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Scene perception in age-related macular degeneration: Effect of spatial frequencies and contrast in residual vision

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A B S T R A C T

Age-related macular degeneration (AMD) is characterized by a central vision loss. Here, we investigated the ability of AMD patients to process the spatial frequency content of scenes in their residual vision, depending of the luminance contrast level. AMD patients and normally-sighted elderly participants (controls) performed a categorization task involving large scenes (outdoors vs. indoors) filtered in low spatial frequencies (LSF), high spatial frequencies (HSF), and non-filtered scenes (NF). Luminance contrast of scenes was equalized between stimuli using a root-mean square (RMS) contrast normalization. In Experiment 1, we applied an RMS contrast of 0.1 (for luminance values between 0 and 1), a value situated between the mean contrast of LSF and HSF scenes in natural conditions. In Experiment 2, we applied an RMS contrast of 0.3, corresponding to the mean contrast of HSF scenes in natural conditions. In Experiment 3, we manipulated four levels of linearly-increasing RMS contrasts (0.05, 0.10, 0.15, and 0.20) for HSF scenes only. Compared to controls, AMD patients gave more non-responses in the categorization of HSF than NF or LSF scenes, irrespective of the contrast level of scenes. Performances improved as contrast increased in HSF scenes. Controls were not differentially affected by the spatial frequency content of scenes. Overall, results suggest that LSF processing is well preserved in AMD patients and allows efficient scene categorization in their parafoveal residual vision. The HSF processing deficit could be partially restored by enhancing luminance contrast.

1. Introduction

Age-related macular degeneration (AMD) is characterized by central vision loss caused by the destruction of macular photoreceptors. AMD therefore affects low-level visual functions of central vision, such as acuity, high spatial resolution and contrast sensitivity, and consequently, the activities of daily life, such as reading (Fine & Peli, 1995; Fletcher, Schuchard, & Watson, 1999; Legge, Rubin, Pelli, & Schleske, 1985), face recognition (Bullimore, Bailey, & Wacker, 1991; Tejeria, Harper, Artes, & Dickinson, 2002) and processing of facial emotion (Boucart, Dinon, et al., 2008). Interestingly, activities which involve the peripheral residual vision of AMD patients, such as objet and scene perception (Boucart, Despretz, Hladiuk, & Desmettre, 2008; Boucart, Moroni, Despretz, Pasquier, & Fabre-Thorpe, 2010), driving (Rovner & Casten, 2002), and mobility (Hassan, Lovie-Kitchin, & Woods, 2002; Salive et al., 1994) are also affected.

Many studies have directly demonstrated that in AMD patients contrast sensitivity decreases for middle and high spatial frequencies in sinusoidal gratings (Brown & Lovie-Kitchin, 1988; Kleiner, Enger, Alexander, & Fine, 1988; Midena, Degli Angeli, Blarzino, Valenti, & Segato, 1997). Recent studies have focused on the residual abilities of AMD patients to process more complex daily visual stimuli, such as objects, faces, and scenes. Tran, Guyader, Guerin, Despretz, and Boucart (2011) showed that the detection of an animal in a scene is impaired in AMD patients, but that this could be improved by surrounding the animal with a white space. AMD patients were also more affected by contrast reduction during a similar animal detection task than normally-sighted, age-matched people (Tran, Despretz, & Boucart, 2012). In Bordier, Petra, Dauxerre, Vital-Durand, and Knoblauch (2011), AMD patients had to name an object in a scene sequence starting with a scene in low spatial frequencies and spatial frequency information was progressively added. Results showed a reduction in the

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bandwidth necessary for the object identification when the background was darkened by lowering its luminance. Other findings have pointed to a deficit for AMD patient in the processing of high spatial frequencies in complex visual stimuli. When assessing the recognition of facial emotional expressions in AMD patients, Boucart, Dinon, et al. (2008) showed that visual processing was impaired when the decision relied on the perception of fine details conveyed by high spatial frequencies. Using a categorization task involving large scenes which encompassed the parafoveal vision, Musel et al. (2011) demonstrated a specific deficit in AMD patients in the processing of high spatial frequencies (HSF) in scenes, and preserved skills in the processing of low spatial frequencies (LSF). The specific visual impairment for HSF scene categorization is consistent with the loss of photoreceptors and ganglion cells specifically tuned to HSF in the central area of the macula in AMD patients. However, luminance contrast is higher for LSF than for HSF scenes. Luminance contrast in scenes decreases as spatial frequency increases, following a 1/f function (Field, 1987). The low luminance contrast in HSF scenes may have contributed to the HSF deficit.

The aim of the present study was to examine the processing of spatial frequencies in AMD patients' parafoveal residual vision, and in particular to investigate whether low luminance contrast in scene could in fact explain the visual deficit of AMD patients in the categorization of HSF scenes. For this purpose, we conducted three experiments in which AMD patients and normally-sighted elderly participants had to categorize indoor and outdoor scenes filtered in LSF and HSF, and non-filtered scenes (NF). From a pragmatic point of view, this categorization task can be performed whatever type of filter is used (low-pass, high-pass, or pass-band). Furthermore, this task is simple and quick to administer, but also easy to perform even for patients with age-related macular degeneration (Musel et al., 2011). We examined the effect of contrast equalization on spatial frequency processing in the residual vision of AMD patients in the two first experiments. In the third experiment, we directly examined whether contrast increase could improve the processing of HSF information.

2. Experiment 1

Experiment 1 aimed specifically to investigate whether the deficit of AMD patients for categorizing HSF scenes (Musel et al., 2011) could be explained by the low luminance contrast in HSF scenes. In this experiment, luminance contrast of NF, LSF, and HSF scenes was equalized using an RMS (root mean square) contrast normalization. RMS contrast corresponds to the standard deviation of luminance values. It is the most frequently-used normalization, and it has been shown to be the most reliable indicator of the visibility of broadband filtered images (Bex & Makous, 2002). We chose an RMS value situated between the mean contrast values of LSF and HSF scenes in natural conditions (RMS contrast of 0.1 for luminance values between 0 and 1) in order to avoid affecting one spatial frequency condition more than another. Therefore, this contrast normalization enhances contrast in HSF scenes while reducing contrast in LSF scenes. If the visual deficit of AMD patients in scene categorization is mainly explained by the spatial frequency content, we expected that AMD patients would commit more errors than controls for HSF only, irrespective of the luminance contrast level.

2.1. Materials and methods

2.1.1. Participants

Nineteen patients with exudative AMD (Table 1) were included in the experiment. They were followed and treated with intravitral injections of ranibizumab using a pro re nata regimen in the course of a flexible anti-VEGF therapy regimen for the treatment of neovascular AMD. Patients were seen monthly and treated on an "as-needed" basis. The inclusion criterion was visual acuity between 1 and 0.2 LogMAR in the most severely impaired eye. Only one eye was tested in twelve patients (seven males; mean age ± S.D. = 69 ± 6 years; range 60–77; AMD 1–12 in Table 1). Patients with unilateral AMD were tested on their pathological eye. Patients with bilateral AMD were tested on the eye with the best-corrected visual acuity. Twelve normally sighted elderly participants (six males; 65 ± 3 years; range 61–72; Table 1) were also tested unilaterally, in the eye with the best-corrected visual acuity (Control group). The inclusion criterion for controls was visual acuity between 0.2 and 0 LogMAR in the selected eye. Seven patients with unilateral AMD (five males; 73 ± 8 years; range 62–82; AMD 13–19 in Table 1) were tested twice, once on the AMD eye and a second time on the healthy eye. Performances measured in the healthy eye allowed us to use patients as their own controls. The order of the eye tested was counterbalanced across patients.

Table 1
Demographic and clinical data of Experiment 1. Patients AMD 1 to AMD 12, and Controls were tested in only one eye. Patients AMD 13 to AMD 19 all have unilateral AMD. They were tested in both eyes (AMD eye and healthy eye).

	Gender	Age (years)	Lesion type	Eye test	Visual acuity (LogMAR)		Gender	Age (years)	Visual acuity (LogMAR)
AMD 1	M	72	Bilateral	Left	0.2	Control 1	M	61	0
AMD 2	M	72	Bilateral	Right	0.2	Control 2	M	62	0
AMD 3	F	77	Bilateral	Left	0.2	Control 3	F	63	0
AMD 4	M	61	Bilateral	Left	0.3	Control 4	F	63	0
AMD 5	M	70	Unilateral	Right	0.3	Control 5	M	66	0
AMD 6	F	74	Unilateral	Left	0.3	Control 6	F	67	0
AMD 7	M	76	Bilateral	Left	0.4	Control 7	M	67	0
AMD 8	M	63	Unilateral	Right	0.6	Control 8	F	68	0
AMD 9	M	60	Unilateral	Right	0.7	Control 9	F	68	0
AMD 10	F	67	Bilateral	Left	0.7	Control 10	M	65	0.1
AMD 11	F	73	Bilateral	Left	0.8	Control 11	F	72	0.1
AMD 12	F	70	Bilateral	Left	0.9	Control 12	M	61	0.2

	Gender	Age (years)	Lesion type	AMD eye	Visual acuity (LogMAR) AMD eye	Visual acuity (LogMAR) Healthy eye
AMD 13	M	82	Unilateral	Right	0.2	0
AMD 14	F	67	Unilateral	Left	0.3	0
AMD 15	M	80	Unilateral	Right	0.6	0.1
AMD 16	M	62	Unilateral	Right	0.7	0
AMD 17	M	77	Unilateral	Right	0.7	0.1
AMD 18	F	80	Unilateral	Right	0.7	0.1
AMD 19	M	65	Unilateral	Left	1	0