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Reduced peripheral vision in glaucoma and boundary extension

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Keywords : boundary extension, spatial memory, scene perception, size, glaucoma

Running head: spatial memory in glaucoma

ABSTRACT

Clinical relevance

Peripheral vision is known to be critical for spatial navigation yet, visual cognition, has been the object of few interests in glaucoma; a pathology that affects peripheral vision.

Background

Spatial memory was assessed with a paradigm developed by Intraub and Richardson (1989) known to induce a robust memory distortion called “boundary extension” in which participants erroneously remember seeing more of a scene than was present in the sensory input.

Methods

15 patients with glaucoma and 15 age matched normally sighted controls took part in the experiment. Participants were shown 10 photographs of natural scenes randomly displayed for 0.5s or for 10s. Following each scene the participant was asked to draw it from memory.

Results

On average, boundary extension was larger, by 12%, for patients than for controls, but the difference was significant for 4 photographs. Patients tended to add more space between the object and the edges than there was between the objects and the border of the photograph. A control experiment in which participants were asked to draw isolated objects without scene context resulted in a significant reduction of the memory distortion in both groups but patients still drew the objects smaller than controls.

Conclusion

The results suggest that the reduced field of view in glaucoma has an impact on spatial memory for scenes and on perception of size.

INTRODUCTION

Glaucoma is a progressive optic neuropathy characterized by irreversible retinal ganglion cell and optic nerve fiber loss. Vision loss in glaucoma is classically described as loss of peripheral vision. Indeed, people with advanced glaucoma have significantly reduced peripheral vision as measured by visual field tests. Some patients with a greater amount of field loss report difficulties seeing objects on one or both sides.[1] Bilateral glaucoma is associated with limitations in driving, bumping into objects, slower walking, and falls.[2] Yet, very few patients describe their perception of the world as vision through a black tunnel. Crabb et al.[3] showed that 26% of the patients are unaware of their vision loss.

With reduced peripheral vision, the ability to obtain information for navigation and memory of scene views is different. This may lead to systematic distortions in spatial representations. Experimental support for spatial distortions comes from a study showing that simulated peripheral field loss in normally sighted participants led to systematic distortions in remembered target locations in a virtual environment.[4] This finding was extended to real peripheral field loss due to retinitis pigmentosa. Patients reported distortions in spatial representations which increased with decreasing field of view.[5]

In normal vision a paradigm was developed by Intraub and Richardson[7] to investigate scene representations. They presented normally sighted young people with photographs of natural scenes for a limited presentation time and asked them to draw the scenes from memory. They noticed a systematic error in the participants' drawings: people remembered having seen a surrounding, unseen but highly likely layout, from beyond the camera's point of view. This phenomenon was called the "boundary extension effect". Boundary extension is not limited to drawing from memory. The same outcome was observed in recognition,[8] matching[9] and adjustment tasks,[10] with presentation times varying from 250ms to more than 10s [9] and with pictures of various sizes.[11] This “extrapolation” was interpreted as resulting from the activation of a mental representation that includes memory for prior views of a similar scene as well as anticipated continuation of the scene beyond the boundaries of the view.[12]

Does a restricted field of view affect the memory representation for scenes and, as a consequence, impact the boundary extension effect? This issue was examined in normally sighted young people with vision blocking goggles.[13] Performance was compared in two monocular tunnel vision conditions in which vision was restricted to 3 cm or to 0.6 cm, and a binocular normal viewing condition. The results showed that scenes were remembered with extended boundaries (by 30%) in all three conditions suggesting that artificial restriction of the peripheral field had no effect on memory. However, in contrast to an artificial tunnel vision in normally sighted people, patients with an ocular pathology lose their peripheral vision over decades. It might be that they compensate their visual field loss by remembering scenes larger than they are. As a consequence the boundary extension might be amplified in patients with progressive peripheral field loss compared to normally sighted participants. The present study assessed this issue in testing patients with advanced glaucoma. If a restricted field of view produces memory distortions[4,5] then patients should draw the scenes smaller than they were presented and thus exhibit a larger boundary extension. However, an alternative possibility is that, due to their peripheral vision loss, the patients perceive the objects smaller than they are. Indeed, Legge et al.[6] showed that artificial restriction of the visual field, to a narrow field of 8° in normally sighted observers, impaired spatial location of a target but also judgments of the size of unfamiliar rooms. To assess whether a larger boundary extension, observed in patients, results from a distortion in the memory representation of scenes or from a distortion in the perception of size a control experiment was conducted in which participants were asked to draw isolated objects extracted from the scenes. The boundary extension effect is known to be specifically related to memory for scenes. Intraub et al.[14,15] compared performance for scenes and for isolated objects extracted from the scenes. They found boundary extension only for the scene version of images. If a larger boundary extension in patients resulted from a distortion in the memory representation of scenes to compensate for the smaller field of view then it should not be observed for isolated objects. If it resulted from a distortion in the perception of size then isolated objects should also be perceived and drawn smaller than their representation on the photos.

METHODS

Participants

Glaucoma patients

15 adults (9 females, age 58.7 ranging from 28 to 85) with stable (no progression on three successive visual field tests in the last 2 years) bilateral primary open angle glaucoma were recruited from the department of ophthalmology in the Lille's university hospital. To be included in the study, patients had to have a visual acuity 0.2 LogMAR or better in each eye at the Monoyer scale, a score ≥ 25/30 on the Mini-Mental State Examination, indicating that there were no gross deficits in cognitive function, no other ocular disease than glaucoma, no neurological disease and no medication affecting attention. All participants underwent SITA-standard 30-2 perimetry using a Humphrey Visual Field Analyzer (HFA, Carl Zeiss Meditec, CA, USA) and had visual field defects consistent with severe glaucoma at the Hodapp–Parrish–Anderson grading scale with mean deviation (MD) worse than -12 dB. The ophthalmologist checked for each participant if there was a complaint in terms of motor skills or if there was a difficulty in writing. The demographic details and clinical data of the 15 patients are summarized in Table 1. The patients' visual fields are displayed in Figure 1.

Controls

15 normally sighted people (10 females, age 59.1 ranging from 26 to 89) were included. They were either a relative or a friend of patients. Controls had a full eye examination to ensure that they had no ocular pathology. Their visual acuity and MMSE score are presented in Table 1.

Both patients and controls were tested monocularly on their eye with worse mean deviation to Humphrey Visual field for patients with glaucoma and on their preferred eye for controls. The study was approved by the local ethic committee (CPP Nord-Ouest IV). In accordance with the tenets of the Declaration of Helsinki written informed consent was obtained from all participants. No significant difference was found between patients and controls in terms of age (58.7 vs 59.1, $t(14) = 0.068$, $p= 0.95$), MMSE score (patients : 28.3 vs controls: 28.6, $t(14) = 1.073$, $p = 0.30$) or visual acuity (patients : 0.049 LogMar vs controls: 0.033 LogMar, $t(14) = 0.604$, $p = 0.56$).

As there were 30 participants divided in two groups in the main experiment, a post hoc power analysis was conducted with the software G*Power (Faul, Erdfelder, Lang, & Buchner). It showed that the power of the design was : Power (1-βerr prob)= 0.84 ; α=.05; Effect size *d*= 0.94.

[Table 1 and Figure 1 about here]

Stimuli

The main experiment used 10 colored photographs of natural scenes containing an object (Figure 2A). The photographs of scenes were provided by Helene Intraub (University of Delaware). The angular size of the scenes was 35° x 28° (105 x 80 cm) at a viewing distance of 150 cm. A control experiment was performed with isolated objects. In each scene the main object was cut and pasted on a white background. The stimuli are displayed in Figure 2B. The main object had the same size in the isolated version as in the scene version.

Equipment

The scenes were randomly displayed on a large screen (130 cm vertically x 144 cm horizontally) by a video projector (Optoma DX 733) connected to a laptop computer (Dell).

Procedure

Fifteen patients and 15 age-matched controls participated to the scene drawing task. Only 8 patients and 8 normally sighted controls accepted to participate to the control experiment with isolated objects. Participants were tested in a dimly illuminated room with the light off and a weak light coming from the edges of venetian blind of the window. In the main experiment (scene drawing) the 10 photos of scenes were centrally and randomly presented on a black background. Five images were randomly presented for 0.5 s and the 5 others for 10 s. Participants were given 10 sheets of paper containing a black outline of a rectangle (20 x 16 cm). Immediately after each scene presentation they were asked to draw the scene from memory, within the rectangle. There was no time limit. Participants were instructed to draw the pictures in as much detail as possible and to keep the layout of the picture and relative size of the object as accurately as possible. They were told to consider the edges of the rectangle to be the edges of the photograph they had seen on the screen and to draw the pictures accordingly. In the control experiment the 10 photos of isolated objects were centrally and randomly presented for 10 sec each. Participants were given 10 sheets of paper containing a black outline of a rectangle (20 cm x 16 cm). They were asked to draw it within the black rectangle. As in the main experiment with scenes there was no time limit and participants were instructed to keep the layout of the picture and relative size of the object as accurately as possible. They were told to consider the edges of the rectangle to be the edges of the photograph they had seen on the screen and to draw the pictures accordingly. The duration of each experiment varied between 20 to 30 min depending on the degree of details of the drawings performed by each participant.

[Figure 2 about here]

Data analysis

For each participant, and each photograph, the magnitude of the boundary extension was computed using the following formula: (area object drawn / area of the object in the picture)*100. The areas of the objects (photograph and drawing) were measured in drawing a rectangle surrounding the object. The measure was made manually for each drawing. We then measured the distance between the edge of the object (top, bottom, left and right) and the outline contour of the rectangle.

The completion was also measured. The completion was defined by as a cropped object on photograph made whole (i.e., more completed) on the drawing from memory (e.g., butterfly, bird house, racquet, phone pole and fork; see Figure 2).

RESULTS

1. Scene drawing

The boundary extension effect

An ANOVA using the software Systat 8.0 (Systat Software, Inc. San Jose, California) was conducted on the data. The factors were the group and the exposure time. Five objects were not drawn: 2/10 by one patient and 1/10 by three other patients. That occurred only at the 0.5 s exposure time. The results are presented in Figure 3 for each photograph and in Table 1 for each participant.

Consistent with previous studies on normally sighted participants [9] there was no significant effect of the exposure duration of the photographs on the magnitude of the boundary extension (0.5 s: 49.4% vs 10 s: 52.2% $F1(1, 28) = 3.63$, p =.067, Cohen's d = .14). On average patients tented to exhibit a larger boundary extension effect than controls. The objects drawn covered 44.7% of the surface for patients vs 57% for controls. Due to the large inter individual variability (see Figure 3) the difference was not statistically significant ($F1(1, 28) = 3$, p =.09, Cohen's d = .64).

An analysis performed on each image showed that the boundary extension was significantly larger for patients than for controls on 4 photos: panda, lantern, racquet and phone pole (see Figure 3).

<u>Object completion</u>

On average the 5 objects that were cropped by the picture's boundaries (phone pole, racquet, fork, butterfly and bird house) were significantly more completed (e.g., participants drew the complete fork) by controls than by patients ($F(1, 8) = 7.35$, p = .027, Cohen's d = 2.87) see Figure 4.

[Figure 3 about here]

[Figure 4 about here]

2) Object drawing

The results are presented in Figure 5 for each photograph and in Table 1 for each participant. On average the object was drawn smaller by patients than by controls (51.05% vs 63.53%) but the difference was not significant ($F(1, 14) = 2.13$, p = 0.16, Cohen's d = .78).

The comparison of the two versions of pictures (scenes and isolated objects), in the long exposure time (10 s), showed a significant main effect of the version of image ($F1(1, 42) = 48.4$, $p < .001$, Cohen's $d = 2.02$) with a larger boundary extension in the scene version (patients: 45.7% and controls: 58.7%) than in the isolated object version (patients: 51.05% and controls: 63.53%) and a main effect of group $F(1, 36) = 6.36$, $p < .01$, Cohen's $d = .38$) with patients drawing the pictures smaller than controls in both experiments. There was no interaction between group and experiment.

[Figure 5 about here]

Correlations

No significant correlation was found between the magnitude of visual field defect and the magnitude of boundary extension ($r = 0.147$).

DISCUSSION

Few studies have investigated the impact of glaucoma on cognitive functions like spatial cognition and how patients perceive the world.[16] The present study examined whether progressive peripheral field loss due to glaucoma affects spatial memory for scenes using the ubiquitous boundary extension effect.

The results showed that patients tended to add more space between the object and the edges of the rectangle than there was between the object and the border of the photograph, suggesting that, though very few people with glaucoma are aware of their reduced peripheral vision,[3] it does affect spatial representations. During a navigation task, a distortion in spatial representation was also reported in patients with retinisis pigmentosa; a pathology that also reduces peripheral vision.[5] Lenoble et al.[17] showed that patients with glaucoma over-estimated the distance of objects in their peripersonal space.

In normally sighted people Intraub and Richardson[7] described two components in the boundary extension effect: 1) the increase in space between the main object and the edges of the rectangle and 2) the completion of cropped objects and/or the addition of objects not present in the photograph but likely to be found in the scene. In the present study the completion of cropped objects, in the scene version, was higher in the control group than in the patient's group, especially at short exposure time. A 0.5 s exposure time allows only 2 fixations. As there was no gap between the fixation cross and the onset of the picture, it is likely that the first fixation was exactly at the center of the image. The cropped part therefore appeared in the periphery. It might be that parts of the objects were less visible by people with a peripheral scotoma when the exposure duration did not allow exploration of the images. Moreover, it has been shown that participants with glaucoma exhibit reduced visual exploration.[18,19] A study in normally sighted participants showed that impeding eye movements by having participants view room-sized spatial layouts through small apertures (a field of view restricted to 3° of visual angle) made subsequent retrieval of spatial memory slower and less accurate.[20]

The control experiment showed that the isolated version of object was also drawn smaller than their representation on the photos. Intraub et al.[15] compared drawing performance when the same objects were presented in the context of a scene and in isolation. Boundary extension was observed for objects in scenes. When the same objects were presented on a blank background performance varied as a function of picture view: close-ups (large objects) were remembered and drawn as smaller and wide-angle views (small objects) were remembered and drawn as larger. Consistent with these results, Figure 5 shows that smaller objects (panda, lantern and bird house) were drawn larger whereas large objects (bench, house, butterfly, pole phone, racquet and fork) were drawn smaller. The car was an exception. However, for all participants (patients and controls) the space occupied by the object was smaller in the drawing than it was on the photo. Intraub et al.[15] used a large number of photos and an equal number of close-ups and wide angle views. The small number of pictures and small number of wide angle views might explain why the boundary extension was not totally suppressed in the present study. Nevertheless, the comparison of the two experiments showed that the memory distortion was significantly larger with scenes than with isolated objects in both groups of participants.

In a drawing task with normally sighted participants, Konkle & Oliva[21] showed that the drawn size of the object depends on the assumed size of the object in the world with small objects, like a key, being drawn small and large objects, like a house, being drawn larger. In the present study small objects were drawn larger and large objects were drawn smaller. This result is not inconsistent with their study as they also showed that participants were sensitive to the amount of space specified by a frame, drawing objects in such a way that a consistent ratio between the object and the paper size was preserved over a range of different frame sizes. Nevertheless, participants with glaucoma drew both isolated objects and objects in scene smaller than controls consistent with Legge et al.[6] who found that artificial peripheral field loss led to a deficit in the estimation of room sizes. This was explained by a deficit in the encoding of spatial cues due to restricted eye movements. Impaired visual exploration cannot completely account for the results as small objects like the lantern or panda did not require visual exploration. Rather it might be that the representation of size is affected in glaucoma.

There is evidence from animal studies and voxel-based morphometry techniques in humans that damage of the optic nerve in glaucoma propagates by means of transneuronal degeneration towards the visual cortex.[22,23] There is also evidence that neurodegeneration in glaucoma spreads beyond the primary visual cortex.[24] The primary visual cortex has widespread connections to other areas in the brain, such as the hippocampus, involved in spatial memory.[25,26] Neuroimaging studies in healthy young observers have shown that the boundary extension phenomenon is associated with a strong activation in the retrosplenial cortex and the hippocampus.[27,28] Interestingly, Frezzotti et al.[29] showed grey matter atrophy in cortical regions involved in object (the lateral occipital complex) and scene (the parahippocampal place area) recognition in patients with glaucoma. It might be that the alteration in size perception and memory for scenes results from a functional deficit in the network involved in scene perception in glaucoma.

In a previous study with simulated peripheral field loss in normally sighted participants Intraub reported no significant difference in boundary extension between the conditions with small and large monocular tunnel vision and normal binocular vision.[13] The present study showed that boundary extension was larger in patients with reduced peripheral vision than in normally sighted people. Two main differences might explain this result: (1) the use of more close-up views than Intraub.[13] Other studies from that group showed that tight close-ups elicit the greatest boundary extension compared to wide angle views;[14,15] (2) people with glaucoma have had years to functionally adapt to the gradual reduction of their visual field. It might be that seeing smaller parts of real world scenes, though not being aware of it, has an impact on memory for scenes and size. People with reduced visual field perceive and remember objects smaller than they are.

CONCLUSION AND LIMITATIONS

This study shows that people with glaucoma exhibit larger boundary extension than controls when asked to draw photographs of scenes from memory suggesting that they compensate their reduced visual field by activating larger representations of scenes but the control experiment, with isolated objects, showed that they also draw objects smaller than seen on the screen suggesting that the perception of size is also affected. However, most of the objects were close up views and it has been shown that observers have a tendency to draw these large objects smaller than they appear.[13,30] The difference between patients and controls might have been more reliable with more images and wider angle views. Participants were tested under monocular viewing condition on the most severely impaired eye. The spatial memory and the representation of size might have been less distorted under binocular viewing condition.

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Figure legends

Table 1. Clinical and demographic data about patients and controls. MD = mean deviation in decibel. VF = visual field. % BE = percentage of boundary extension, E1 = Experiment 1, E2 = Experiment 2.

Table 2. Percentage of completion of the cropped objects as a function of the exposure duration (0.5s vs 10s) and the group (patients vs controls).

Figure 1. Gray-scale plot from the Humphrey Visual Field (30-2) of the tested eye of the 15 patients. * = patients 7 and 12 had a severe glaucoma that did not allow testing with a 30-2 perimetry. These two patients were tested with a 10-2 visual field.

Figure 2. A: The 10 photographs of scene used in Experiment1. B: The 10 photographs of isolated objects used in Experiment 2.

Figure 3. The boundary extension, in terms of percent object drawn (see formula in the result section) and the standard errors (*= $p<.05$, **= $p<.02$) as a function of the image used in Experiment 1 and the group (patients vs controls).

Figure 4. Examples of drawings from control participants and from patients with glaucoma.

Figure 5. Comparison of the boundary extension for Scene Drawing Experiments (top) and Object Drawing Experiment (bottom), in terms of percent object drawn (see formula in the result section), and the standard errors, as a function of the image and the group (patients vs controls).

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Table 1

PATIENTS	AGE	GENDER	TESTED EYE	ACUITY (LogMAR)	MMSE	MD (dB)	VF(degree)	%BE E1 scene	%BE E2 object
1	56	F	R	0.00	30	-21.29	12	58	76.5
2	83	F	L	0.10	25	-23.05	12	35	
3	37	M	R	0.00	27	-27.03	11	66	51.3
4	60	F	R	0.10	29	-15.67	12	32	62.2
5	68	M	R	0.00	28	-29.39	10	43	51.2
6	85	M	R	0.10	28	-24.00	10	36	61.9
7	46	M	R	0.00	30	-24.04	12	48	
8	52	F	R	0.00	26	-10.87	12	17	17.2
9	50	F	R	0.10	28	-16.31	11	47	35.9
10	39	M	L	0.00	30	-12.86	12	99	
11	83	F	L	0.10	27	-15.58	10	67	
12	64	F	L	0.20	30	-33.72	6	37	52.2
13	70	F	R	0.10	28	-15.55	12	47	
14	60	F	R	0.10	30	-17.70	10	17	
15	28	M	R	0.10	29	-22.76	12	36	

CONTROLS	AGE	GENDER	TESTED EYE	ACUITY (logMAR)	MMSE	%BE E1 scene	%BE E2 object
1	32	M	R	0.00	30	68	76
2	56	F	R	0.00	28	76	
3	79	F	R	0.10	28	75	75.1
4	65	M	R	0.00	30	56	90.1
5	54	F	R	0.00	30	82	51.6
6	54	M	R	0.00	28	60	53.9
7	41	M	R	0.00	30	69	
8	53	F	R	0.00	30	21	49.7
9	65	F	R	0.00	28	33	67.8
10	88	F	R	0.00	27	61	
11	26	M	R	0.00	30	66	
12	62	F	R	0.00	26	53	44.1
13	45	F	R	0.00	29	66	
14	89	F	L	0.10	26	16	
15	78	M	R	0.00	30	58	

For Review

Fig.1.

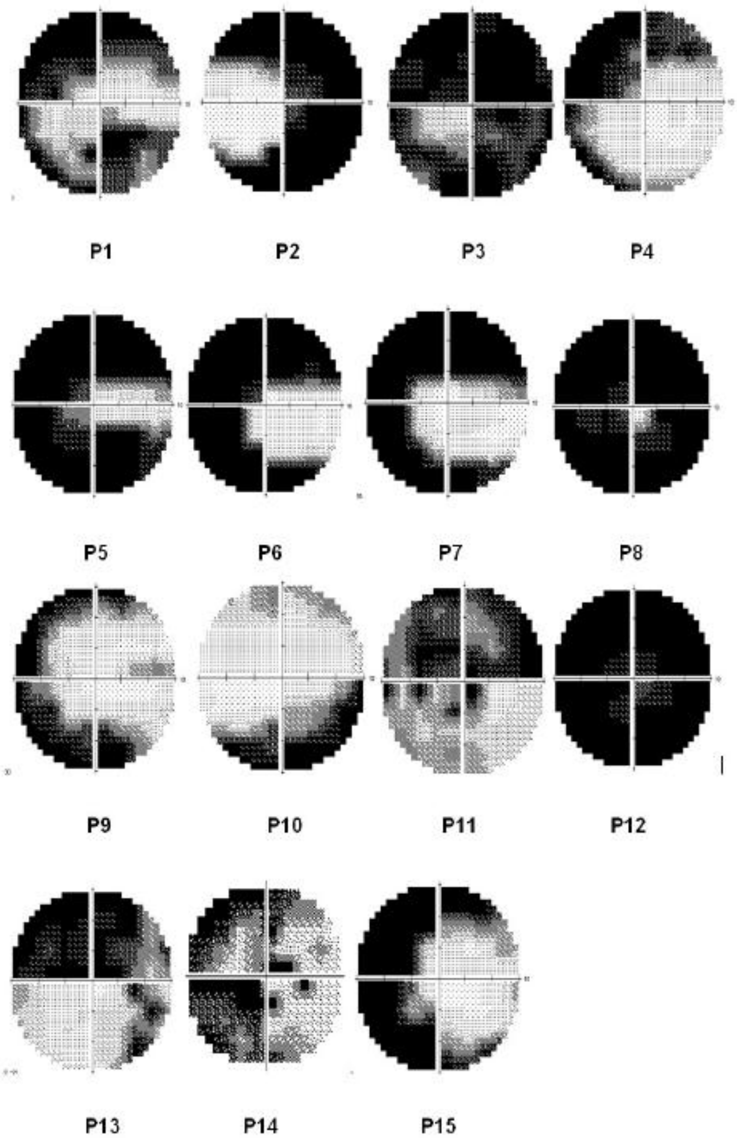

Fig.2.

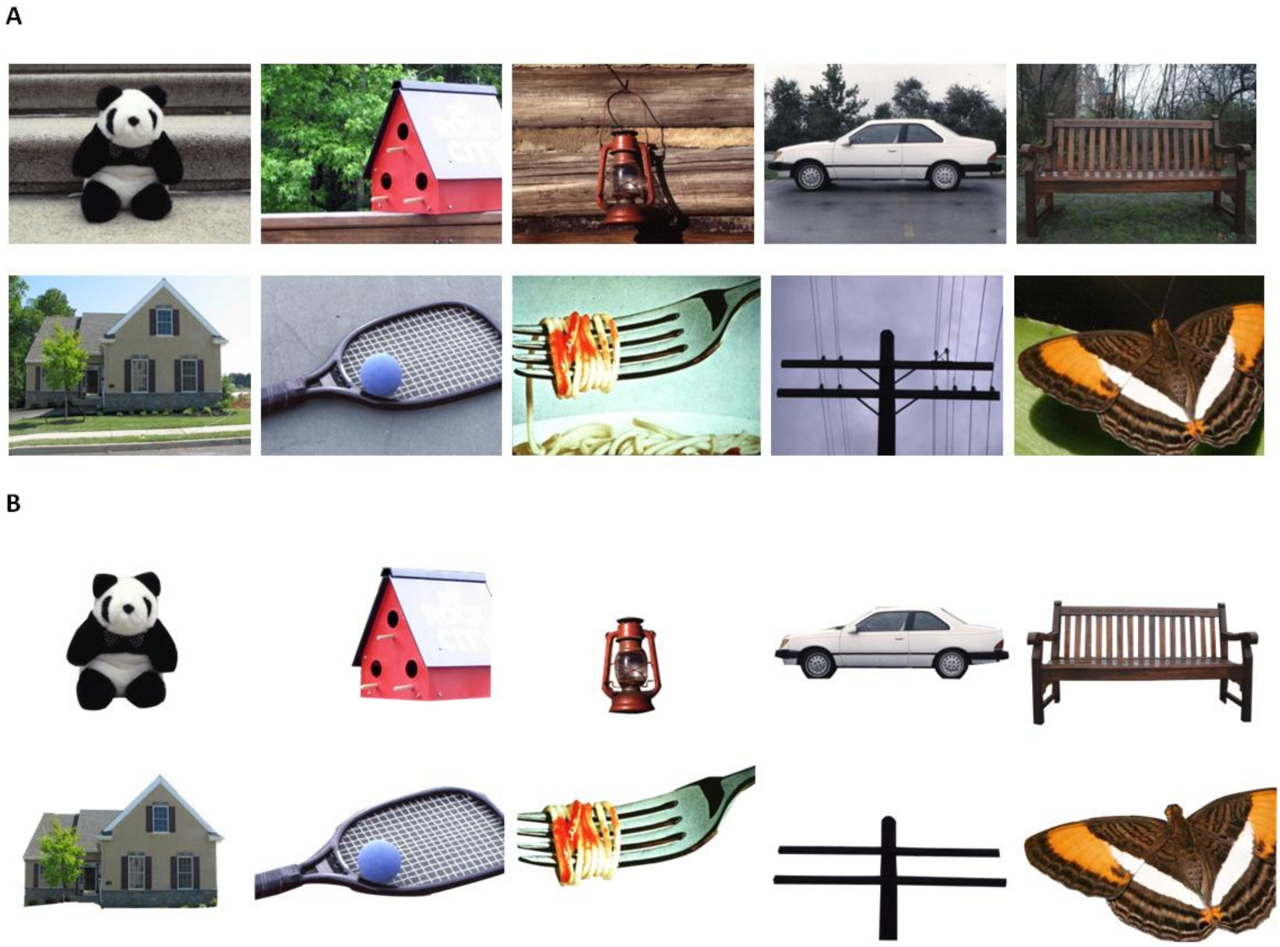

Fig.3

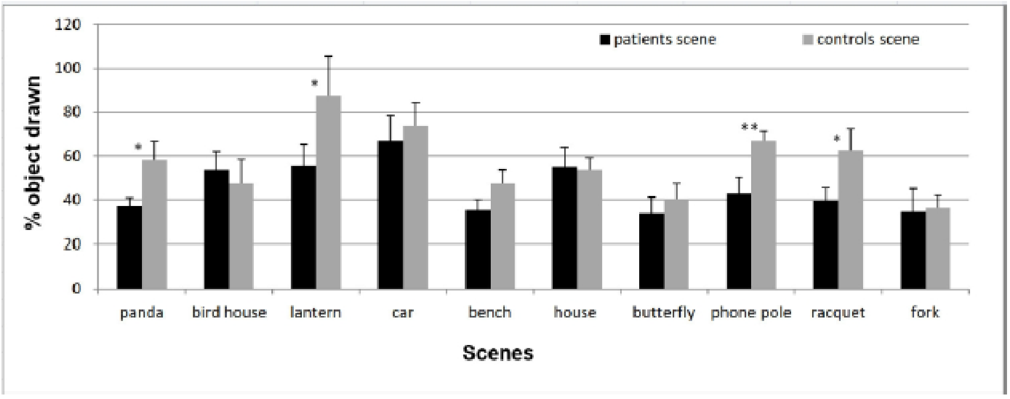

Figure 3. The boundary extension, in terms of percent object drawn (see formula in the result section) and the standard errors (*= p<.05, **= p<.02) as a function of the image used in the Scene Drawing Experiment and the group (patients vs controls).

140x54mm (300 x 300 DPI)

Fig.4.

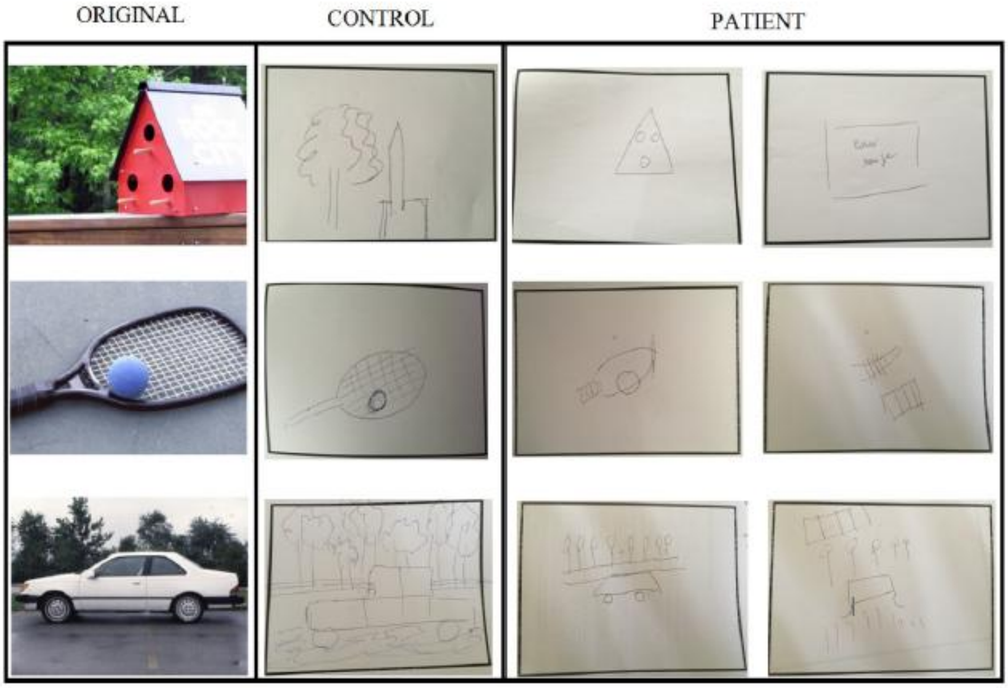

Figure 4. Examples of drawings from control participants and from patients with glaucoma.

Fig.5.

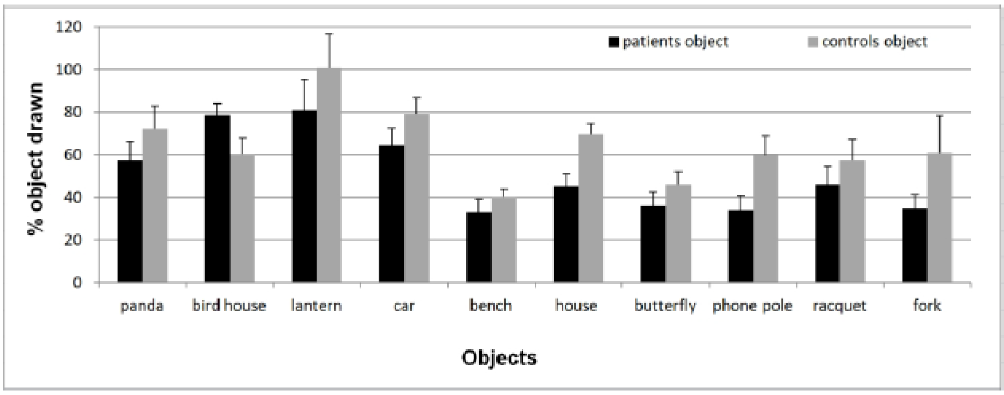

Figure 5. Comparison of the boundary extension for the Object Drawing Experiment, in terms of percent object drawn (see formula in the result section), and the standard errors, as a function of the image and the group (patients vs controls).