&gt;60</td>
<td>18</td>
<td>21.95</td>
</tr>
</tbody>
</table>

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Discussion

Binocular vision is the ability to integrate visual stimuli reaching each eye into a single perception. This requires the formation of similar and good optical quality images in each retina as well as sensory fusion or simultaneous perception of both images and precise motor coordination of both eyes.6

Glaucoma gives rise to dysfunctions and loss of CGR, the neurons located in the retina the axons of which constitute the anterior optic pathway. This cell loss, which is bilateral although generally asymmetric, could involve a progressive disruption of the optic pathway at a very primary level of binocular integration.7 The consequence of this could be slow and progressive visual deprivation in such a way that the degradation of monocular visual information would cause the disruption of binocular vision.
significant differences in stereoacuity between the glaucoma group and the other 2 groups but not between the HT0 and the control groups. Visual acuities did not exhibit differences between the 3 groups. In this event, stereoeuity reduction would be related to the MD campimetric values. In a subsequent study, Essock et al.\textsuperscript{9} observed that stereoscopic acuity of glaucoma subjects (305.08°) and of hypertensive subjects (118.2°) differed statistically from those of control subjects (16.8°). Gupta et al.\textsuperscript{10} explored stereopsis with the Frisby test and also found stereoeuity differences between glaucoma subjects (148.1°) and ocular hypertensive subjects (144.1°) when compared to normal subjects (26.6°). However, said author does not specify the average campimetric MD of each group.\textsuperscript{9}

In this study stereoeuity of glaucoma and hypertensive subjects was very similar, suggesting that an early disruption of binocular vision could occur in glaucoma due to greater susceptibility of neuronal circuits (including CGR) which control the perception of disparity. A further study which considered only 2 groups (early glaucoma and control), El-Gohary and Siam\textsuperscript{11} found that stereoscopic equities differed in over 200° with high statistical significance (p = 0.000). More recently, Kotecha,\textsuperscript{12} who worked with two study groups (glaucoma and control subjects), found that the former exhibited a mean stereoacuity of 55° whereas the control group had 40°, a difference which turned out to be significant (p = 0.020). The visual acuities of both groups did not exhibit statistically significant differences.

Our conclusions about stereopsis are similar to the findings of Bassi and Galanis,\textsuperscript{8} as only the glaucoma group was different to the other 2. On the basis of this assumption, stereoeuity reduction would be fundamentally related to campimetric deterioration (MD). There would be no differences in stereopsis between hypertensive and control subjects because there were no differences between their respective average MD values. However, the other referenced authors sustain that ocular hypertension subjects exhibit stereoeuity levels similar to that of glaucoma patients and that this is significantly different to that of healthy subjects. This study provides double stereoeuity measurement due to the utilization of 2 different tests. The stereoeuity values provided by the Titmus test were better than those delivered by TNO for each study group. This could be due to the different sensory nature of the visible disparity in said tests (contours against random points) and, accordingly, each test responds to a different mode of binocular disruption.\textsuperscript{17}

It can be concluded that POAG is mainly associated to increased near exophoria, FA reduction in near vision, increased distancing of NCP, appearance of central suppression in far vision and loss of stereoeuity. These alterations do not seem to be clinically precocious since no differences were observed between ocular hypertensive and control subjects.

**Conflict of interests**

No conflict of interests has been declared by the authors.

**References**