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The contribution of central and peripheral vision in scene categorization: A study on people with central vision loss

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ABSTRACT

Studies in normally sighted people suggest that scene recognition is based on global physical properties and can be accomplished by the low resolution of peripheral vision. We examine the contribution of peripheral and central vision in scene gist recognition in patients with central vision loss and age-matched controls. Twenty-one patients with neovascular age related macular degeneration (AMD), with a visual acuity lower than 20/50, and 15 age-matched normally sighted controls participated in a natural/urban scene categorization task. The stimuli were colored photographs of natural scenes presented randomly at one of five spatial locations of a computer screen: centre, top left, top right, bottom left and bottom right at 12° eccentricity. Sensitivity (d') and response times were recorded. Normally sighted people exhibited higher sensitivity and shorter response times when the scene was presented centrally than for peripheral pictures. Sensitivity was lower and response times were longer for people with AMD than for controls at all spatial location. In contrast to controls patients were not better for central than for peripheral pictures. The results of normally sighted controls indicate that scene categorization can be accomplished by the low resolution of peripheral vision but central vision remains more efficient than peripheral vision for scene gist recognition. People with central vision loss likely categorized scenes on the basis of low frequency information both in normal peripheral vision and in low acuity central vision.
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1. Introduction

The gist of a scene includes all levels of processing, from low-level features (color, spatial frequency, orientation…) to intermediate image properties (surface, volumes, texture) and high level information (semantic knowledge) (Oliva, 2005). Studies on normally sighted people have shown that scene gist recognition is particularly robust, even in conditions of limited presentation time (around 20 ms) (Greene & Oliva, 2009a; Joubert et al., 2007; Rousselet, Joubert, & Fabre-Thorpe, 2005), limited spatial frequency information (Oliva & Schyns, 2000), limited attentional allocation (Fei-Fei et al., 2005) and large visual eccentricities (Boucart et al., 2013; Thorpe et al., 2001). The question of the contribution of central versus peripheral vision on natural scene perception has been addressed in normally sighted observers and in pathologies inducing a visual field loss. For instance, Thorpe et al., (2001) have looked at performance of young normally-sighted people for object categorization at large eccentricities. Photographs of natural scenes were randomly presented on a hemispheric screen from 0° (central) to 75° eccentricity. Surprisingly, they found that performance to detect an animal in a natural scene was above 70% at 60° eccentricity though participants claimed to perform the task by guessing. This "perception without awareness" at large eccentricities has been confirmed and extended by Boucart et al. (2010). They reported both implicit recognition (measured by priming effects) and explicit recognition (measured by recognition of previously seen pictures) of colored photographs of objects at 30° eccentricity. Only non conscious implicit recognition occurred at 50° eccentricity in normally sighted people and in 4 patients with Stargardt disease (a juvenile maculopathy inducing central vision loss). Larson and Loschky (2009) examined the contribution of central versus peripheral vision on scene gist recognition in a verification task (a matching between a word and a photograph). They presented participants with central photographs of real world scenes (27 × 27° of visual angle) for 106 ms each. Performance was compared in two conditions: a window condition showing the central portion of the scene and blocking peripheral information and a scotoma condition blocking out the central portion and showing only the periphery. The radii of the window and

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scotoma were 1°, 5°, 10.8° and 13.6°. Performance was barely above chance in the 1° window condition and, when all information was eliminated from foveal and parafoveal vision (in the 5° scotoma condition), accuracy was no worse than when the entire image was shown. This suggests that central vision is not necessary for recognizing scene gist. Accuracy increased as the radius of the window increased or the radius of the scotoma decrease. The authors suggested that peripheral (and parafoveal vision) is more useful than high resolution foveal vision for scene gist recognition. However, a control experiment showed that the advantage of the periphery resulted from a difference in the size of the viewing field. When viewing field size was equalized there was an advantage for central vision in their study. A further control study showed that central vision required less than half as many pixels as peripheral vision required to achieve the same gist accuracy, suggesting that central vision was more efficient at extracting scene gist.

Tran et al., (2010) investigated scene gist recognition in people with central vision loss resulting from macular degeneration (AMD). Colored photographs of scenes (15 × 15° of visual angle) were centrally displayed for 300 ms. People with AMD and normally sighted age-matched controls were asked to categorize the scenes either as natural versus urban or as indoor versus outdoor in a go/nogo task (i.e., half of the participants in each group pressed a key for a pre-defined target (e.g., the natural, the urban, the indoor or the outdoor scene depending on the participant) and refrained from responding for the other category). It was found that people with AMD performed with high accuracy in both categories of scenes (84% hits for natural/urban and 79% hits for indoor/outdoor scenes). As people with AMD had a central vision loss, these results are consistent with studies on normally sighted people (Larson & Loschky, 2009) showing that scene recognition can be accomplished with the low resolution of peripheral vision. However, in the Tran et al., (2010) study, the pictures were always displayed at the same spatial location, in the centre of the computer screen. Therefore, as the location was predictable, it might be that people with AMD oriented their gaze in such a way that the images fell in their preferred retinal location (PRL). When the macular scotoma affects the fovea, the visual system develops preferred retinal loci (PRLs) as a "pseudofovea" to perform visual tasks (Crossland et al., 2005). The PRL refers to one or several retinal areas used for fixation. It is task specific (Crossland, Crabb, & Rubin, 2011a), and it is used on repeated testing (Crossland, Engel, & Legge, 2011b). The PRL tends to develop in a functional retinal area near the edge of the scotoma (Cheung & Legge, 2005; Crossland et al., 2005).

The present study was designed to compare scene gist recognition in central and in peripheral vision in people with central vision loss and normally sighted age-matched observers. In addition to the previous study (Tran et al., 2010) the spatial location of the pictures was unpredictable, appearing randomly at one of five spatial locations on a computer screen (centre, top left, top right, bottom left and bottom right). Also, in the Tran et al., (2010) study images were displayed for 300 ms. Though that duration does not allow visual exploration it does provide enough time for two moderate (150 ms) fixations. In the present study images were displayed at a duration that was shorter for a saccade at 12° eccentricity. If a reliable scene representation can be built from low level features (Larson & Loschky, 2009; Torralba & Oliva, 2003) then peripheral presentation should not impair performance, both in people with AMD and in normally sighted controls.

2. Method

2.1. Participants

Twenty-one patients with neovascular age-related macular degeneration were included. Due to the asymmetry of the pathology only one eye of each patient was tested. In cases of bilateral AMD, we tested eye with the best corrected visual acuity. If both eyes had equal acuity, one eye was randomly selected. Best corrected visual acuity (BCVA) was determined using Early Treatment Diabetic Retinopathy Study (ETDRS) charts at a distance of 4 m, which was converted to logMAR visual acuity for statistical purpose. Slit lamp examination, intraocular pressure, and funduscopy were performed in all patients and controls. The diagnosis of neovascular AMD was confirmed by fluorescein angiography, using a confocal scanning laser ophthalmoscope (Heidelberg Retina Angiograph, HRA2; Heidelberg Engineering, Dossenheim, Germany). The area of the lesion (mm^2) and the greatest linear diameter of the lesion were measured from digital angiograms by outlining the lesion, using image analysis software (Heidelberg Eye Explorer, Heidelberg Engineering) (Barbazetto et al., 2003; Hogg et al., 2003). Clinical assessment and experiments were performed at the same visit in the hospital.

The age-matched control group, with normal visual acuity, was composed of 15 volunteers. Control participants had no history of ophthalmologic or neurological diseases and no cognitive impairment. They were either relatives of participants with AMD or patients who underwent successful cataract surgery with normal visual acuity ranging from 20/25 to 20/20. Controls were tested monocularly on their preferred eye. Clinical and demographic data are provided in Table 1.

Both participants with AMD and controls were recruited in the Ophthalmology department of Saint Vincent the Paul hospital, Lille, France. The study was approved by the ethical committee of Lille, in accordance with the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants.

2.2. Stimuli and apparatus

The stimuli were displayed on a 30 in color monitor (Dell) connected to a computer (Dell T 3400). The stimuli were photographs of natural scenes. Two categories were represented: natural (deserts, forests, mountains, rivers) versus urban scenes (cities, skyscrapers, streets and highways). Examples are shown in Fig. 1. The amplitude spectra were computed for the two categories of scenes to assess whether they differed on the orientation (horizontal/vertical) of low, medium and high spatial frequency components. As shown in Table 2, the difference (ratio) in vertical and horizontal components between the two categories of scenes was small for low spatial frequencies. It increased for medium and high spatial frequencies. The angular size of the photographs was 15° × 15° at a viewing distance of 1 m. The participant's head was not fixed. The scenes were displayed on a light gray

Table 1
Demographic and clinical data of the study population.

AMD participants	$n = 21$
Mean age (years) (mean, SD, range)	79 ± 5.7 (66–89)
Gender (M/F)	6 Males/15 females
Mean MMSE (SD)	27 ± 2
Mean VA (LogMAR)	0.6 ± 0.22
Mean greatest linear lesion diameter (mm) (mean, SD, range)	3.57 ± 1.38 (1.3–7.5)
Mean area of the lesion (mm^2) (mean, SD, range)	8 ± 6.8 (0.6–30.6)
Controls	$n = 15$
Mean age (years) (mean, SD, range)	74.6 ± 6 (66–83)
Gender (M/F)	7 Males/8 females
Mean VA (LogMAR)	0.06 ± 0.04
Mean MMSE (SD)	28.7 ± 1.9

VA = Visual Acuity; MMSE = Mini Mental State Examination; SD = Standard Deviation.

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