Glaucoma Affects Viewing Distance for Recognition of Sex and Facial Expression

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Purpose. To measure the distance for sex and facial expression recognition in patients with glaucoma.

Methods. Sixteen patients with open-angle glaucoma, 16 age-matched controls, and 12 young controls participated. During each trial, a face covering $0.36° \times 0.5°$, simulating the angular size of a face viewed at 20 m, was presented centrally. The angular size increased automatically by steps of 5 cm, simulating the face moving progressively closer. The participants were asked to stop the progression with a keypress, first, when they were able to recognize the sex, and second, when they were able to recognize the facial expression (angry, happy, neutral). We measured the threshold equivalent viewing distance to recognize the sex and the facial expression.

Results. Participants with glaucoma, both those with and without reduced central acuity, required a shorter viewing distance (i.e., a larger face) than did controls to recognize both the sex (by 2.59 m, $F_{1,30} = 8.7$, $P < 0.006$) and the facial expression (by 3.64 m, $F_{1,30} = 14$, $P < 0.001$). No significant difference was found between younger and older controls.

Conclusions. Face perception is a skill that is reliant on central vision. Our behavioral results are consistent with the hypothesis of reduced central sensitivity in glaucoma. We suggest that the necessity to view larger faces in patients might result from a higher sensitivity to crowding that increases the difficulty to perceive the relevant features for recognition of both sex and facial expressions, akin to normal peripheral vision.

Keywords: glaucoma, face perception, size, central vision, distance

Glaucoma is an ocular pathology characterized by irreversible retinal ganglion cell and optic nerve fiber loss, and it is traditionally described as affecting the peripheral part of the visual field. However, neuroanatomical studies[1] indicate glaucomatous damage in the macular region, which contains a high density of retinal ganglion cells,[2] even at early stages of the disease.[3] Damage in the macular part of the retina is often underestimated with standard perimetry for glaucoma because the 24–2 visual field tests only four points spaced 6° apart in the center of the visual field, and the 10–2 visual field, which tests points spaced 2°, is used by clinicians at advanced stages of the disease.

The macular region is critical for object and face recognition. Indeed, people with macular degeneration exhibit impairment in face recognition,[4–6] even at several magnification levels,[7] and their performance in object identification is reduced by 30% compared with that of normally sighted age-matched controls.[8] In glaucoma, behavioral studies have demonstrated impaired performance with global motion, shape, and object perception in central vision,[9,10] but face perception has not received much attention. Roux-Sibilon et al.[11] asked patients with glaucoma, with or without central visual field defect at the 24–2 Humphrey visual field test, to categorize faces within distractors (animals and vehicles). Stimuli were presented at two levels of contrast (2.5% and 10.0%). The researchers observed that patients with central visual field defect exhibited impaired performance only at low contrast in comparison with both patients without central visual field defect and normally sighted controls. With the highly contrasted gray-level faces of the Cambridge Face Memory Test, Glen et al.[12,13] found impaired performance for face recognition in a sample of patients with significant central 10° defects on a Humphrey Visual Field Analyzer.

Faces are socially relevant stimuli. Adequate perception of facial features is critical for social interactions, as they provide information about an individual's sex, age, familiarity, intention, and emotional state. In daily life, we are exposed to faces across a wide range of viewing distances and thus at different sizes. For instance, we might view a small face at a distance down the street or a larger face at a conversational distance. When questioned about the problems that they encounter in their daily lives, some patients with glaucoma report having difficulties with faces. An example was provided by Glen and Crabb[14] (p. 6); "I know quite a few people who live locally. However, I feel that if I'm a certain distance I'm probably not going to be able to recognize them because I don't see enough detail in their face." In normally sighted observers, the effect of viewing distance on face perception has been investigated in two ways: either by filtering the face to mimic its spatial frequency composition at

TABLE 1. Clinical and Demographic Data About Patients and Controls

Patient No., Age/Sex	Acuity, LogMAR			VF MD		Central		
	RE	LE	Binoc	RE	LE	Deficit	Binoc VF	MMSE/30
P1 61/M	0	0	0	−21.89	−18.69	Unilateral	No	28
P2 75/M	0.1	0.3	+0, 1	−8.15	−14.07	Unilateral	10° Normal	25
P3 69/M	0	0	0	−13.98	−7.62	Unilateral	No	30
P4 54/F	0	0	0	−7.02	−7.09	No	No	
P5 64/F	0	0.1	0	−1.33	−4.36	No	No	27
P6 71/M	PL	0	0	NM	−12.75	Unilateral	10° Normal	27
P7 56/M	0	0.1	0	−3.97	−16.51	Unilateral	No	
P8 70/F	0	0	0	−2.89	−12.59	Unilateral	No	29
P9 61/M	0	0.1	0	−10.96	−13.48	No	No	28
P10 63/F	0	0.5	0	−6.7	−21.69	Unilateral	No	29
P11 58/M	0	0	0	−18	−10.43	Unilateral	No	
P12 51/F	0	0	0	−5.46	−4.08	No	No	
P13 66/M	0	0.1	0	−7.89	−12.78	Unilateral	No	28
P14 80/F	0.1	0.1	+0, 1	−16.38	−22.15	Bilateral	Deficit 10°	30
P15 48/M	0	0	0	−3.34	−7.37	Bilateral	No	
P16 67/M	0.1	0.3	+0, 1	−13.55	−14.54	Unilateral	10° Normal	27

An MD comprised between −6 and −12 dB is classified as moderate. It is classified as severe between −12 and −20 dB. Below −6 dB, the glaucoma is at an early stage. Binoc, binocular; LE, left eye; NM, not measurable; RE, right eye.

different distances or by shrinking the face so that it subtends the visual angle corresponding to various distances.[15–18] Loftus and Harley[15] (Experiment 2) showed that the psychophysical functions for the size and filtering techniques were proportional to one another. Guo[18] showed size-invariance for the categorization of facial expression within social interaction space (size mimicking distances from 0.62–4.96 m). In contrast, other studies have reported evidence for size-dependent changes in processing facial identity[15] or facial expressions[16] at larger simulated distances than those of Guo[18] (e.g., from 3.3–105 m in the Smith and Schyns[16] study with a spatial filtering technique).

To investigate the effect of viewing distance on face perception in glaucoma, we used a variant of a technique developed by Lott and colleagues.[19] They examined the effect of normal aging on face recognition. In their study, faces were centrally displayed at six sizes, ranging from 0.75 to 24 m, to simulate normal-sized faces at different viewing distances. Participants were initially shown a set of faces with associated names and were told that they would see each face displaying one of four facial expressions. The results showed that when participants were required to correctly identify both the expression and the name of the person depicted, the threshold equivalent viewing distance (EVD) was on average 17.1 m for a sample of 10 young observers (mean age: 32.9 years old), 6.61 m for the group ranging in age from 64 to 70 years, and 1.74 m for the group older than 85 years. Performance was better when participants were asked to name the person only or to recognize the expression only, but it still declined with age.

In the present study, we investigated the effect of glaucoma and the effect of normal aging on the recognition of sex and facial expression as a function of viewing distance. We used the technique of face shrinking to simulate viewing distance, but rather than selecting a sample of sizes,[19] we used a more dynamic technique in presenting faces at a size corresponding to a viewing distance of 20 m and increasing the size automatically to simulate the face approaching. Based on the study by Lott et al.,[19] we hypothesized that older controls would recognize sex and facial expressions at shorter distances (i.e., larger face) than would young participants. Regarding patients, we expected that they would require an even shorter distance (larger face size) than age-matched controls would, as reduced sensitivity in the central visual field should hinder the discriminability of facial features.

METHODS

Participants

The characteristics of the population are summarized in Tables 1 to 3. Sixteen patients (10 males), with visual field defects in both eyes due to primary open-angle glaucoma, who came to consult in the department of ophthalmology in Lille University Hospital, were recruited. The patients ranged in age from 48 to 80 (mean 63.4 ± 8.7) years. Each patient benefited from a complete ophthalmological examination, including a visual field evaluation just before the experiment. Visual field sensitivity (expressed as the mean deviation [MD]) was measured with a Humphrey Field Analyzer (Carl Zeiss Meditec, Dublin, CA, USA). For 14 patients, the 30–2 technique (Swedish Interactive Testing Algorithm standard) was used. Two patients who were addressed by another hospital came with a 24–2 visual field test. The 30–2 visual field test measures 76 stimuli (spots varying in luminance) in the central 30° of the visual field. The 24–2 visual field test measures 54 stimuli in the central 24° of the visual field. Both the 24–2 and the 30–2 measure the same number of stimuli in the central 10° of the visual field. In addition to the 30–2 monocular visual field, four patients (2, 6, 14, and 16) were tested with a binocular visual field (Mon CvOne standard automated perimetry from MetroVision [Perenchies, France]; provided in the public domain, https://metrovision.fr/perimeters-us.html): patients 2, 14, and 16 because of a lower acuity than that of the other patients, and patient 6 because the visual field was not measurable on the right eye and a central deficit was found on the left eye. Patient 15, with a bilateral central field defect, did not accept testing with the binocular visual field. The visual fields of patients 2, 6, 14, 15, and 16 are presented in Figure 1. Sixteen age-matched controls (9 males) ranging in age from 48 to 80 (mean: 63.2 ± 9) years were recruited from the relatives of patients. The young participant group included 12 students in medicine (4 males) ranging in age from 19 to 30 (mean 25.9 ± 3.4) years. The inclusion criteria for patients and controls were the following: no history of neurological and/or

TABLE 2. Age-Matched Controls

Age/Sex	Acuity RE	Acuity LE	MMSE/30
75/M	0	0	28
67/F	0	0	30
72/M	0	0	28
56/F	0	0	
64/F	0	0	30
70/M	0	0	27
55/M	0	0	
57/M	0	0	
59/F	0	0	
48/M	0	0	
55/F	0	0	
67/M	0	0	28
74/F	0	0	27
57/M	0	0	
56/M	0	0	
80/M	0	0	29

psychiatric disease, a binocular acuity equal or better than 8/10 (equivalent Snellen), a lack of chronic use of drugs that can affect attention (benzodiazepines), no ocular disease for controls, and no ocular disease other than glaucoma (e.g., AMD or cataract) for patients. In addition, all the patients and the age-matched controls older than 60 were assessed with the French version of the Mini Mental State Examination (MMSE) to check for cognitive impairment. The MMSE test is used to assess cognitive deterioration (e.g., for people with a risk of Alzheimer disease). This is why it is usually not performed in those younger than 60 years. Participants whose MMSE score was lower than 25/30 were excluded from the study. Both young and older participants had benefited from an ophthalmological examination during the 18 months preceding study inclusion without any sign of glaucoma, and they had no family history of glaucoma. An evaluation of the participants' visual acuity was performed again just before the testing. All participants, young and older, were asked to come with their habitual optical correction. Older patients and older age-matched controls wore progressive spectacles for close and distant vision. If the acuity test performed before the experimental session showed that the participant's optical correction was not appropriate at the viewing distance of the experiment, then the ophthalmologist (author AS) provided a correction. Patients and age-matched controls did not differ significantly in age. The study was approved by the local ethics committee (Reconnaissance des Visages chez des Patients avec un Glaucome 2018 – 270–60). In accordance with the tenets of the Declaration of Helsinki, written informed consent was obtained from all participants.

TABLE 3. Young Controls

Age/Sex	Acuity RE	Acuity LE
30/F	0	0
30/F	0	0
29/F	0	0
25/F	0	0
24/M	0	0
27/F	0	0
27/M	0	0
29/F	0	0
25/M	0	0
21/F	0	0
19/M	0	0
25/F	0	0

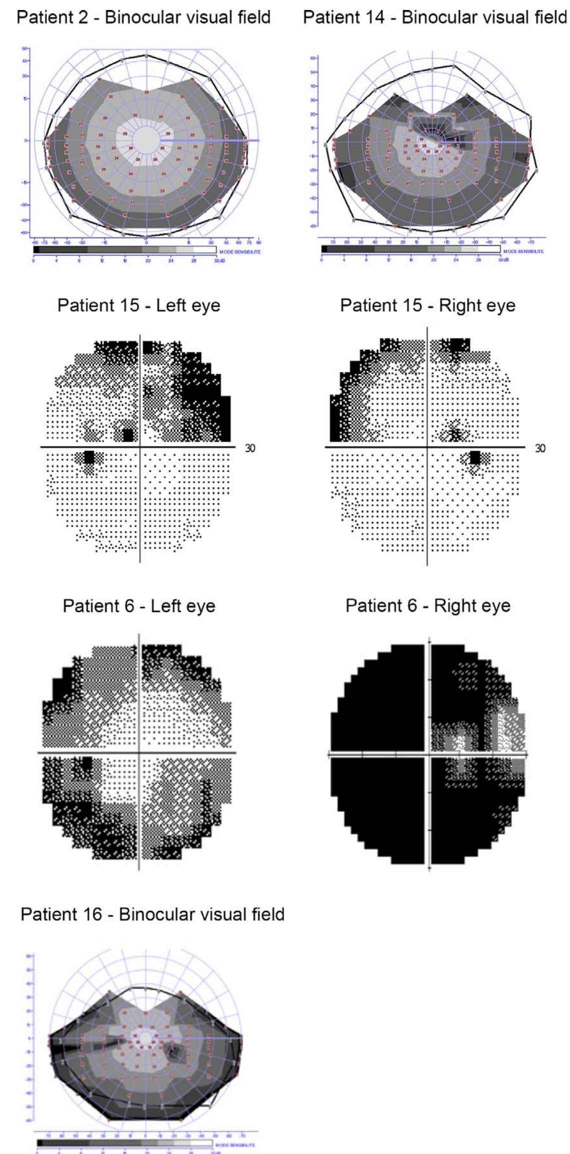

FIGURE 1. The visual field of the three patients (2, 14, 16) with a lower visual acuity, of patient 6 with a central field defect on his testable eye, and patient 15 with a bilateral central field defect.

Stimuli

The stimuli were colored photographs of male and female faces randomly selected from the NimStim sorted emotions database.[20] Each face was surrounded by a black background screen but separated from the background by a white rectangle so that dark hair was visible. We selected three facial expressions: angry, happy, and neutral. Each of the three facial expressions was presented five times with different male faces and five times with different female faces for a total of 30 trials. Examples of the three facial expressions are shown in Figure 2.

Procedure

Participants were seated at a viewing distance of 2 m from a large screen (Speechi 84 inches; Speechi Interactive Whiteboard Specialist, Lille, France). Stimuli were presented in

FIGURE 2. An example of the three facial expressions (happy, angry, neutral) used in the study.

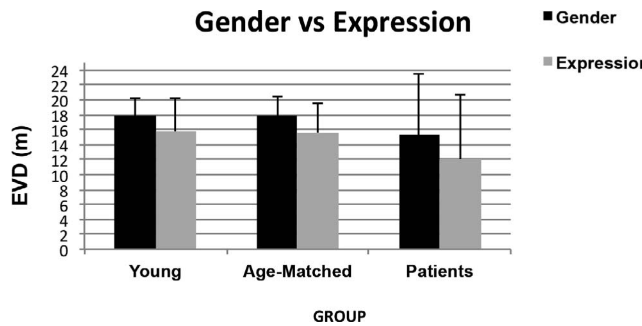

FIGURE 3. Mean threshold EVD in meters and SDs for the categorization of sex (averaged over male/female) and facial expression (averaged over happy, angry, and neutral faces) as a function of the group of participants.

photopic conditions with light coming from the ceiling; the window's light was occluded. At the beginning of the experiment, participants were shown an example of the three facial expressions on paper. During each trial, a central white fixation cross was displayed for 1 second on a black background. It was followed, 100 ms later, by a face covering $0.36° \times 0.5°$; this simulated the angular size of an average face viewed at a distance of 20 m. The angular size increased automatically by steps of 5 cm, simulating the face moving progressively closer. The participant was asked to stop the progression (i.e., the increase in size) with a keypress as soon as he or she was able to identify the sex of the face. The experimenter recorded the answer and entered it on the keyboard. At this moment, the participant was asked if he or she was able to categorize the facial expression. If not, then a keypress on the space bar started the increase in size of the face again until a new keypress by the participant stopped the progression when he or she was able to name the facial expression (angry, happy, or neutral). The experimenter then entered the answer. Following the categorization of the facial expression, the participant provided a judgment of confidence from 1 (totally unsure) to 5 (very sure). The computer recorded the EVD for the categorization of the sex, the categorization of the facial expression, and the level of confidence for the categorization of facial expression. Before the experiment, patients were asked if they felt any difficulties in recognizing faces during daily life. Five patients (2, 3, 4, 7, and 10) reported difficulties in low lighting situations and when a face was far away.

RESULTS

Statistical Analysis

Statistical analyses were conducted with the software Systat 8 (Systat Software, Inc., San Jose, CA, USA). The main measure was the EVD in meters. Two ANOVAs were conducted, one on patients with glaucoma versus age-matched controls to assess the effect of pathology and one on young participants versus patients' controls to assess the effect of aging. We also compared the EVD for the categorization of sex versus the categorization of facial expression; the group was the between factor. As the visual field was tested monocularly and the categorization task was performed binocularly, we assumed that the better eye would determine binocular sensitivity. Indeed, Gutierrez et al.[21] found that the MD of the better eye correlated better with quality-of-life measures than the MD of the worse eye. The relationship between threshold EVD and age for patients and age-matched participants, and the relationship between threshold EVD and the MD of the best eye for patients were assessed using the Spearman rank correlation.

The results are presented in Figure 3 for the categorization of sex versus facial expression and in Figure 4 for the three facial expressions. Patients' individual data are presented in Figure 5. The angular sizes corresponding to the EVD of each group for sex and expression categorization are presented in Table 4.

A global ANOVA involving the three groups showed a significant main effect of group for the threshold EVD of sex recognition ($F_{2,41} = 7.3$, $P < 0.002$), for the threshold EVD of expression recognition ($F_{2,41} = 11.4$, $P < 0.001$), and a significant main effect of facial expression ($F_{2,82} = 18.7$, $P < 0.001$). Separate analyses were conducted on patients/age-matched controls to assess the effect of pathology and on young/older controls to assess the effect of normal aging.

Patients and Age-Matched Controls: Effect of Pathology

Patients categorized the sex of faces at a shorter distance than did the controls (15.28 vs. 17.87 m, $F_{1,30} = 8.7$, $P < 0.006$). Patients also required a shorter distance (i.e., a larger size) to recognize the facial expression (12.01 vs. 15.65 m, $F_{1,30} = 14$, $P < 0.001$). There was no main effect of the face's sex (16.51 m for female faces vs. 16.64 m for male faces; $F_{1,30} = 0.63$, NS). Happy faces were recognized at a longer distance (14.7 m) than were angry (13.28 m) and neutral (13.52 m) faces ($F_{2,60} = 17.5$, $P < 0.001$). Sex was recognized at a farther distance than was facial expression (16.58 vs. 13.83 m, $F_{1,30} = 117.7$, $P < 0.001$). A significant interaction was observed between the group and the type of categorization ($F_{1,30} = 4.3$, $P < 0.046$). This interaction resulted from a smaller difference in EVD between patients and controls for categorizing sex (2.59 m) than for categorizing facial expression (3.64 m). No other significant interaction was observed.

Due to their glaucoma, three patients (2, 14, and 16) had a lower acuity than did the other patients. A new analysis, performed without these three patients, showed that the 13 other patients with glaucoma and normal acuity still required a shorter distance than did age-matched controls for the categorization of sex (16.32 vs. 17.87 m, $F_{1,27} = 7.2$, $P < 0.012$) and for the categorization of facial expression (13.32 vs. 15.65 m, $F_{1,27} = 10.2$, $P < 0.004$). Within the five patients (2, 3, 4, 7, and 10) who self-reported difficulties recognizing faces when they are far away and in low lighting conditions, two recognized the sex and the facial expression at a shorter distance than the mean EVD for patients (patient [P]2 sex: 12.41 m, expression: 9.45 m, and P3 sex: 12.64 m, expression: 10.59 m). The other three patients (P4, P7, and P10) recognized faces at a longer distance than the mean EVD for patients.

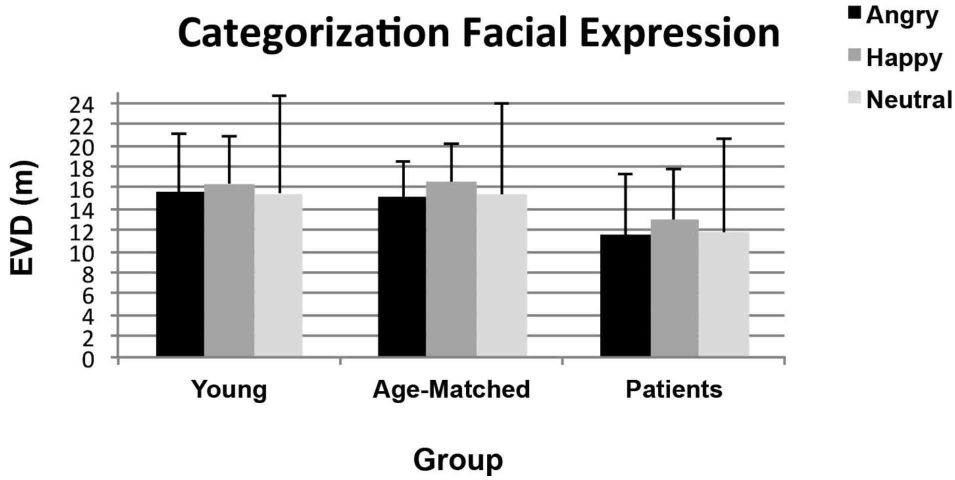

FIGURE 4. Mean threshold EVD in meters and SDs for the categorization of happy, angry, and neutral faces as a function of the group of participants.

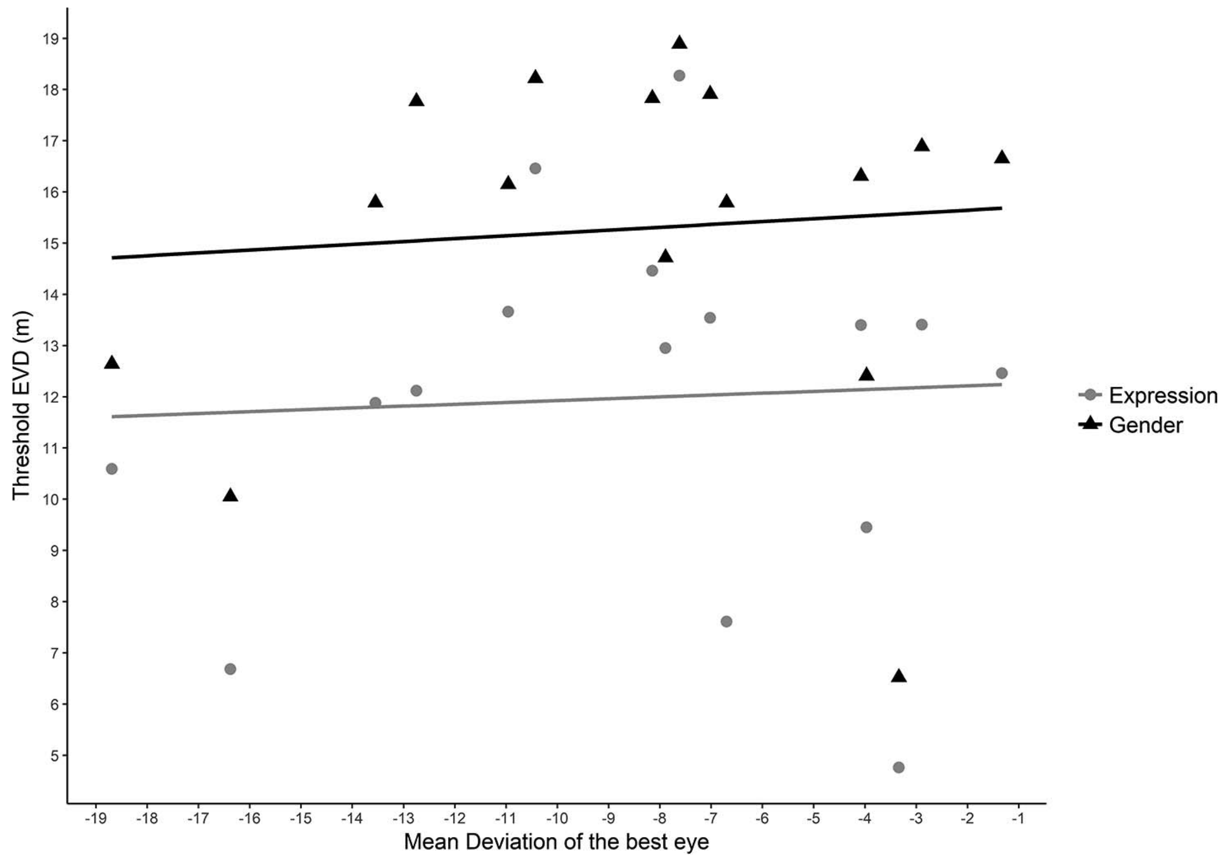

FIGURE 5. Threshold EVD in meters of the 16 patients for the categorization of sex and facial expressions, ordered as a function of the severity of the deficit in terms of MD of the best eye.

TABLE 4. Mean Threshold EVD (in meters) and SD for Sex, Facial Expression, and the Corresponding Angular Size of the Face

Characteristic	Young	Age-Matched	Patients	Effect of Group
Sex, EVD, m (SD)	17.84 (0.81)	17.86 (0.98)	15.28 (3.34)	$P < 0.002$
AS horizontal	0.40	0.40	0.47	
AS vertical	0.56	0.56	0.66	
Expression, EVD, m (SD)	15.83 (1.57)	15.64 (1.58)	12.01 (3.54)	$P < 0.001$
AS horizontal	0.46	0.46	0.60	
AS vertical	0.63	0.64	0.83	

AS, angular size.

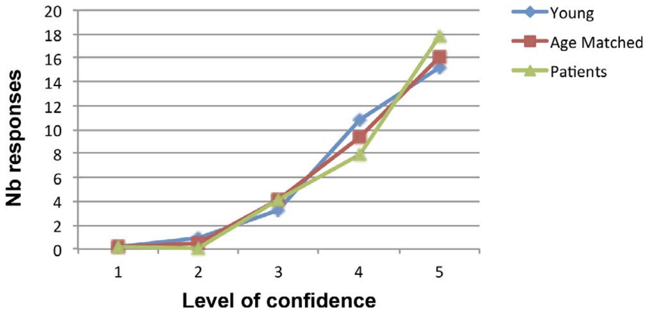

FIGURE 6. Level of confidence on five points (1, very unsure, to 5, very sure) for the categorization of facial expressions.

There was no significant correlation between threshold EVD for sex and age (age-matched controls: $r = 0.10$, $P = 0.71$; patients: $r = 0.19$, $P = 0.49$) and between threshold EVD for facial expression and age (age-matched controls: $r = -0.07$, $P = 0.81$; patients: $r = 0.11$, $P = 0.70$). For patients, no significant correlation was observed between the MD of the best eye and threshold EVD for sex ($r = 0.07$, $P = 0.81$) and for facial expression ($r = 0.01$, $P = 0.99$). The regression lines are reported in Figure 5.

Young and Older Controls: Effect of Aging

We compared the performance for the 12 young controls and for the 16 older controls. The analysis showed no significant difference between groups on the EVD for sex categorization (young: 17.84 m versus older: 17.87 m, $F < 1$) and for the categorization of facial expression (young: 15.83 m versus older: 15.65 m, $F < 1$). Happy faces were recognized at a longer EVD (16.48 m) than were angry (15.32 m) and neutral (15.40 m) faces ($F_{2,52} = 12.4$, $P < 0.001$) for both groups (see Fig. 3). There was no significant interaction involving group.

Level of Confidence

Following the categorization of each facial expression, participants were asked to rate their level of confidence from 1 (very unsure) to 5 (very sure). The results are presented in Figure 6. Participants gave very few responses of 1 and 2, suggesting that they waited for the face to become sufficiently large (close) to be sure of their categorization. Consistent with this result, we found very few errors (less than 2%) in the categorization of facial expressions. The number of responses of 4 and 5 was significantly larger than that of the lower levels of confidence of 1 to 3 ($F_{4,164} = 35.9$, $P < 0.001$) for all participants. There was no significant main effect of group ($F_{2,41} < 1$) and no interaction between group and rating ($F_{8,164} < 1$).

DISCUSSION

Facial expressions reflect a person's emotional state and intentions. Rapidly decoding accurate information from the expressions is thus an important skill for successful social behavior. We assessed the impact of glaucoma on face perception as a function of viewing distance, which was simulated by a progressive increase of the size of faces. The results showed that participants with glaucoma required a significantly shorter viewing distance (i.e., a larger face) than did normally sighted participants, both young and older, to recognize both the sex and the facial expression of faces. This finding was true not only for the three patients (2, 14, and 16) with reduced central acuity but also for the other patients with high acuity. However, in spite of this shorter distance, patients were generally able to recognize the sex and facial expression of a small face (less than 1° of angular size). The judgment of confidence showed that all three groups waited to be sure (ratings 4 and 5) before giving their response. This result suggests that the difference between patients and controls was perceptual rather than decisional in nature.

Viewing distance modulates the spatial frequency content of the stimulus projecting on the retina. Low spatial frequencies capture large-scale luminance variations (coarse information), whereas high spatial frequencies represent small-scale luminance variations of the image (i.e., fine features such as edges and small elements). From far away, we can see a blurry percept conveyed by low spatial frequencies. As the face moves progressively closer, we perceive higher spatial frequencies and finer details that allow recognition of the facial expression[17] and the person's identity.[15] The contribution of different spatial frequencies to the perception of faces has been investigated in several studies. Studies on normally sighted observers have reported different use of spatial frequencies depending on the facial expression (e.g., happy, sad, fear, pain); however, most studies have shown that the happy expression is dependent on low spatial frequencies[22] and can be categorized at a farther distance than can other expressions such as anger, fear, and sadness, which require higher spatial frequencies and a closer distance to be categorized.[16] Consistent with these studies, the happy faces of the present study were categorized at a farther distance than were angry and neutral faces in the three groups of participants. The categorization of sex has been reported to be better and faster with low spatial frequency than with high spatial frequency filtered faces, in contrast to familiarity judgments, which require both low and high frequencies.[23] Consistent with this result, sex was categorized at a farther distance than that of facial expression in the three groups in the present study. In glaucoma, there is no evidence of a selective reduction in sensitivity of channels tuned to high or low spatial frequency bandwidths. In the literature, impairment in the perception of high frequencies is thought to be indicative of parvocellular damage, whereas impairments in the perception of low frequencies is associated with magnocellular damage.[24] There has been some previous debate in the literature regarding whether there is damage of the magnocellular pathway in glaucoma. Some psychophysical studies using gratings varying in chromatic information and/or in temporal and spatial frequencies have suggested that glaucoma might be associated with a selective deficit of the magnocellular pathway,[25,26] but other studies[9,27,28] have reported reductions in sensitivity that are not selective of the magno- or parvocellular pathway in patients with glaucoma. A recent study performed in our group on faces filtered in low or in high frequencies showed that patients with glaucoma were impaired compared with controls regarding the two versions of faces but that the deficit was more marked on high-frequency-filtered faces.

In their study, Glen et al.[12] suggested that reduced contrast sensitivity might have contributed to the face recognition difficulties displayed by some of their patients. We did not directly measure the contrast sensitivity function. Previous studies have reported correlations between the visual field assessment with automated perimetry and contrast sensitivity in glaucoma,[29,30] but other studies in patients with low vision have reported that reduced visual acuity is more detrimental than reduced contrast sensitivity is to face perception.[4,5,31] Furthermore, our stimuli (colored faces) were displayed highly above contrast threshold. Studies on normally sighted participants have shown that at high contrast levels (beginning at 20%), the functions became flat for spatial frequencies ranging from 0.25 and 25 cycles/deg,[32] a range that includes the relevant bandwidths for the recognition of sex, of various facial expressions, and even of face identity.[22]

We suggest that the reduced sensitivity in central vision in participants with glaucoma, whether on contrast or on high frequencies or both, might have increased the sensitivity to crowding akin to the higher sensitivity to crowding in normal peripheral vision.[33] Crowding describes an inability to recognize an object (or a letter) when other objects (letters) are presented nearby. When adjacent objects closely surround the target object, the features of the target and flankers combine unless their spacing exceeds a critical crowding distance, which grows linearly with eccentricity (the "Bouma law").[34] Crowding is particularly detrimental in regions of reduced sensitivity (e.g., in normal peripheral vision).[33,35] In crowding, recognition is impaired but detection is spared. Crowding occurs for simple stimuli, such as lines, verniers, letters, and Gabors,[36] but it has also been reported for more complex stimuli, such as faces, due to "inner" crowding by facial features[37,38] and complex shapes.[39] Increasing the spacing between facial features[37] or the size of faces[40] reduces crowding and improves performance in normal peripheral vision. Consistent with our speculation, patients required a larger size to recognize facial expression and sex in the present study. Crowding also can occur in central vision, such as in strabismic amblyopia, a pathology characterized by reduced contrast sensitivity and strong foveal crowding.[41,42] The mechanisms underlying crowding are not yet well understood. Some accounts propose feature pooling,[43,44] grouping,[45] feature averaging,[43] changes in appearance,[39] limits of attentional resolution,[46] or tuning selectivity.[47] Crowding is a cortical phenomenon, although the site is yet unclear. Imaging evidence for crowding has been reported from V1 to V4, increasing in strength from early to late visual areas.[36] In strabismic amblyopia, functional physiological abnormalities have been reported in cortical area V1 but also in higher level areas of the occipitotemporal cortex.[48,49] We are not suggesting that glaucoma is clinically similar to strabismic amblyopia, but that reduced central sensitivity can have the same cortical and functional consequence in terms of sensitivity to crowding. Indeed, neuroimaging studies in patients with glaucoma have shown structural brain changes both in the optic radiations[50] and in gray matter, with reduced volume in the primary visual cortex[51,52] and in the temporal cortex.[53,54]

In contrast to Lott and colleagues,[19] we did not find any significant difference between young and older participants in EVD for the categorization of facial expressions. Both age difference and methodological aspects may account for this difference. Our age-matched group was slightly younger and less homogeneous, ranging in age from 48 to 80 years, than was the youngest group of Lott and colleagues.[19] Additionally, they used gray-level faces, whereas we used colored faces. At a perceptual level, color facilitates surface segmentation[55] and might have increased the saliency of facial features compared with that of gray-level faces. Their young participants had a better visual acuity (−0.13 ± 0.08 logMAR) than did their group of 64- to 70-year-old participants (0.02 ± 0.09 logMAR). In the present study, young and older participants had the same normal or corrected-to-normal visual acuity.

Conclusions

With a questionnaire, Glen and Crabb[14] showed that some patients with glaucoma report subjective difficulties in the recognition of distant faces. The present study shows that patients with glaucoma do require larger faces than those of normally sighted controls to recognize sex and facial expressions, but that they are nevertheless able to accomplish these tasks with small faces (less than 1° of visual angle). We suggest that the patients requiring larger faces than those of the controls might result from a higher sensitivity to crowding, which alters the appearance of faces and increases the difficulty to perceive the relevant features for recognition of sex and facial expressions. In normal peripheral vision, where crowding is strong, increasing the size of faces[40] or increasing the spacing between facial features improves performance.[37] Our account must be corroborated by a larger number of patients both with and without central field defect, with a larger number of facial expressions and with a manipulation of the spacing between facial features. Increasing the size and/or the spacing between facial features in photos of faces might facilitate recognition in glaucoma. In a subsequent study, we will assess whether the shorter distance (larger angular size) required for recognition of sex and facial expressions in patients generalizes to three-dimensional representations of faces. In addition to the relatively small sample of participants, another limitation of this study is that some patients were tested with a 24–2 visual field test and others with a 30–2 visual field test. This should not impact the present data, as these two tests measure a deficit in sensitivity at different eccentricities (24° and 30°, respectively) but the number of stimuli tested in the central 10° is equivalent in the two tests.

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References

1. Hood DC. Improving our understanding, and detection, of glaucomatous damage: an approach based upon optical coherence tomography (OCT). *Prog Retin Eye Res*. 2017;57: 46–75.
2. Curcio CA, Allen KA. Topography of ganglion cells in human retina. *J Comp Neurol*. 1990;300:5–25.
3. Hood DC, Slobodnick A, Raza AS, de Moraes CG, Teng CC, Ritch R. Early glaucoma involves both deep local, and shallow widespread, retinal nerve fiber damage of the macular region. *Invest Ophthalmol Vis Sci*. 2014;55:632–649.
4. Bullimore MA, Bailey IL, Wacker RT. Face recognition in age-related maculopathy. *Invest Ophtalmol Vis Sci*. 1991;32: 2020–2029.
5. Tejeria L, Harper RA, Artes PH, Dickinson CM. Face recognition in age related macular degeneration: perceived disability, measured disability, and performance with a bioptic device. *Br J Ophthalmol*. 2002;86:1019–1026.
6. Boucart M, Dinon JF, Despretz P, Desmettre T, Hladiuk K, Oliva A. Recognition of facial emotion in low vision: a flexible usage of facial features. *Vis Neurosci*. 2008;25:603–609.
7. Johnson AP, Woods-Fry H, Wittich W. Effects of magnification on emotion perception in patients with age-related macular degeneration. *Invest Ophthalmol Vis Sci*. 2016;58:2520–2526.
8. Thibaut M, Tran TH, Delerue C, Boucart M. Misidentifying a tennis racket as keys: object identification in people with age-related macular degeneration. *Ophthalmic Physiol Opt*. 2015; 35:336–344.
9. McKendrick AM, Badcock DR, Morgan WH. The detection of both global motion and global form is disrupted in glaucoma. *Invest Ophthalmol Vis Sci*. 2005;46:3693–3701.
10. Lenoble Q, Lek JJ, McKendrick AM. Visual object categorisation in people with glaucoma. *Br J Ophthalmol*. 2016;100: 1585–1590.

11. Roux-Sibilon A, Rutgé F, Aptel F, et al. Scene and human face recognition in the central vision of patients with glaucoma. *PLoS One*. 2018;13:e0193465.
12. Glen FC, Crabb DP, Smith ND, Burton R, Garway-Heath DF. Do patients with glaucoma have difficulty recognizing faces? *Invest Ophthalmol Vis Sci*. 2012;53:3629–3637.
13. Glen FC, Smith ND, Crabb DP. Saccadic eye movements and face recognition performance in patients with central glaucomatous visual field defects. *Vision Res*. 2013;82:42–51.
14. Glen FC, Crabb DP. Living with glaucoma: a qualitative study of functional implications and patients' coping behaviours. *BMC Ophthalmol*. 2015;15:128.
15. Loftus GR, Harley EM. Why is it easier to identify someone close than far away? *Psychon Bull Rev*. 2005;12:43–65.
16. Smith FW, Schyns PG. Smile through your fear and sadness: transmitting and identifying facial expression signals over a range of viewing distances. *Psychol Sci*. 2009;20:1202–1208.
17. Brady TF, Oliva A. Spatial frequency integration during active perception: perceptual hysteresis when an object recedes. *Front Psychol*. 2012;3:462.
18. Guo K. Size-invariant facial expression categorization and associated gaze allocation within social interaction space. *Perception*. 2013;42:1027–1042.
19. Lott LA, Haegerstrom-Portnoy G, Schneck ME, Brabyn JA. Face recognition in the elderly. *Optom Vis Sci*. 2005;82:874–881.
20. Tottenham N, Tanaka JW, Leon A, et al. The NimStim set of facial expressions: judgments from untrained research participants. *Psychiatry Res*. 2009;168:242–249.
21. Gutierrez P, Wilson MR, Johnson CA, et al. The influence of glaucomatous visual field loss and health-related quality of life. *Arch Ophthalmol*. 1997;115:777–784.
22. Sowden PT, Schyns PG. Channel surfing in the visual brain. *Trends Cogn Sci*. 2006;10:538–545.
23. Goffaux V, Jemel B, Jacques C, Rossion B, Schyns PG. ERP evidence for task modulations on face perceptual processing at different spatial scales. *Cognitive Science*. 2003;27:313–325.
24. Yoonessi A, Yoonessi A. Functional assessment of magno, parvo and konio-cellular pathways; current state and future clinical applications. *J Ophthalmic Vis Res*. 2011;6:119–126.
25. Anderson RS, O'Brien C. Psychophysical evidence for a selective loss of M ganglion cells in glaucoma. *Vision Res*. 1997;37:1079–1083.
26. Wen W, Zhang P, Liu T, et al. A novel motion-on-color paradigm for isolating magnocellular pathway function in preperimetric glaucoma. *Invest Ophthalmol Vis Sci*. 2015;56:4439–4446.
27. Ansari EA, Morgan JE, Snowden RJ. Psychophysical characterisation of early functional loss in glaucoma and ocular hypertension. *Br J Ophthalmol*. 2002;86:1131–1135.
28. McKendrick AM, Badcock DR, Morgan WH. Psychophysical measurement of neural adaptation abnormalities in magnocellular and parvocellular pathways in glaucoma. *Invest Ophthalmol Vis Sci*. 2004;45:1846–1853.
29. Wilensky JT, Hawkins A. Comparison of contrast sensitivity, visual acuity, and Humphrey visual field testing in patients with glaucoma. *Trans Am Ophthalmol Soc*. 2001;99:213.
30. Hawkins AS, Szlyk JP, Ardickas Z, Alexander KR, Wilensky JT. Comparison of contrast sensitivity, visual acuity, and Humphrey visual field testing in patients with glaucoma. *J Glaucoma*. 2003;1:134–138.
31. McCulloch DL, Loffler G, Colquhoun K, Bruce N, Dutton GN, Bach M. The effects of visual degradation on face discrimination. *Ophthalmic Physiol Opt*. 2011;31:240–248.
32. Georgeson MA, Sullivan GD. Contrast constancy: deblurring in human vision by spatial frequency channels. *J Physiol*. 1975;252:627–656.
33. Pelli DG. Crowding: a cortical constraint on object recognition. *Curr Opin Neurobiol*. 2008;18:445–451.
34. Bouma H. Interaction effects in parafoveal letter recognition. *Nature*. 1970;226:177–178.
35. Pelli DG, Tillman KA. The uncrowded window of object recognition. *Nat Neurosci*. 2008;11:1129–1135.
36. Herzog MH, Sayim B, Chicherov V, Manassi M. Crowding, grouping, and object recognition: a matter of appearance. *J Vis*. 2015;15(6):5.
37. Martelli M, Majaj NJ, Pelli DG. Are faces processed like words? A diagnostic test for recognition by parts. *J Vis*. 2005;5(1):58–70.
38. Sun HM, Balas B. Face features and face configurations both contribute to visual crowding. *Atten Percept Psychophys*. 2015;77:508–519.
39. Sayim B, Wagemang J. Appearance changes and error characteristics in crowding revealed by drawings. *J Vis*. 2017;17(11):8.
40. Mäkelä P, Näsänen R, Rovamo J, Melmoth D. Identification of facial images in peripheral vision. *Vision Res*. 2001;41:599–610.
41. Bonneh YS, Sagi D, Polat U. Spatial and temporal crowding in amblyopia. *Vision Res*. 2007;47:1950–1962.
42. Norgett Y, Siderov J. Effect of stimulus configuration on crowding in strabismic amblyopia. *J Vis*. 2017;17(13):5.
43. Greenwood JA, Bex PJ, Dakin SC. Positional averaging explains crowding with letter-like stimuli. *Proc Natl Acad Sci U S A*. 2009;106:13130–13135.
44. Pelli DG, Palomares M, Majaj NJ. Crowding is unlike ordinary masking: distinguishing feature integration from detection. *J Vis*. 2004;4(12):1136–1169.
45. Chicherov V, Plomp G, Herzog MH. Neural correlates of visual crowding. *NeuroImage*. 2014;93:23–31.
46. Intriligator J, Cavanagh P. The spatial resolution of visual attention. *Cogn Psychol*. 2001;43:171–216.
47. Motter BC. Stimulus conflation and tuning selectivity in V4 neurons: a model of visual crowding. *J Vis*. 2018;18(1):15.
48. Muckli L, Kiess S, Tonhausen N, Singer W, Goebel R, Sireteanu R. Cerebral correlates of impaired grating perception in individual, psychophysically assessed human amblyopes. *Vision Res*. 2006;46:506–526.
49. Levi DM. Image segregation in strabismic amblyopia. *Vision Res*. 2007;47:1833–1838.
50. Boucard CC, Hanekamp S, Ćurčić-Blake B, Ida M, Yoshida M, Cornelissen FW. Neurodegeneration beyond the primary visual pathways in a population with a high incidence of normal-pressure glaucoma. *Ophthalmic Physiol Opt*. 2016;36:344–353.
51. Yu L, Xie B, Yin X, et al. Reduced cortical thickness in primary open-angle glaucoma and its relationship to the retinal nerve fiber layer thickness. *PLoS One*. 2013;8:e73208.
52. Yu L, Xie L, Dai C, et al. Progressive thinning of visual cortex in primary open-angle glaucoma of varying severity. *PLoS One*. 2015;10:e0121960.
53. Li C, Cai P, Shi L, et al. Voxel-based morphometry of the visual-related cortex in primary open angle glaucoma. *Curr Eye Res*. 2012;37:794e802.
54. Lawlor M, Danesh-Meyer H, Levin LA, Davagnanam I, De Vita E, Plant GT. Glaucoma and the brain: trans-synaptic degeneration, structural change, and implications for neuroprotection. *Surv Ophthalmol*. 2018;63:296–306.
55. Gegenfurtner KR, Rieger J. Sensory and cognitive contributions of color to the recognition of natural scenes. *Curr Biol*. 2000;10:805–808.

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