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6

7 **A saccadic choice task for target face detection at large visual eccentricities**  
8 **in patients with glaucoma**

9

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28

29

### Abstract

30 **Significance:** Little is known about the perception of glaucomatous patients at large visual  
31 eccentricities. We show that the patients' performance drops beyond 40° eccentricity even for  
32 large images of scenes suggesting that clinical tests should assess the patients' vision at larger  
33 eccentricities than 24 or 30°.

34 **Purpose:** Daily activities such as visual search, spatial navigation and hazard detection  
35 require rapid scene recognition on a wide field of view. We examined whether participants  
36 with visual field loss at standard automated perimetry 30-2 were able to detect target faces at  
37 large visual eccentricities.

38 **Methods:** Twelve patients with glaucoma and 14 controls were asked to detect a face in a  
39 two-alternative saccadic forced choice task. Pairs of scenes, one containing a face, were  
40 randomly displayed at 10, 20, 40, 60 or 80° eccentricity on a panoramic screen covering 180°  
41 horizontally. Participants were asked to detect and to saccade towards the scene containing a  
42 face.

43 **Results:** Saccade latencies were significantly slower in patients (264ms, CI: 222 to 306ms)  
44 than in controls (207ms CI: 190 to 226ms) and accuracy was significantly lower in patients  
45 (70% CI: 75% to 85%) than in controls (75.7% CI : 71.5% to 79.5%). Though still  
46 significantly above chance at 60°, the patients' performance dropped beyond 40° eccentricity.  
47 The controls' performance was still above chance at 80° eccentricity.

48

49 **Conclusions:** In patients with various degrees of peripheral visual field defect, performance  
50 dropped beyond 40° eccentricity for large images at a high contrast. This result could reflect  
51 reduced spread of exploration in glaucoma.

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59 Glaucoma is an optic neuropathy characterized by structural (retinal ganglion cells and optic  
60 nerve fiber loss) and functional (visual field loss) deficit. The progressive loss of retinal  
61 ganglion cells is accompanied by matching retinotopic loss of contrast sensitivity in the visual  
62 field. Loss of contrast sensitivity due to glaucoma starts in peripheral vision but anatomical,<sup>1</sup>  
63 physiological<sup>2</sup> and behavioral data<sup>3-5</sup> indicate that central vision is also affected. Few  
64 experimental studies have investigated glaucomatous patients' performance at very large  
65 visual eccentricities (above 50°). However, most of the visual field is in peripheral vision,  
66 regardless of how peripheral vision is defined (i.e., starting after the fovea, the perfovea or  
67 the macula).<sup>6</sup> Detecting an object at large visual eccentricity is frequent in daily life. Indeed,  
68 the detection of relevant stimuli like a pedestrian crossing, a moving car and a facial  
69 expression at peripheral locations might be critical in everyday life. Daily activities like visual  
70 search, spatial navigation (walking or driving), spatial memory and detection of potential  
71 danger require quick scene gist recognition on a wide field of view. Despite its low spatial  
72 resolution, peripheral vision provides critical information about the environment.  
73 Experimental studies in normally sighted participants have shown that the coarse information  
74 provided by peripheral preview guides eye movements towards targets in visual search tasks<sup>7</sup>  
75 and peripheral vision is efficient for scene gist recognition at very large eccentricities (above  
76 60°).<sup>6,8</sup>

77 As far as glaucoma is concerned, studies on perception in peripheral vision have been  
78 conducted with driving simulators or in laboratory-based hazard detection tasks on real-world  
79 driving scenes, mostly with relatively narrow fields of view or relatively small eccentricities,  
80 for the location of road hazards (around 30°), see Kasneci et al. for a review.<sup>9</sup> For instance,  
81 some studies showed lower pedestrian detection rates in the patients' group than in the control  
82 group when the pedestrians appeared at 30° eccentricity.<sup>10</sup> However, considerable inter-  
83 individual variability was noted, detection rates varying from 27% to 90%. Other studies  
84 showed delayed first fixation on peripheral hazards in patients compared to controls<sup>11</sup> or a  
85 higher number of collisions in patients than in controls. However, this was observed only in  
86 older patients with lower acuity.<sup>12</sup> Szlyk et al.<sup>13</sup> used a wider field of view with three  
87 monitors providing a visual field of 160° horizontal viewing. They reported that patients with  
88 glaucoma exhibited a higher rate of simulator accidents than controls, but the visual  
89 eccentricity of hazards was not reported.

90 The present study was designed to assess visual perception at eccentricities larger than  
91 those classically measured by automatic standard perimetry and seldom explored in  
92 experimental studies. In glaucoma, peripheral fibers of the optic nerve are affected first  
93 suggesting that the signal transmitted to the part representing the peripheral visual field in the  
94 cortex might be degraded. To assess signal processing in peripheral vision in glaucoma, we  
95 used a panoramic screen covering 180° of the visual field. In a two-alternative forced choice  
96 task, participants were asked to saccade towards the scene containing a human face, at  
97 eccentricities varying from 10 to 80° on each side of central fixation. Human faces were used  
98 as targets as previous studies in normally sighted participants have demonstrated that human  
99 faces elicit the fastest saccadic responses, faster than other stimuli like animals or transports at  
100 small eccentricities (8°)<sup>14</sup>; and that the faster saccades for human faces extend across the  
101 whole visual field (up to 80° in young participants).<sup>15</sup> Based on clinical data, we could have  
102 expected performance to deteriorate in extrafoveal vision in patients with glaucoma.  
103 However, conventional automated perimetry measures performance at levels of luminance  
104 close to threshold, and for randomly distributed small visual spots. Several studies have  
105 shown that increasing the size of stimuli in conventional automated perimetry (e.g., from 0.01  
106 to 2.67°) improves detection performance and reduces variability in participants with  
107 glaucoma.<sup>16, 17</sup> As our stimuli were wide and presented at a high contrast, we expected the  
108 target to be detected above chance at large eccentricities, even for patients showing reduced  
109 sensitivity in peripheral vision on the visual field test. In line with previous studies on eye  
110 movements in glaucoma,<sup>18, 19</sup> we expected longer saccade latencies for patients than for  
111 controls.

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## METHOD

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### Participants

#### Patients with glaucoma

118 Fourteen adults (8 females) ranging in age from 46 to 74 years, mean 62.7 years, with  
119 bilateral primary open angle glaucoma agreed to participate in the experiment. However, two  
120 patients were excluded owing to difficulties in calibration of the eye tracker. The patients

121 were recruited in the ophthalmology department at Lille university hospital. They were being  
122 treated for glaucoma. To be included in the study, patients had to have a visual acuity of 0.1  
123 LogMar or better in each eye, a score above 26/30 on the Mini-Mental State Examination<sup>20</sup>  
124 for people above 60 years old indicating that they had no major cognitive deficits, no other  
125 ocular disease than glaucoma (except for uneventful lens replacement cataract surgery), no  
126 history of neurological disease and no medication affecting attention. All participants  
127 underwent SITA-standard 30-2 perimetry on a Humphrey Visual Field Analyzer (HFA,  
128 Carl Zeiss Meditec, CA, USA) showing glaucomatous defects that were consistent with  
129 structural damage, as observed in OCT and fundus. We did not use the 60-4 Humphrey visual  
130 field analyser as, to our knowledge, there are no normative data on this test.

131

132 Normally sighted age-matched controls

133 Fourteen normally sighted people (9 females) ranging in age from 45 to 74 years, mean 61.1  
134 years, were included. They were either a relative or a friend of patients. Controls had a full  
135 eye examination to ensure that they had no ocular pathology. To be included in the study,  
136 controls had to have a visual acuity of 8/10 or better in each eye on the Monoyer scale (i.e.,  
137 0.1 to 0.0 LogMar), a score above 26/30 on the Mini-Mental State Examination for people  
138 above 60 years old and no history of neurological or psychiatric disease.

139 Both patients and controls were tested binocularly. The study was approved by the ethics  
140 committee of the university. In accordance with the tenets of the Declaration of Helsinki,  
141 written informed consent was obtained from all participants.

142 The demographic details and clinical data of the 12 patients and 14 controls are summarized  
143 in Table 1. The patients' visual fields are presented in Figure 1.

144

145 [Table 1 and Figure 1 about here]

146

147

148 Stimuli

149

150 The stimuli consisted of 275 grey-level photographs of human faces from various ethnic  
151 groups and 400 photographs of various objects (animals, vehicles, plants, buildings) in scenes  
152 containing no human faces, selected from a large photo-library database (Corel). Examples of  
153 stimuli are presented in Figure 2. For all photographs, the resolution was 512 x 512 pixels,  
154 covering 18° X 18° of visual angle at a viewing distance of 2.04 m. As contrast sensitivity  
155 rapidly decreases at large eccentricities, especially for high spatial frequencies,<sup>21</sup> the images  
156 were presented at their original full contrast.

157

### 158 Apparatus

159

160 The stimuli were displayed by means of three projectors (Optoma HD83) fixed on the ceiling  
161 and connected to a PC computer (Dell). Participants were seated 2.04 meters from a  
162 hemispheric rigid light grey (68 cd/m<sup>2</sup>) screen covering 90° eccentricity on each side of  
163 central fixation (see Figure 2). The presentation software was written in Matlab (MathWorks,  
164 Inc., Natick, MA, USA) by the lab programmer. Saccade responses were recorded by means  
165 of the iViewXTM HED eye tracker from SensoMotoric Instruments (Teltow, Germany) with  
166 a scene camera. The video-based eye tracker is head-mounted, using infrared reflection to  
167 provide an eye-in-head signal at a sampling rate of 50 Hz and accuracy of about 1°. The scene  
168 camera mounted on the head was positioned so that its view field was aligned with the  
169 observer's line of sight. Calibration was performed using a five-point grid. Following  
170 calibration, the eye tracker creates a cursor indicating an eye-in-head position that is merged  
171 with the video from the scene camera. The video records were analyzed using the software  
172 BeGaze from SensoMotoric Instruments (Teltow, Germany). We recorded the latency of the  
173 first saccade (from the onset of the photographs). As the scene camera covers 40° and the  
174 hemispheric screen covers 180°, we could only record the direction of the saccade (left/right),  
175 not its amplitude. Before the experiment, participants were presented with a central white  
176 square (40° X 40°) containing five calibration points. They were asked to fixate the black dots  
177 (center, top right, top left, bottom right, bottom left) while their eye positions were recorded  
178 by the system. Once the calibration was completed, this was removed and participants started  
179 the saccadic-choice task. As the iViewXTM HED head-mounted eye tracker records eye  
180 movements only on one eye, half of the participants in each group were recorded on the left  
181 eye and the other half on the right eye.

182

183

184 **Procedure**

185  
186 The experimental trials were organized as follows: a black fixation cross (5° X 5°) was  
187 displayed centrally for 1 s. It was followed by a gap (blank screen) of 200 ms. A gap task is  
188 known to facilitate the production of express saccades.<sup>22</sup> Following the gap, a pair of  
189 photographs (a target and a distractor) were simultaneously presented left and right of  
190 fixation, at the same eccentricity, for 1 s. The inter-trial interval was fixed at 1500 ms. Human  
191 faces were defined as targets. There were 160 trials determined by 5 eccentricities (10, 20, 40,  
192 60 and 80°) X 2 spatial locations of the target (left/right of fixation) X 16 images randomly  
193 software-selected within the folders of 275 photographs of human faces and 400 photographs  
194 of objects. Images were presented only once. The 5 eccentricities and the 2 spatial locations of  
195 the target were randomly and equally represented. Participants were asked to saccade towards  
196 the scene containing a human face. A saccadic forced choice task was preferred to a manual  
197 (left/right) forced choice task because previous studies with other populations of patients  
198 (Alzheimer disease) have shown that saccade responses were more sensitive to show deficits  
199 than a manual response task in which patients have time to explore images before  
200 responding.<sup>23</sup> We measured accuracy in target detection. As the scene camera of the eye  
201 tracker did not cover the whole screen accuracy was determined by the direction of the  
202 saccade.

203  
204 [Figure 2 about here]

205  
206 **Data analysis**

207  
208 An ANOVA was conducted on the data (saccade latencies and accuracy) using the IBM SPSS  
209 Statistics 20 software. Whenever Mauchly's test<sup>24</sup> indicated that the assumption of sphericity  
210 had not been fulfilled, the degrees of freedom were adjusted using the Greenhouse-Geisser  
211 correction. For pairwise comparisons, degrees of freedom were also corrected whenever the  
212 assumption of homogeneity of variance had been violated. The within-subject factors were the  
213 spatial location of the target (left/right) and eccentricity (10°, 20°, 40°, 60° and 80°). Group  
214 (patients/controls) was a between-subject factor. The mean saccade latencies and accuracy are  
215 presented in Figures 3 and 4. Individual data for patients and controls are presented in Figure  
216 5 for accuracy.

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[Figures 3 and 4 about here]

## RESULTS

223 There was no significant main effect of the spatial location (left/right) of the target ( $F_{1, 24} =$   
224  $.003, P = .955$  for saccade latencies and  $F_{1, 24} = 3.5, P < .070, \eta^2_p = 0.13$  for accuracy). The  
225 results presented in Figure 3 and 4 are averaged over the spatial location of the target. As  
226 expected, accuracy decreased ( $F_{4, 96} = 24.9, P < .001, \eta^2_p = 0.509$ ) and saccade latencies  
227 increased ( $F_{4, 96} = 65.7, P < .001, \eta^2_p = 0.732$ ) as eccentricity increased. There was a  
228 significant group effect both on saccade latencies ( $F_{1, 24} = 8.05, P < .009, \eta^2_p = 0.251$ ), with  
229 longer saccades for patients than for controls, and on accuracy ( $F_{1, 24} = 5.28, P < .031, \eta^2_p =$   
230  $0.180$ ), with a lower accuracy for patients than for controls.

231 Group interacted significantly with eccentricity on accuracy ( $F_{3, 24, 77.8} = 4.31, P < .003, \eta^2_p =$   
232  $0.152$ ). A separate analysis for each eccentricity showed that accuracy was better for controls  
233 than for patients at all eccentricities (see Figure 4), but the difference was significant only at  
234 large eccentricities (by 3.1% at  $10^\circ: t_{14, 45} = 0.864, P = 0.42$ ; by 2.9% at  $20^\circ: t_{24} = 0.722, P =$   
235  $0.477$ , by 1.4% at  $40^\circ: t_{24} = 0.281, P = 0.781$ , by 17.4% at  $60^\circ: t_{24} = 3.09, P < .005$ ; by 14%  
236 at  $80^\circ: t_{24} = 2.71, P < .012$ ). We checked whether accuracy was above chance (50%) at the  
237 largest eccentricities. Performance was still significantly above chance for controls at  $80^\circ$   
238 (66.7%  $t_{13} = 4.3, P < .001$ ). Accuracy was significantly above chance at  $60^\circ$  eccentricity for  
239 patients (60.35%  $t_{11} = 2.3, P < .041$ ), but it was not the case at  $80^\circ$  (52.7%  $t_{11} = 0.87, ns$ ). No  
240 interaction involving group reached statistical significance for saccades.

241

[Figure 5 about here]

242

243 We checked for correlations (Spearman) between the mean deviation of the best eye and  
244 performance as well as between age and performance. As the visual field was tested  
245 monocularly and the saccadic choice task was performed binocularly, we presumed that the  
246 better eye would determine binocular sensitivity. It has been reported that the MD of the  
247 better eye correlated better with quality-of-life measures than the MD of the worse eye.<sup>25</sup>  
248 There was no significant correlation between the MD of the best eye and accuracy at  $10^\circ$

249 eccentricity ( $r = 0.496$ ),  $20^\circ$  ( $r = 0.322$ ),  $40^\circ$  ( $r = 0.252$ ),  $60^\circ$  ( $r = 0.126$ ) and  $80^\circ$  ( $r = 0.154$ ),  
250 and no significant correlation between the MD of the best eye and saccade latency at  $10^\circ$   
251 eccentricity ( $r = 0.287$ ),  $20^\circ$  ( $r = 0.077$ ),  $40^\circ$  ( $r = 0.336$ ),  $60^\circ$  ( $r = 0.343$ ) and  $80^\circ$  ( $r = 0.182$ ).  
252 For patients, age was not significantly correlated with accuracy, but it was for saccade latency  
253 at eccentricities  $40^\circ$  ( $r = 0.516$ ,  $P < .05$ ),  $60^\circ$  ( $r = 0.593$ ,  $P < .05$ ) and  $80^\circ$  ( $r = 0.537$ ,  $P < .05$ ).  
254 Older patients exhibited longer saccade latencies as eccentricity increased. For controls, no  
255 significant correlation was observed either between age and saccade latency or between age  
256 and accuracy at each eccentricity.

257  
258

## 259 DISCUSSION

260

261 Standard automatic perimetry is a useful clinical tool to assess deficit in contrast sensitivity  
262 due to glaucoma and to monitor the evolution of the pathology. However, it does not provide  
263 a complete picture of the patients' vision of the environment. Mönter et al.<sup>26</sup> have developed  
264 a new technique of repeated kinetic presentations to estimate isopter positions without  
265 interactive input from the clinician, as it is the case in the manual kinetic Goldmann  
266 perimetry, to examine the peripheral field of patients with moderately advanced glaucoma.  
267 They found that patients with similar central visual field loss at the automated visual field test  
268 may have strikingly different peripheral visual field. This study shows that tests that examine  
269 the peripheral visual field beyond the range of static perimetry may provide relevant  
270 information both for clinicians and for patients (e.g., on their ability to quickly detect a  
271 peripheral signal). Indeed, Crabb et al.<sup>27</sup> showed that patients are unaware of the true extent  
272 of their visual defect. At eccentricities in the range of those measured by automated perimetry  
273 peripheral visual field loss in glaucoma has little effect on the accomplishment of natural  
274 actions.<sup>28</sup> Rubinstein et al.<sup>29</sup> showed that visual localization and pointing precision to high  
275 contrast stimuli remained largely unaffected by reductions in visual field sensitivity within the  
276 central  $15^\circ$  of vision in patients with glaucoma. In a driving simulator using a wider view  
277 field ( $160^\circ$  of horizontal viewing field), Szlyk et al.<sup>13</sup> observed only 7 simulator accidents in  
278 40 patients with peripheral visual field loss and 1 simulator accident in the control group  
279 ( $N=17$ ), but the eccentricity and the size at which the road hazards were presented was not  
280 specified. Our results show that, when asked to detect a scene containing a human face on the  
281  $180^\circ$  of the visual field, the patients' performance is globally lower than that of controls, both  
282 in terms of accuracy and saccade latencies, but the difference is significant only beyond  $40^\circ$

283 eccentricity. Except for patients 2 and 12, accuracy dropped at 40° eccentricity, even though  
284 the scenes were displayed at a high contrast and covered 18° x 18° of visual angle. This result  
285 can be explained by the loss of optic nerve fibers conveying information from the peripheral  
286 field of view. Another possible, and complementary, account is a reduced spread of  
287 exploration, reported in several studies in patients with glaucoma.<sup>30,31</sup> Smith et al.<sup>30</sup> showed  
288 that the average elliptical region scanned by glaucomatous patients, measured by a bivariate  
289 contour ellipse area (BCEA) analysis, was more restricted than that of controls (by 23%) in  
290 free viewing of images of natural scenes subtending 20.3° X 14.9°. Glen et al.<sup>32</sup> found that  
291 making larger saccades appeared to be associated with better face recognition performance for  
292 patients with bilateral visual field defects in their central 10° of visual field. Wiecek et al.<sup>33</sup>  
293 reported that fixation duration, saccade size, and number of saccades per trial were not  
294 significantly different between patients with peripheral field loss and normally sighted  
295 controls in a visual search task but they observed different strategies. Some patients made  
296 fewer eye movements into areas of impaired vision whilst others were more likely to make an  
297 eye movement into an unsighted location suggesting that some patients do not compensate for  
298 peripheral visual field loss. Studies on glaucoma often report large inter individual variability  
299 in eye movements, either in free viewing or in active viewing tasks, and large variability in  
300 compensatory strategies that are adopted by patients.<sup>9,30,32</sup>

301 The drop in accuracy at 40° eccentricity might also reflect cortical remapping consecutive to  
302 reduced neural input to the visual cortex as a result of degeneration of retinal ganglion cells in  
303 glaucoma. Murphy et al.<sup>34</sup> showed evidence that glaucoma deterioration is already present in  
304 the brain before substantial vision loss can be detected by clinical assessment. In a brain  
305 imaging study, Zhou et al.<sup>35</sup> investigated changes in brain function corresponding to central  
306 (< ±12 degrees) and peripheral (> ±12 degrees) vision in order to assess cortical remapping in  
307 glaucoma. The stimuli, covering 55° x 55°, were expanding rings and rotating wedges. They  
308 found that bold responses were similar in patients and controls in the central visual field but  
309 that they were attenuated in the peripheral visual field, in V1, V2 and V3, in patients with  
310 mild-to-moderate glaucoma compared to controls. Our behavioral data also show a substantial  
311 deficit in peripheral vision but only at large visual eccentricities. The difference between  
312 patients and controls was not significant below 40°. Though the fusiform face area (FFA),  
313 selective to faces, is located in the temporal cortex<sup>36</sup> the processing of faces starts with the  
314 filters of area V1.<sup>37</sup> A low quality signal send to FFA from the peripheral part of V1 could

315 account for the failure to discriminate a target face from a distractor beyond 40° eccentricity  
316 in patients.

317 Saccades were slower in patients than in controls. Using a novel methodology Crabb  
318 et al. <sup>38</sup> demonstrated that, in addition to clinical measurements (visual field, intra-ocular  
319 pressure, OCT), features extracted from extensive maps of saccades made during free viewing  
320 of TV films for several seconds could discriminate a group of patients with glaucoma from  
321 age-related normally sighted controls with a sensitivity of 76% by using the saccade maps  
322 alone. Evidence for impaired saccadic eye movements in glaucoma has also been reported in  
323 several other studies. For instance, Kanjee et al. <sup>18</sup> had 16 patients and 21 controls saccade  
324 towards high-contrast red discs subtending 0.1° in diameter, located 10° left and right of  
325 central fixation. They found that median saccade response time was significantly increased  
326 (by 28 ms) in patients with glaucoma compared to controls. They also reported that the  
327 duration, amplitude and peak velocity of saccades was not altered, suggesting that the  
328 glaucomatous pathological process seems to alter mainly the initiation of saccades. Lamirel et  
329 al. <sup>19</sup> also reported delayed saccade latency, by 23 ms on average, during saccades towards a  
330 static target at 7° eccentricity, in patients with glaucoma compared to controls. At larger  
331 eccentricities, Mazumdar et al. <sup>39</sup> recorded eye movements towards target spots at 54 spatial  
332 locations, corresponding to the locations of the 24-2 Humphrey field analyzer. Glaucomatous  
333 eyes exhibited longer saccade response times (by 170 to 260 ms depending on age group) than  
334 normally sighted age-matched controls. Our results also show delayed saccade latencies in  
335 patients compared to controls, with an increase in the difference as eccentricity increases (by  
336 36 ms at 10° to 74 ms at 60°), and a lower difference at 80°, where patients were at chance.

337 With the same saccadic choice task as that used in the present study, but at 8°  
338 eccentricity in normally sighted young participants, Crouzet and Thorpe <sup>14</sup> observed that the  
339 fastest saccades were triggered for faces as early as 100–110 ms after stimulus onset. They  
340 suggested that, in addition to higher-order cortical structures involved in face perception in  
341 the temporal cortex, the processing required to initiate these fast responses might involve  
342 subcortical processing pathways such as the amygdala and the superior colliculus (SC). The  
343 SC is a pivotal structure in the regulation of eye movements in primates.<sup>40</sup> It receives early  
344 visual input via the retino-tectal and retino-geniculo-cortico-tectal pathways.<sup>41</sup> The motor  
345 burst of collicular neurons serves as a signal for triggering both express and regular saccades  
346 <sup>22</sup>. Compared to age-matched controls Najjar et al. <sup>42</sup> reported slower and hypometric saccades  
347 in patients with glaucoma at a pre-perimetric stage with no detectable glaucomatous visual

348 field loss on standard automated perimetry. They suggested that these disruptions could  
349 originate from impaired neuronal signaling due to potential disordered cortical and subcortical  
350 saccadic regulation, particularly in the SC, as a result of neurodegeneration. Zhang et al.<sup>43</sup>  
351 found significantly reduced fMRI responses to transient achromatic stimuli in the  
352 magnocellular layers of the lateral geniculate nucleus and in the superficial layer of the SC, as  
353 well as from the early visual cortices (V1, V2 and MT), in patients with early-stage glaucoma  
354 compared to controls. The delayed saccades in patients with glaucoma in the present study  
355 might reflect a slower connectivity and/or a slower image analysis before saccade initiation  
356 due to reduced contrast sensitivity. In monkeys, modulation of stimulus luminance and  
357 contrast has been shown to affect the timing and magnitude of visual responses in the SC<sup>44,45</sup>  
358 and in V1.<sup>46</sup>

359  
360 **Conclusion and limitations:** The results of the present study are consistent with previous  
361 studies showing impaired eye movements in glaucoma, specifically for large eccentricities.  
362 There are several limitations in this study. The number of participants was small, and they  
363 exhibited various stages of visual field defect. A future study could include groups at different  
364 stages of the disease. Colored images might have captured attention better than achromatic  
365 images. A measure of head movements might have shown that patients move their heads more  
366 than normally sighted observers to compensate for visual field loss in peripheral vision.  
367 Nevertheless, such a simple test may provide a complement of the clinical assessment of  
368 patients. It can be used to complement information obtained with static perimetry in which a  
369 small spot at contrast threshold can easily be missed.

370  
371

## 372 **References**

- 373 1. Hood DC. Improving our Understanding, and Detection, of Glaucomatous Damage: An  
374 Approach Based Upon Optical Coherence Tomography (OCT). *Prog Retin Eye Res* 2017;57:  
375 46-75.
- 376 2. Jung KI, Jeon S, Kim YC, et al. Comparison of Pattern Electroretinograms of Glaucoma  
377 Patients with Parafoveal Scotoma versus Peripheral Nasal Step. *Sci Rep* 2019; 9: 3547.

378 3. Lenoble Q, Lek JJ, McKendrick AM. Visual Object Categorisation in People with  
379 Glaucoma. Br J Ophthalmol 2016;100:1585-90.

380 4. Roux-Sibilon, A, Rutgé, F, Aptel, F, et al. Scene and Human Face Recognition in the  
381 Central Vision of Patients with Glaucoma. PLoS One. 2018; 13: e0193465.  
382

383 5. Schafer A, Rouland JF, Peyrin C et al. Glaucoma Affects Viewing Distance for  
384 Recognition of Sex and Facial Expression. Invest Ophthalmol Vis Sci 2018 ;59:4921-28.

385 6. Loschky LC, Szaffarczyk S, Beugnet C, et al. The Contributions Of Central And Peripheral  
386 Vision to Scene-Gist Recognition with a 180° Visual Field. J Vis. 2019; 19:15. doi:  
387 10.1167/19.5.15.

388 7. Torralba A, Oliva A, Castelhana MS, et al. Contextual Guidance of Eye Movements and  
389 Attention in Real-World Scenes: The Role of Global Features in Object Search. Psychol Rev  
390 2006.113:766-86.

391 8. Boucart M, Moroni C, Thibaut M, et al. Scene Categorization at Large Visual  
392 Eccentricities. Vis Res. 2013;86:35-42.

393 9. Kasneci E, Black AA, Wood JM. Eye-Tracking as a Tool to Evaluate Functional Ability in  
394 Everyday Tasks in Glaucoma. J Ophthalmol 2017:6425913.

395 10. Qiu C, Jung JH, Tuccar-Burak M, et al. Measuring Pedestrian Collision Detection With  
396 Peripheral Field Loss and the Impact of Peripheral Prisms. Transl Vis Sci Technol 2018;7:1.  
397 doi: 10.1167/tvst.7.5.1.  
398

399 11. Lee SS, Black AA, Wood JM. Effect of Glaucoma on Eye Movement Patterns and  
400 Laboratory-Based Hazard Detection Ability. PLoS One 2017;12:e0178876.

401 12. Kunimatsu-Sanuki S, Iwase A, Araie M et al. The Role of Specific Visual Subfields in  
402 Collisions with Oncoming Cars during Simulated Driving in Patients with Advanced  
403 Glaucoma. Br J Ophthalmol 2017;101:896–901.  
404

405 13. Szlyk JP, Mahler CL, Seiple W et al. Driving Performance of Glaucoma Patients  
406 Correlates with Peripheral Visual Field Loss. J Glaucoma. 2005;14:145-50.

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Mis en forme : Français (France)  
Code de champ modifié  
Mis en forme : Français (France)  
Mis en forme : Français (France)

- 407 14. Crouzet SM, Kirchner H, Thorpe SJ. Fast Saccades Toward Faces: Face Detection in Just  
408 100 ms. *J Vis* 2010;10:16.1-17. doi: 10.1167/10.4.16.
- 409 15. Boucart M, Lenoble Q, Quetelart J, et al. Finding Faces, Animals and Cars in Far  
410 Peripheral V. *J Vis* 2016;doi: 10.1167/16.2.10.
- 411 16. Wall M, Kutzko KE, Chauhanf BC. Variability in Patients with Glaucomatous Visual  
412 Field Damage Is Reduced Using Size V Stimuli. *Invest Ophthalmol Vis Sci* 1997;38:426-35.
- 413 17. Redmond T, Garway-Heath DF, Zlatkova MB, et al. Sensitivity Loss in Early Glaucoma  
414 Can be Mapped to an Enlargement of the Area of Complete Spatial Summation. *Invest*  
415 *Ophthalmol Vis Sci* 2010;51:6540-48.
- 416 18. Kanjee R, Yücel YH, Steinbach MJ, et al. Delayed Saccadic Eye Movements in  
417 Glaucoma. *Eye Brain* 2012;4:63-8.
- 418 19. Lamirel C, Milea D, Cochereau I, et al. Impaired Saccadic Eye Movement in Primary  
419 Open-Angle Glaucoma. *J Glaucoma* 2014;23:23-32.
- 420 20. Folstein MF, Folstein SE, McHugh PR. Mini-Mental State: A Practical Method for  
421 Grading the Cognitive State of Patients for the Clinician. *J Psych Res* 1975;12: 189-98.
- 422 21. Cannon MW Jr. Perceived Contrast in the Fovea and Periphery. *J Opt Soc Am A* 1985;2:  
423 1760-8.
- 424 22. Sparks D, Rohrer WH, Zhang Y. The Role of the Superior Colliculus in SaccadeI: a Study  
425 of Express Saccades and the Gap Effect. *Vis Res* 2000;40:2763-77.
- 426
- 427 23. Boucart M, Calais G, Lenoble Q et al. Differential Processing of Natural Scenes in  
428 Typical and Atypical Alzheimer Disease Measured with a Saccade Choice Task. *Front Integr*  
429 *Neurosci.* 2014;60. doi: 10.3389
- 430
- 431 24. Mauchly JW. Significance Test for Sphericity of a Normal  $n$ -Variate Distribution. *Annals*  
432 *of Mathematical Statistics* 1940;11:204-9.
- 433
- 434 25. Gutierrez P, Wilson MR, Johnson CA, et al. The Influence of Glaucomatous Visual Field  
435 Loss and Health-Related Quality of Life. *Arch Ophthalmol* 1997;115:777-84.

436

437 26. Mönter VM, Crabb DP, Artes PH. Reclaiming the Periphery: Automated Kinetic  
 438 Perimetry for Measuring Peripheral Visual Fields in Patients with Glaucoma. Invest  
 439 Ophthalmol Vis Sci 2017;58:868–75.

440

441 27. Crabb DP, Smith ND, Glen FC, et al. How Does Glaucoma Look? Patient Perception of  
 442 Visual Field Loss. Ophthalmology 2013;120:1120-26.

443

444 28. Dive S, Rouland JF, Lenoble Q, et al. Impact of Peripheral Field Loss on the Execution of  
 445 Natural Actions: A Study with Glaucomatous Patients and Normally Sighted People. J  
 446 Glaucoma 2016;25:e889-96.

447 29. Rubinstein NJ, Anderson AJ, Ma-Wyatt A et al. The Effects of Ageing and Visual Field  
 448 Loss on Pointing to Visual Targets. PLoS One 2014; 9: e97190.

449 30. Smith ND, Crabb DP, Glen FC et al. Eye Movements in Patients with Glaucoma When  
 450 Viewing Images of Everyday Scenes. Seeing and Perceiving 2012;25: 471–92

451

452 31. Asfaw DS, Jones PR, Mönter VM et al. Does Glaucoma Alter Eye Movements when  
 453 Viewing Images of Natural Scenes? A between-Eye Study. Invest Ophthalmol Vis Sci  
 454 2018;59:3189–98.

455

456 32. Glen FC, Smith ND & Crabb DP Saccadic Eye Movements and Face Recognition  
 457 Performance in Patients with Central Glaucomatous Visual Field Defects. Vis Res 2013;  
 458 82:42–51

459 33. Wiecek E, Pasquale LR, Fiser J et al. Effects of Peripheral Visual Field Loss on Eye  
 460 Movements During Visual Search. Front Psychol 2012;3:472. doi:  
 461 10.3389/fpsyg.2012.00472.

462 34. Murphy MC, Conner IP, Teng CY et al. Retinal Structures and Visual Cortex Activity are  
 463 Impaired Prior to Clinical Vision Loss in Glaucoma. Sci Rep 2016;6:31464.

Code de champ modifié

464 35. Zhou W, Muir ER, Kundandeeep S et al. Retinotopic fMRI Reveals Visual Dysfunction  
465 and Functional Reorganization in the Visual Cortex of Mild to Moderate Glaucoma Patients. J  
466 Glaucoma 2017;26:430–7.

467 36. Kanwisher N, McDermott J, Chun MM. The Fusiform Face Area: a Module in Human  
468 Extrastriate Cortex Specialized for Face Perception. J Neurosci 1997;17:4302-11.

Code de champ modifié

469 37. Keil MS. "I look in Your Eyes, Honey": Internal Face Features Induce Spatial Frequency  
470 Preference for Human Face Processing. PLoS Comput Biol 2009;5:e1000329.

471 38. Crabb DP, Smith ND, Zhu H. What's on TV? Detecting Age-Related Neurodegenerative  
472 Eye Disease Using Eye Movement scanpaths. Front Aging Neurosci 2014;6:312. doi: 10.3389

473 39. Mazumdar D, Pel JJ, Panday M et al. Comparison of Saccadic Reaction Time Between  
474 Normal and Glaucoma Using an Eye Movement Perimeter. Indian J Ophthalmol 2014;62: 55-  
475 9.

Code de champ modifié

Code de champ modifié

Code de champ modifié

476 40. Shen K, Valero J, Day GS et al. Investigating the Role of the Superior Colliculus in  
477 Active Vision with the Visual Search Paradigm. Eur J Neurosci 2011;33:2003-16.

478 41. Cusick CG. Anatomical Organization of the Superior Colliculus in Monkeys:  
479 Corticotectal Pathways for Visual and Visuomotor Functions. Prog Brain Res 1988;75:1-15.

480 42. Najjar RP, Sharma S, Drouet M, et al. Disrupted Eye Movements in Preperimetric  
481 Primary Open-Angle Glaucoma. Invest Ophthalmol Vis Sci 2017;58:2430-37.

Code de champ modifié

482 43. Zhang P, Wen W, Sun X, et al. Selective Reduction of FMRI Responses to Transient  
483 Achromatic Stimuli in the Magnocellular Layers of the LGN and the Superficial Layer of the  
484 SC of Early Glaucoma Patients. Hum Brain Mapp 2016;37:558-69.

485 44. Marino RA, Levy R, Boehnke S, et al. Linking Visual Response Properties in the Superior  
486 Colliculus to Saccade Behavior. Eur J Neurosci 2012;35: 1738-52.

487 45. Marino RA, Levy R, Munoz DP. Linking Express Saccade Occurrence to Stimulus  
488 Properties and Sensorimotor Integration in the Superior Colliculus. J Neurophysiol 2015;114:  
489 879-92.

490 46. Gawne TJ. The Simultaneous Coding of Orientation and Contrast in the Responses of V1  
491 Complex Cells. *Exp Brain Res* 2000;133:293-302.

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**Figure and Table legends**

**Table 1.** Demographic and clinical data of patients with glaucoma and normally sighted age-matched controls. LE = left eye, RE = right eye, MD = mean deviation. GCL= Ganglion Cell Complex ( $\mu\text{m}$ ), RNFL = Retina Nerve Fiber Layer ( $\mu\text{m}$ ). Some patients did not have an OCT measuring RNFL and GCL at the time of testing.

**Fig.1.** Patients' visual fields (Humphrey 30-2).

**Fig.2.** Example of display. Two scenes, one containing a target face, were projected simultaneously on a panoramic screen randomly at 10, 20, 40, 60 or 80° eccentricity. A head-mounted eye tracker recorded the direction of the first saccade towards the target face.

**Fig.3.** Boxplot of Saccade latencies (ms) with standard deviations as a function of retinal eccentricities (10 to 80°) in age-matched normally sighted controls (left panel) and in patients with glaucoma (right panel). X = mean. Cercles = extreme values.

**Fig.4.** Boxplot of accuracy (%) with standard deviations as a function of retinal eccentricities (10 to 80°) in age-matched normally sighted controls (left panel) and in patients with glaucoma (right panel). X = mean. Cercles = extreme values.

**Fig.5.** Individual data for 12 patients (right) and 14 controls (left) as a function of eccentricity.

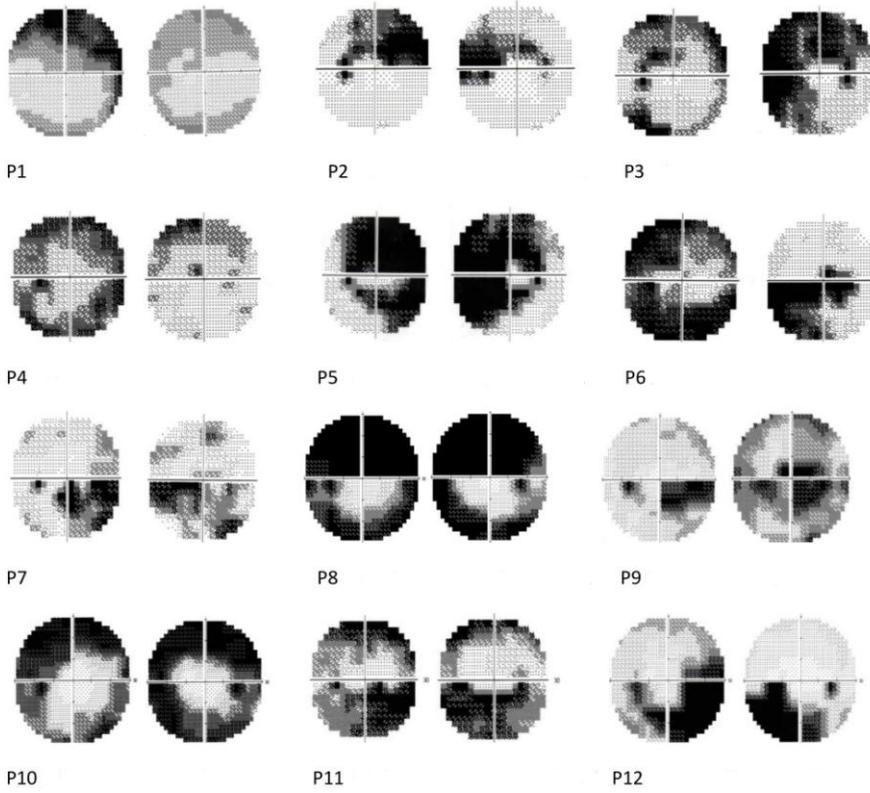
518 Table 1

Patients	Gender	Age	Acuity (LogMAR)		MD		GCL		RNFL	
			RE	LE	RE	LE	LE	RE	LE	RE
1	F	63	0	0	-12.15	-16.17				
2	F	67	0	0	-6.67	-7.98	73	74	76	78
3	H	61	0.1	0	-16.08	-8.57	62	59	58	48
4	F	70	0.1	0.1	-6.02	-10.93				
5	F	74	0	0	-22.14	-20.74	52	33	61	68
6	H	59	0.1	0	-16.49	-16.31	67	54	64	57
7	H	49	0	0	-12.9	-11.13				
8	F	63	0	0	-21.68	-22.47	64	73	59	63
9	F	74	0.1	0	-14.48	-9.11			63	58
10	F	58	0	0	-16.2	-11.2				
11	H	46	0	0	-15.63	-17.39	67	65	67	71
12	F	68	0	0	-10.37	-15.09				
<b>Controls</b>	<b>Gender</b>	<b>Age</b>	<b>Acuity (LogMAR)</b>							
			<b>RE</b>	<b>LE</b>						
1	F	54	0	0						
2	H	74	0.1	0.1						
3	H	64	0	0						
4	F	56	0	0						
5	H	57	0	0						
6	F	66	0	0						
7	F	76	0.1	0.1						
8	F	60	0	0						
9	F	45	0	0						
10	H	56	0	0						
11	F	61	0	0						
12	F	66	0.1	0.1						
13	H	61	0.1	0.1						
14	F	59	0	0						

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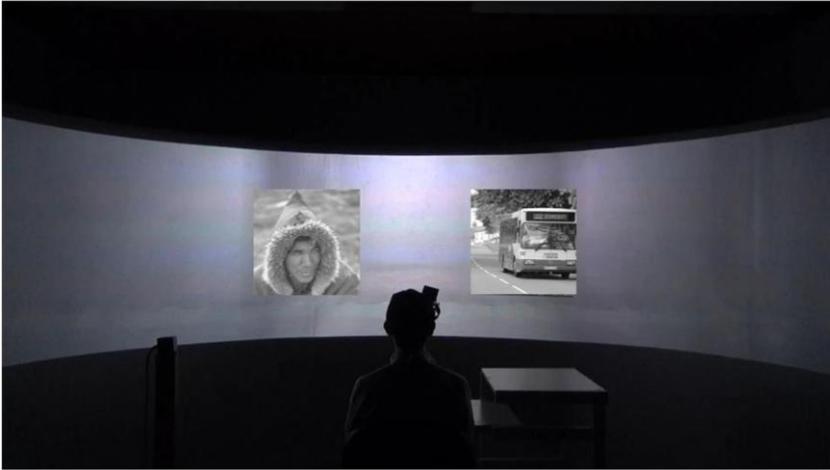
521 Figure 1



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524 Figure 2

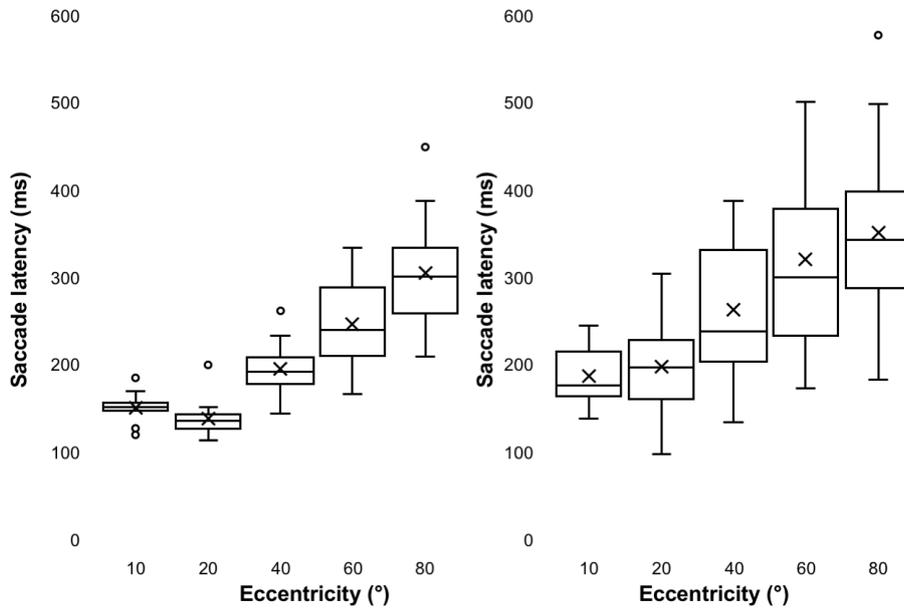


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527 Figure 3

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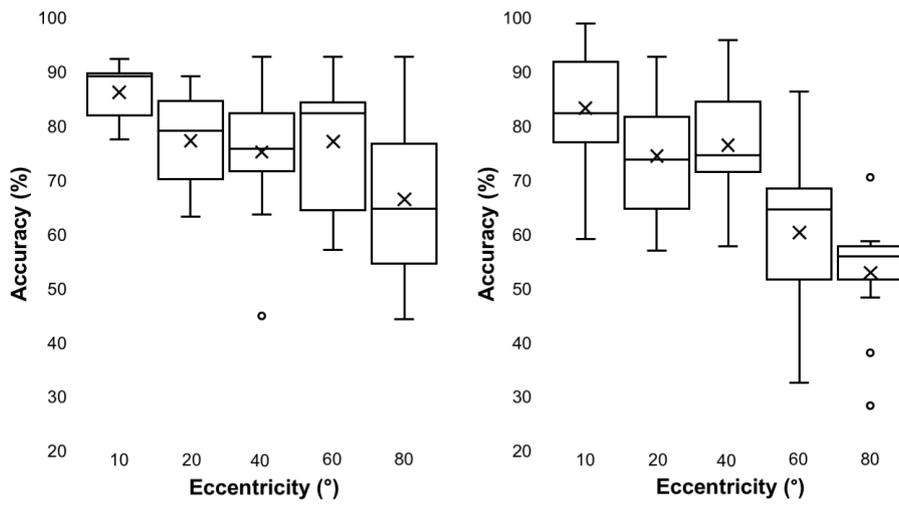
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542

543

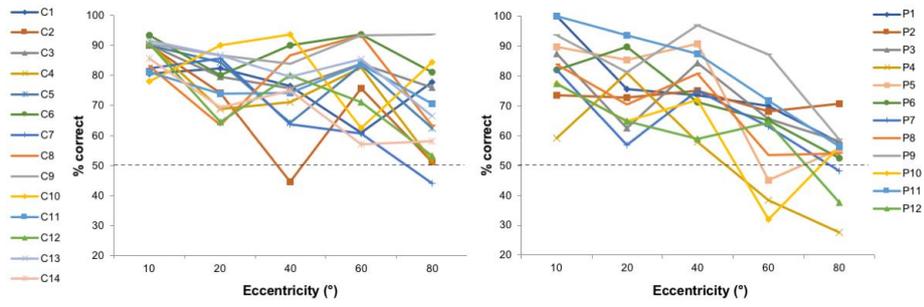
544 Figure 4



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547 Figure 5



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