Visual Neuroscience (2008), Page 1 of 7. Printed in the USA.

doi:10.1017/S0952523808080656

Recognition of facial emotion in low vision: A flexible usage of facial features

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(RECEIVED April 14, 2008; ACCEPTED May 14, 2008)

Abstract

Age-related macular degeneration (AMD) is a major cause of visual impairment in people older than 50 years in Western countries, affecting essential tasks such as reading and face recognition. Here we investigated the mechanisms underlying the deficit in recognition of facial expressions in an AMD population with low vision. Pictures of faces displaying different emotions with the mouth open or closed were centrally displayed for 300 ms. Participants with AMD with low acuity (mean 20/200) and normally sighted age-matched controls performed one of two emotion tasks: detecting whether a face had an expression or not (expressive/non expressive (EXNEX) task) or categorizing the facial emotion as happy, angry, or neutral (categorization of expression (CATEX) task). Previous research has shown that healthy observers are mainly using high spatial frequencies in an EXNEX task while performance at a CATEX task was preferentially based on low spatial frequencies. Due to impaired processing of high spatial frequencies in central vision, we expected and observed that AMD participants failed at deciding whether a face was expressive or not but categorized normally the emotion of the face (e.g., happy, angry, neutral). Moreover, we observed that AMD participants mostly identified emotions using the lower part of the face (mouth). Accuracy did not differ between the two tasks for normally sighted observers. The results indicate that AMD participants are able to identify facial emotion but must base their decision mainly on the low spatial frequencies, as they lack the perception of finer details.

Keywords: Low vision, Macular degeneration, Face perception, Emotion, Spatial frequency

Introduction

Age-related macular degeneration (AMD) is a degenerative disorder affecting the region of the retina corresponding to central vision: the macula. It is clinically characterized by geographic atrophy in the dry form of AMD (Penfold et al., 2001) and by abnormal choroidal neovascularization in the wet type of AMD (Kulkarni & Kupperman, 2005). At late stages of AMD, there is a massive destruction of photoreceptors in this area. At the end of its evolution, AMD affects all the functions of central vision: acuity, high spatial resolution, and contrast sensitivity. The loss of central vision induces impairments in reading words of little size, watching TV, recognizing familiar faces, and recognizing objects and colors (Legge et al., 1985, 1992; Ebert et al., 1986; Mangione et al., 1999; Tejeria et al., 2002). Different aspects of the daily life of people with AMD are impaired including cognitive functions (Hart et al., 1999; Cohen et al., 2000; Brody et al., 2001; Holzschuch et al., 2002), mobility (Hassan et al., 2002), and social life as this pathology induces a deficit in the recognition of faces and facial expressions (Mangione et al., 1999; Tejeria et al., 2002). This constitutes the main complaint of patients with AMD, after reading impairments.

In the present study, we evaluate the capabilities of AMD participants to recognize facial emotion in novel faces. Although the majority of studies on the visual function of AMD participants concern the recognition of alphanumeric characters (Higgins et al., 1996; Fine & Rubin, 1999; Legge et al., 2001; Nilsson et al., 2003), the effect of AMD on the recognition of faces has been scarcely investigated. Previous studies assessing face recognition abilities in people with AMD have explored the relations between objective clinical measures of visual functions and performance on tasks involving face recognition and recognition of facial expression. Tejeria et al. (2002) found that the loss in recognition of familiar (learned) faces was related to depletion in distance acuity, while the loss in recognition of facial expression was related to depletion in continuous text-reading acuity. Bullimore et al. (1991) found that the loss in recognition of faces was most closely related to depletion in word-reading acuity. Peli (1994) asked patients with low-vision deficits (diabetic retinopathy, central retinal vein occlusion, and AMD) to select a favorite enhancement by comparing images of the same face enhanced in different bands of frequencies and at various levels of contrast. He has reported that patients tend to prefer filtered images within the band of 4–8

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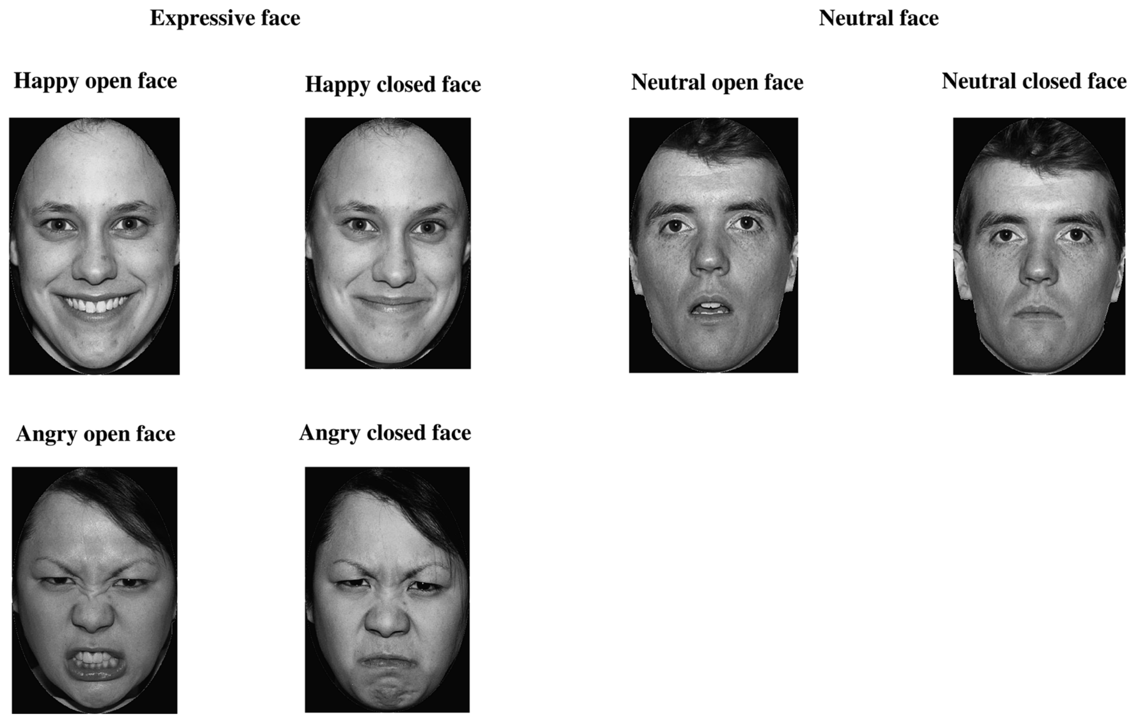

Fig. 1. Examples of faces used in EXNEX and CATEX tasks.

cycles/face resulting from a contrast enhancement of a band of spatial frequencies (between 4 and 8 cycles/face), a result consistent with the studies on face perception by normally sighted observers (Bachmann, 1991; Costen et al., 1996).

Although normal aging is characterized by a deficit in contrast sensitivity leading to difficulties in perception of faces, objects, or road signs at low contrast (Owsley et al., 1981; Owsley & Sloane, 1987; Lott et al., 2005), AMD dramatically increases the loss in sensitivity to contrast and high spatial frequencies (Sjostrand & Friseu, 1977; Kleiner et al., 1988; Jin et al., 1992; Midena et al., 1997; Faubert & Overbury, 2000). High spatial frequencies provide detailed information about contours and object shapes (regions of rapid luminance variations), while low–spatial frequency bands carry information about smooth and slow luminance variations. Detecting a face among other objects or identifying its gender is a task that can be performed based on low spatial frequencies (Sergent, 1986; Sergent et al., 1992; Costen et al., 1994, 1996; Schyns & Oliva, 1999); however, characterizing the identity of a face needs the resolution of the details (Calder et al., 1996). Faced with a loss of fine-scale resolution, we expect people with low vision induced by AMD to be impaired with facial perception tasks requiring the processing of diagnostic information in higher spatial frequency bands.

Depending on the information requirements of the task, it has been shown that the visual system can preferentially select spatial frequency scales (Oliva & Schyns, 1997; Schyns & Oliva, 1999; Morrison & Schyns, 2001). In Schyns and Oliva (1999), healthy young participants were asked to perform different categorization tasks (gender, categorization of emotion) on identical face stimuli. These face stimuli mixed two different faces at two different spatial frequency bands: hybrid faces combined a man or a woman with a particular expression (e.g., happy) at a low–spatial frequency band with a face of the opposite gender with a different expression at the fine spatial scale (e.g., angry). They found a peculiar result with facial emotion tasks: when asked to quickly detect whether the face had an expression or not (EXNEX task), participants primarily used the high–spatial frequency face, whereas when asked to categorize the emotion of the face (happy, angry, or neutral; CATEX task), observers mainly based their responses on the low–spatial frequency face. Schyns and Oliva (1999) suggested that, despite the fact that emotions could be recognized at both spatial scales, detection of an emotion and categorization of the emotion spontaneously engaged the use of different spatial scales: while observers' responses in the EXNEX task were biased toward the face in high spatial frequencies, the CATEX task could be efficiently performed using a configural structure of the face, already available at low resolution. In a related vein, Gosselin and Schyns (2001) found that the mouth region was the main diagnostic local feature used by observers while performing the EXNEX task.

In the present study, we used the EXNEX and CATEX tasks to explore the deficit of facial emotion recognition in AMD participants. Since all the AMD participants in the study have low vision, we expect that they will perform significantly better in a CATEX task than in an EXNEX task, the former being biased toward the use of low–spatial frequency bands, whereas the latter would be engaged to the use of high spatial frequencies, a level of resolution that patients with low vision have lost (Peli, 1994). AMD participants' performance in the CATEX task, which can be performed using configural information in low spatial frequency, should be close to normal. Moreover, we used stimuli face with open and closed mouth (Fig. 1) to explore to which extend the lower part of the face is used by participants with low vision for emotion categorization (Gosselin & Schyns, 2001). With a deficit in processing high spatial frequencies, together with a bias to look at the mouth in the EXNEX task, we predict that participants with low vision would perform the facial expression task using mostly the shape of the mouth as the diagnostic information, classifying open-mouth face as *expressive* and closed-mouth face as *nonexpressive*.

Table 1. *Demographic and clinical data of participants with AMD**

People with AMD	Gender	Age (years)	Best eye	Type of AMD	Acuity (log mar+)
CL	F	82	Left	Dry	1.6
LE	F	81	Right	Dry	0.4
WO	M	83	Left	Wet	1.1
MO	F	71	Left	Dry	0.5
WA	F	84	Left	Dry	0.9
BE	F	77	Right	Wet	0.9
BO	F	71	Left	Dry	1
DO	F	79	Left	Wet	1
GU	M	73	Left	Dry	0.9
HE	F	80	Left	Wet	1.5
LE	F	91	Right	Dry	1
MA	F	76	Right	Wet	1.2
QU	F	80	Left	Wet	1.3
RO	F	88	Left	Dry	1.4
SE	F	86	Left	Wet	0.6
LE	M	83	Right	Wet	0.9
HA	F	80	Right	Wet	1

*F, female; M, male.

Materials and methods

Participants

Seventeen people with AMD (14 females) at the beginning of low-vision rehabilitation participated in the experiment. The AMD observers volunteered to participate after a session of low-vision rehabilitation. They ranged in age from 71 to 91 years (Table 1). The criteria of inclusion were a primary diagnosis of bilateral AMD and a visual acuity in the better eye of 20/200 or worse. The average acuity of AMD participants was 1 (log mar+; Table 1). The diagnosis of bilateral AMD was determined by an angiography (Hanutsaha et al., 1998; Regillo et al., 1998; Desmettre et al., 2000). People with cataract were excluded because of the loss of contrast sensitivity generated by cataract. Six healthy age-matched observers (69–80 years, mean = 75 years) participated in the experiment. Their visual acuity was corrected to normal (8 to 10/10). Ophthalmological examination showed that none of them had a cataract or starting AMD. Mental deterioration of all participants was assessed by the mini mental state examination (MMSE; Folstein et al., 1975). Participants with an MMSE score under 26 were excluded. For each participant (AMD and control), the MMSE score ranged from 28 to 30. All participants signed a written informed consent. The ethical committee of the Hospital of Lille, France, approved the study.

Stimuli

Two hundred and fifty grayscale photographs of isolated frontal faces (from MacBrain Face DataBase[1]) were used as stimuli. They were presented in optimal contrast condition. The expressive faces were showing an angry or a happy expression. The nonexpressive faces had a neutral attitude. In each category, half of the faces had an open mouth and the other half had a closed mouth. Examples are shown in Fig. 1.

[1]The development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at tott0006@tc.umn.edu for more information concerning the stimulus set; Web site: http://www.sacklerinstitute.org/~nim/.

Apparatus

The faces were displayed on a computer monitor (21′, with a resolution of 600 × 800 pixel size, 60 Hz) at a viewing distance of 57 cm. The minimum and maximum luminance levels measured on a black and a white square were, respectively, 0.07 and 121.54 cd/m^n. Observers were tested in a darkened room. They were adapted to this darkness for 5 min before the session.

Procedure and design

AMD participants were tested monocularly on their better eye to avoid a phenomenon of binocular inhibition (Faubert & Overbury, 2000; Tarita-Nistor et al., 2006). The normally sighted participants were also tested monocularly on their preferred eye. Half of the participants started with the EXNEX task followed by the CATEX task. The order was reversed for the other half of the participants in each group. The stimuli were presented centrally for a duration of 300 ms. This duration was chosen because it allowed a single fixation. The angular size of the pictures was 14 deg for horizontal extent (400 pixels) by 21 deg for vertical extent (600 pixels). In the EXNEX task, participants were given a response box with two keys and had to press the right key when the face was expressive and the left key when the face was nonexpressive. In the CATEX task, participants had to name the facial expression (angry, happy, or neutral, recorded by the experimenter). To ensure that observers would remain focused at the center of the screen, four black dots (subtending each 5 deg of visual angle) were displayed at the locations corresponding to the corners of the imaginary square containing the face for 500 ms before the appearance of the face. They disappeared when the face appeared. One hundred and twenty pictures were displayed in each task. In the EXNEX task, half of the pictures (60) corresponded to expressive faces and the other half (60) corresponded to nonexpressive faces. Half of the expressive faces (30) were angry faces and the other half were happy faces. In addition, half of the faces in each category were ‘‘open-mouth faces’’ and the other half were ‘‘closed-mouth faces.’’ We used exactly the same faces, number, and distribution of stimuli for the CATEX task. During the test, the three facial expressions were randomly and equally distributed. Each task lasted about 10 min.

Results

Accuracy performance in each condition was evaluated using an index of sensitivity, termed d', combining the correct response to faces with an expression (*hit*) and the errors made on neutral faces (*false alarms*, corresponding to the categorization of a neutral face as an expressive face).

Categorization and accuracy performances are, respectively, summarized in Fig. 2 and Table 2. A triple-factor analysis of variance on the d' values shows a main effect of the population groups [normally sighted participants categorize facial expression better than AMD participants, $F(1, 21) = 43$, $P < 0.0001$], as well as a main effect of task [$F(1, 21) = 11.7$, $P < 0.01$], and mouth

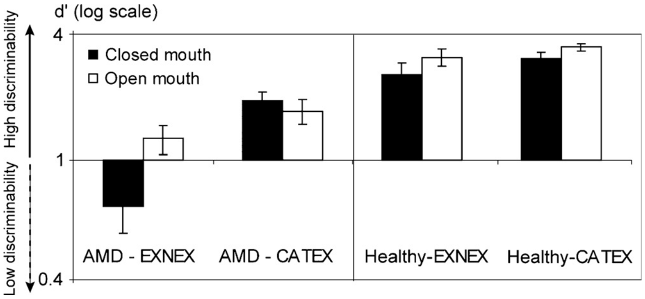

Fig. 2. Mean discrimination performances (d' in log scale) of patients with AMD and controls in the two facial emotion identification tasks (EXNEX and CATEX) and the face openness (closed or open mouth). d' Values superior to 1 correspond to high discriminability between faces with and without expression. Error bars correspond to a standard error of the mean of 1.

openness [$F(1, 21) = 15$, $P < 0.01$]. Performances between EXNEX and CATEX did not differ for the normally sighted population, reaching ceiling performances ($d' > 3$; Table 1). Interestingly, although AMD participants could perform very well the CATEX task (mean $d' = 1.87$), their performance decreased drastically in the EXNEX task as compared to the CATEX task [$F(1, 16) = 16$, $P < 0.001$; Fig. 2], particularly when the mouth was closed. A significant interaction was observed between task and facial openness [$F(1, 16) = 13.6$, $P < 0.01$].

Additional analyses performed on the correct responses (Table 1) showed that AMD participants performed at chance for expressive faces with closed-mouth and neutral faces with open mouth in EXNEX task. Their performance did not differ from chance in these two conditions [expressive closed faces: 55%, $t(16) = 1.4$, $P < 0.2$; neutral open faces: 52%, $t(16) = 0.5$, $P < 0.7$], whereas no difference was found between all four conditions in CATEX task (see accuracy performances detailed in Table 1). These results strongly suggest that the participants with low vision were mainly taking into account the shape of the mouth while deciding if the face had an expression or not. Therefore, they made a lot of false alarms thinking that expressive faces with closed mouth were neutral and conversely that neutral open faces were expressive. Normally sighted participants did not make any false alarm in these conditions.

Discussion

The main results show that AMD participants performed better in the CATEX task than in the EXNEX task, while normally sighted participants performed both tasks with high accuracy and equivalent performance and that AMD participants performed better with expressive open faces and neutral closed faces in EXNEX while they performed very well in the CATEX task in all conditions. Since, in contrast to Schyns and Oliva (1999), nonfiltered photographs of faces were used in our study, we did not expect normally sighted observers to succeed more in one task or the other.

Both low and high spatial frequencies have been shown to carry enough information to permit face and person identification (Fiorentini et al., 1983; Costen et al., 1994, 1996; Schyns & Oliva, 1999; Halit et al., 2006). Faces can be recognized based on two different mechanisms operating in parallel (see Peterson & Rhodes, 2005, for a review). One mechanism based on *featural* processing leads to an individual recognition of the facial features (e.g., Cleopatra's nose) and is mostly carried by fine details information and high spatial frequencies. The other mechanism, the *configural* processing, is based on the geometric interactions between the facial features (e.g., the metric distance between the eyes). Configural information is available at all spatial scales but can be performed using low–spatial frequency components (Sergent, 1984; Maurer et al., 2002). In people with low vision, as high–spatial frequency processing is deficient, we expect tasks requiring featural processing to be more impaired than tasks that are more based on configural processing. EXNEX and CATEX tasks are well suited to evaluate performance in featural versus configural processing modes: determining whether a face has an expression or not can be performed by focusing on a local region only, searching for a crease, whereas determining the exact emotion requires to combine a set of localized features that are diagnostic of a specific expression, requiring to attend more to a configuration of parts or even the global level of the face (Schyns & Oliva, 1997; Gosselin & Schyns, 2001; Smith et al., 2005). Schyns and Oliva (1999) suggested that, depending on the information requirements of the categorization task (e.g., gender discrimination, emotion categorization, identity), different levels of information (spatial frequency scales and global or local levels of analysis) could be preferentially recruited during perception at a glance. Gosselin and Schyns (2001) later determined that the mouth was the main diagnostic region looked at by normally sighted observers performing an expressive/nonexpressive task but that the precise categorization of facial emotions (happy, angry, neutral, etc.) involved a different configuration of diagnostic regions (e.g., both corners of the mouth for *happiness*, almost the whole face for *neutral*; Smith et al., 2005).

Because people with low vision exhibit reduced sensitivity to contrast and high spatial frequencies (Sjostrand & Friseu, 1977; Kleiner et al., 1988; Jin et al., 1992; Midena et al., 1997; Faubert & Overbury, 2000), we expected AMD participants in our study to base their decision on the visual information they can still

Table 2. *Mean accuracy (% of correct responses) with expressive faces and neutral faces in EXNEX and CATEX tasks for patients with AMD and healthy participants*

	Participants with AMD				Healthy participants			
	Closed mouth		Open mouth		Closed mouth		Open mouth	
	Expressive	Neutral	Expressive	Neutral	Expressive	Neutral	Expressive	Neutral
EXNEX	55 (5.4)	66 (3.7)	86 (3.3)	52 (4.0)	86 (6.9)	90 (4.0)	96 (2.5)	91 (3.3)
CATEX	79 (2.7)	84 (2.8)	81 (4.4)	74 (4.2)	92 (4.6)	93 (3.3)	98 (1.4)	94 (2.2)

perceive, which is mainly low spatial frequencies. Consistent with Schyns and Oliva's (1999) results, participants with low vision were able to perform very well the categorization task (CATEX). Interestingly, they failed in the EXNEX task. A deficit in contrast sensitivity cannot account for the results of AMD participants. The contrast sensitivity function (CSF) of each participant was not measured in our study, but the CSF measures contrast sensitivity at detection threshold for various spatial frequencies, and our stimuli were displayed at optimal contrast in gray levels (Fig. 1). Two possible explanations can account for this peculiar finding: first, the EXNEX task automatically recruited finer scale analysis mechanisms (Schyns & Oliva, 1999), looking for a resolution of details (e.g., creases, wrinkles) that AMD participants here could not reliably process. In a similar vein, the constraints of the EXNEX task might have influences on how observers perceived the similarities between the emotional faces and the neutral faces: by capitalizing on the finer scale features, neutral and emotional faces might be perceived closer, in a perceptual space, than when capitalizing on the global level of the facial features. Measuring perceptual distances in scale space is an interesting avenue of research for further studies of emotion perception.

An alternative explanation is that participants looked preferentially at the lower part of the face carrying useful diagnostic information (mouth, teeth; Gosselin & Schyns, 2001) when asked to quickly decipher whether the face had an expression of not. As the pictures were always displayed at the same spatial location, it might be that the lower part of the face fell in the preferred retinal locus (PRL) of people with AMD. Indeed, people with macular disease develop one or several PRLs. PRL is a small region where acuity is better and is usually located at the border of the scotoma. The location of the PRL was not measured in our study. However, it is known that there is a higher prevalence of lower field and left-field PRLs in patients with macular diseases and that patients with large scotomas have multiple PRLs (Whittaker et al., 1988), which are not necessarily used for different functions (see Cheung & Legge, 2005, for a review).

In the present study, if the participant focused exclusively on the mouth, then an expressive closed face (a happy or angry face with a closed mouth) could be confused with a nonexpressive face, whereas a neutral open face (with a slightly open mouth) could be confused with an expressive face. This confusion was amplified with low-vision capabilities and the lack of sensitivity to high spatial frequencies, as it is the case in low vision. This explains the high rate of false alarms for expressive faces with closed mouth and neutral faces with open mouth in the AMD populations (Table 1), as well as the higher accuracy observed with expressive open faces (with an open mouth) and the neutral closed faces (with a closed mouth), in the EXNEX task. Note that the error rates were not due to a lack of understanding of instructions, as the same patients performed very well in all conditions of the CATEX task (Table 1).

The deficiency in recognition of faces and facial expressions is one of the major complaints in patients with AMD. Indeed, several studies have reported impaired perception of facial expressions in the AMD population (Bullimore et al., 1991; Tejeria et al., 2002). Our results show that patients with AMD are indeed able to categorize facial expressions with presentation duration shorter than those used in previous studies. A possible explanation is that our categorization task, showing a single face at a time, was easier to process than the discrimination task used in previous studies where patients were asked to indicate which one of four simultaneously presented faces displayed a different expression. An alternative explanation is that the patients' complaints in the real life concern less the recognition of a facial expression than the recognition of the strength of this expression (e.g., how happy or sad a person is). Indeed, high spatial frequencies are important to determine the strength of an expression, whereas low spatial frequencies are sufficient to produce categorical discrimination (if the emotion in the face is positive or negative; Calder et al., 2002; Vuilleumier et al., 2003). With AMD, the degeneration of photoreceptors is not homogeneous, and the signal carried by the spatial frequency channels is not uniform (Penfold et al., 2001; Kulkarni & Kupperman, 2005). Spatial frequencies are perceived with more or less sharpness in different areas in the macula, resulting in a deficient perception of the exact metric distance between the facial features. In normal viewing conditions, faces are embedded in cluttered environments and might appear in poor resolution conditions due to variations of illumination, shadows, a ''smoky'' environment, eccentricity, and distance (Loftus & Harley, 2005). These natural conditions enhance the visual difficulties caused by AMD, rendering face recognition and emotion difficult, as witnessed by the patients' complaints in daily life as compared to experimental conditions.

Last, it should be noted that gender differences in the recognition of facial expression have been reported in the literature. Behavioral studies show that female observers are more efficient than males in categorizing facial expression (Thayer & Johnsen, 2000; Cellerino et al., 2004). This was confirmed recently by the results of electrophysiological study (Güntekin & Başar, 2007), indicating larger amplitude of activation in occipital areas in females than in males during recognition of facial expression. As there were more females than males in our study, our results should be generalized to male observers with cautiousness.

To summarize, the present results demonstrate that AMD patients, in the absence of visual clutter, are able to rapidly categorize facial emotion and are likely to base their decision on low–spatial frequency information. Their failure in discriminating whether the same face is expressive or not, in line with Schyns and Oliva's (1997) proposal of *flexible* processing, suggests that different tasks entail the use of different features and spatial scales. The present results also show that people with low vision, like normally sighted people, continue to use the lower part of the face to recognize facial expression. This suggests that rehabilitation procedures should take into account both the informative regions of visual stimuli and the demands of the task.

Acknowledgments

The authors would like to thank Michelle Greene, Danny Dilks, and two anonymous reviewers for helpful comments on the manuscript. This work was funded by a CNRS interdisciplinary grant for life sciences to M.B. and engineering to J.C. Kastelik. J.-F.D. was supported by a Ph.D. graduate fellowship from University Lille 2 and from *Nord-Pas de Calais*, France.

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