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Is the loss of diagnosticity of the eye region of the face a common aspect of acquired prosopagnosia?

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A recent study published in this journal has shown an abnormal performance at discriminating differences with respect to the eyes of unfamiliar faces in two acquired prosopagnosic patients, but preserved processing of the mouth region. Here we extend these findings by showing a similar lack of sensitivity to the eyes in the very same face matching experiment for the prosopagnosic patient PS, who also showed normal performance for detecting differences in the mouth region. These results complement previously published evidence that the patient PS presents a lack of sensitivity to diagnostic information located on the eyes of familiar faces during individual face recognition tasks. More generally, they indicate that the impaired processing of the eyes of faces is a fundamental aspect of acquired prosopagnosia that can arise following damage to different brain localizations.

Acquired prosopagnosia is a rare impairment at recognizing faces following brain damage that has been described since the last century (e.g. Quaglino & Borelli, 1867). Despite the rarity of a disorder that cannot be attributed to intellectual deficiencies or low-level visual problems, numerous cases have been reported since Bodamer (1947) coined the term prosopagnosia. However, there is still little understanding of the nature of the functional impairment characterizing acquired prosopagnosia. One reason that accounts for this lack of understanding is the large variability among patients, both in terms of behavioural deficits and localization of the lesions (e.g. Schweich & Bruyer, 1993; Sergent & Signoret, 1992). Moreover, different authors have approached the deficit with various goals and paradigms. For instance, cases of prosopagnosia have been found to be impaired integrating facial features (some form of 'holistic processing', see

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Barton, Press, Keenan, & O'Connor, 2002; Boutsen & Humphreys, 2002; Farah, Wilson, Drain, & Tanaka, 1995; Levine & Calvanio, 1989; Saumier, Arguin, & Lassonde, 2001; Sergent & Signoret, 1992; Sergent & Villemure, 1989). However, results from these studies are difficult to interpret because they relied on very different tasks, stimuli and conceptual definitions of the processes they aimed to measure.

However, quite interestingly, there is recent evidence from two independent groups of researchers who tested different cases of prosopagnosia that these patients present a similar lack of sensitivity to diagnostic information located on the eyes of faces. Caldara and colleagues (2005) observed this pattern with the brain-damaged patient PS (Rossion *et al.*, 2003) by means a learning paradigm followed by an identification task of faces masked with random apertures ('Bubbles', Gosselin & Schyns, 2001). In contrast to normal viewers, who relied extensively on localized information on the eyes of the faces, PS needed much more information to achieve the same level of performance, and relied mostly on the mouth and lower contours of the faces rather than the eyes. Bukach and colleagues (2006) showed that the brain-damaged prosopagnosic patient LR was able to detect small shape changes in the mouth region as well as variations in metric distances between features of the lower area of the face (e.g. nose–mouth distance), but was strikingly impaired at making similar judgments on the eyes of faces. Most recently, Bukach, Le Grand, Kaiser, Bub, and Tanaka (2008) extended these observations on LR and another case of prosopagnosia (HH) using a face dimensions task in which the participant's sensitivity to parametric manipulations to the shape and distance of facial features was tested. While the patients performed like control participants on all types of changes applied to the mouth, they were severely impaired for individual face discrimination based on the eyes. These observations indicate that, despite their diversity both at the functional and neural levels, several acquired prosopagnosic patients appear to show a similar pattern of performance when dealing with individual faces: they are not as sensitive as normal viewers to diagnostic information at the level of the eyes of faces, and rely instead on the mouth region. While a full understanding of this empirical observation is still lacking, it is important to document and reinforce it with similar paradigms in different patients. This is the reason why, in a joint effort to characterize the behaviour of such rare cases, we briefly report here the data of the prosopagnosic patient PS (Caldara *et al.*, 2005; Rossion *et al.*, 2003) with the same task and stimuli that was applied recently to the study of the patients LR and HH (Bukach *et al.*, 2008).

Methods

Case description

Patient PS

The prosopagnosic patient PS' case has been described extensively in previous publications, both at the functional and anatomical levels (Caldara *et al.*, 2005; Rossion *et al.*, 2003; Schiltz *et al.*, 2006; Sorger, Goebel, Schiltz, & Rossion, 2007). PS is a 57 years old (born in 1950) woman, who sustained a closed head injury in 1992. Anatomical magnetic resonance imaging (MRI) revealed extensive lesions of the right inferior occipital cortex and left mid- fusiform gyrus, with minor damages to the left posterior cerebellum and the right middle temporal gyrus (see Sorger *et al.*, 2007 for detailed anatomical data). Despite these multiple distributed brain lesions and the initial pronounced cognitive deficits following the accident, PS recovered extremely well after medical treatment and neuropsychological rehabilitation. Her only continuing complaint remains a profound difficulty in recognizing faces, including those of her family, as well as her own face. To determine a person's identity, she usually relies on contextual information and non-face cues such as the person's voice, posture, or gait, etc. However, she may also use suboptimal facial cues such as the mouth or the lower external contour of the face (Caldara *et al.*, 2005). The Benton face recognition test (BFRT; Benton & Van Allen, 1968) ranks her as highly impaired (score: 27/54; more recent test: 39/54, with a mean RT of 32 seconds/item). PS is not achromatopsic, and does not present any difficulty in recognizing objects, even at the subordinate level (Rossion *et al.*, 2003; Schiltz *et al.*, 2006). Her visual field is almost full (small left paracentral scotoma, see Sorger *et al.*, 2007) and her visual acuity is good (0.8 for both eyes as tested in August 2003). The performance of PS on standard clinical and neuropsychological tests of visual perception and recognition was reported in Table 1 of Rossion *et al.* (2003) and Sorger *et al.* (2007).

Table 1. The d' scores for the patient PS, her age-matched normal control and the group of controls tested in this study. While the age-matched control's performance was in the normal range for all conditions, PS' d' was in the normal range for the mouth conditions, but below normal range for most conditions involving a discrimination at the level of the eyes (configural or featural change). The d' scores were computed by taking into account the trials requesting a 'same' response (identical for all conditions)

	Degrees	PS	YR (age-matched)	All controls (mean ± *SE*)
Eyes				
Configural	1	0.48	0.68	0.65 ± 0.16
	2	0.48*	1.72	1.36 ± 0.18
	3	0.83*	2.72	2.27 ± 0.20
	4	1.15*	3.10	2.5 ± 0.24
Featural	1	0.83	1.08	0.54 ± 0.21
	2	0.48	3.89	1.90 ± 0.12
	3	0.26**	3.89	2.59 ± 0.30
	4	0.99*	3.89	2.65 ± 0.16
Mouth				
Configural	1	0.26	0.89	0.51 ± 0.14
	2	1.15	1.41	1.15 ± 0.44
	3	2.30	2.45	2.20 ± 0.31
	4	2.30	3.10	2.83 ± 0.31
Featural	1	0.66	0.68	0.56 ± 0.19
	2	1.31	1.41	1.46 ± 0.23
	3	1.64	2.06	2.31 ± 0.25
	4	2.30	2.45	2.55 ± 0.24

Normal participants

We included the data of the five control participants tested in the study of Bukach *et al.* (4 males, 1 female, mean age 46 years old). In addition, one age-matched (YR, 56 years old) female participant was tested in the task in the exact same conditions as PS. The pattern of results of this control participant, who was involved in other experiments as control to the patient PS (Schiltz *et al.*, 2006) did not differ from the other controls of the study.

Stimuli

The stimuli were described in detail in Bukach *et al.* (2008). They consisted of grey-scale digitized photographs of four male and four female faces. An original face was modified along four dimensions: configural/eyes; configural/mouth; featural/eyes; and featural/mouth (see Figure 1). Each dimension was represented by five faces, the original face and four modified face images. The modified faces in the *configural/eyes dimension* were created by moving each eye closer together on the horizontal axis by 5 pixels or 10 pixels (conditions 1 and 2); or moving each eye farther apart by 5, 10 pixels (3 and 4) – always relative to the original face (see Figure 1a). The modified faces in the *configural/mouth dimension* were created by (1) moving the mouth on the vertical axis closer to the nose by 5, 10 pixels; or moving the mouth away from the nose by 5, 10 pixels – (see Figure 1b). The modified faces in the *featural/eye dimension* were created by (1) increasing the size of the eyes by 10%; 20%; or decreasing the size of the eyes by

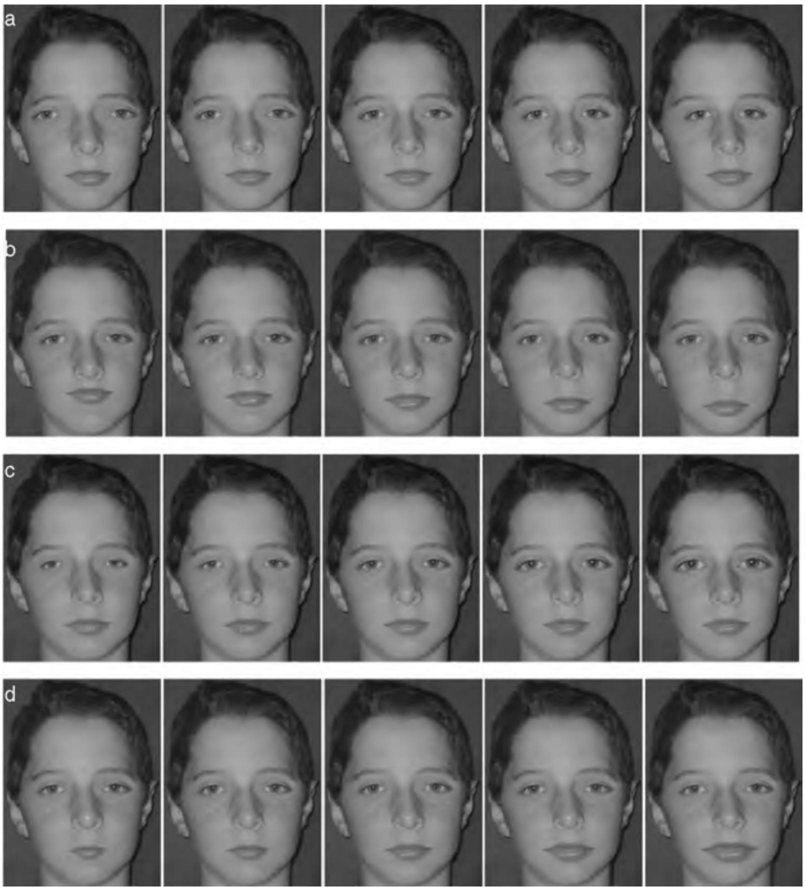

Figure 1. Example of a complete set of the face stimuli. (a) Faces differing in the distances separating the eyes (configural/eyes manipulation). (b) Faces differing in the distance between the nose and mouth (configural/mouth manipulation). (c) Faces differing in the size of the eyes (featural/eyes manipulation). (d) Faces differing in size of the mouth (featural/mouth manipulation). The original upon which the manipulations were made is the middle face of each row.

10%; 20% (see Figure 1c). The modified faces in the *featural/mouth dimension* were created by (1) increasing the size of the mouth by 10%; 20%; or decreasing the size of the mouth by 10%; 20% (see Figure 1d).

Eight original faces (four male, four female) underwent this procedure. In total there were 136 face images: eight face sets each consisting of an original face and four modified faces within the four dimensions. All stimuli were approximately 350 pixels in width (6 cm) and 330 pixels (8.5 cm) in height. The images subtended a visual angle of approximately $5.72° \times 8.10°$ when shown at a viewing distance of 60 cm.

Procedure

For each trial, a fixation cross was presented for 150 ms, followed by a study face that appeared for 500 ms, and then after an inter-stimulus interval of 500 ms, the second test face appeared. If the test face was perceived to be identical to the study face, participants were instructed to press the key labelled ‘same’; otherwise, they were to press the key labelled ‘different’. The study face remained in view until participants indicated their response with a key press. Participants were given a maximum of 3,000 ms to respond.

In line with our previous investigations of the patient PS, she was not placed under pressure and given more time to answer, with the first stimulus presented for 1,500 ms, and the second stimulus remaining on the screen until her response. The age-matched control tested performed the experiment in the exact same conditions as PS.

The experiment consisted of a total of 512 trials presented randomly. For half the trials the two images were identical and for half the trials the images were different. There was an equal number of trials from the eight faces, the four dimensions (configural/eyes; configural/mouth; featural/eyes; featural/mouth), and four degrees of difference within each dimension. Each same and different condition was repeated twice.

Results

First, modified *t* tests (Crawford & Garthwaite, 2002) were used to compare the patient PS’ performance with that of the group controls for each condition separately. PS showed normal sensitivity to featural and configural changes restricted to the mouth region (featural/mouth $d' = 1.43$ vs. 1.72, $t(5) = 0.52$, $p = .31$); and configural/mouth $d' = 1.51$ vs. 1.60, $t(5) = 0.28$, $p = .36$). In contrast, she was impaired at detecting both featural and configural differences restricted to the eye region (featural/eyes $d' = 0.66$ vs. 1.86, $t(5) = 2.36$, $p < .05$ and configural/eyes $d' = 0.75$ vs. 1.67, $t(5) = 2.1$, $p < .05$; see Figure 2a). For response times, she was much slower for both conditions where the eyes differed (configural and featural trials, $t = 10.9$, $p < .0001$; and $t = 4.7$, $p < .01$, respectively), and also for the configural-mouth condition ($t = 3.7$, $p < .01$) (Figure 2b). However, her RTs were in the normal range for featural-mouth trials ($t = 1.4$; $p = .11$).

Then, PS was compared to herself to determine if her sensitivity to mouth and eye regions were equivalent by collapsing data across featural and configural types of changes (two-sample proportion tests). Accuracy was significantly higher for the mouth area of the face than the eyes (62.5 vs. 33%; $p < .001$). In contrast, accuracy to featural and configural differences did not vary as function of the region (eyes or mouth) for PS (34.4 vs. 31%, $p = .7$ for the eye region, and 64 vs. 61%, $p = .73$ for the mouth region).

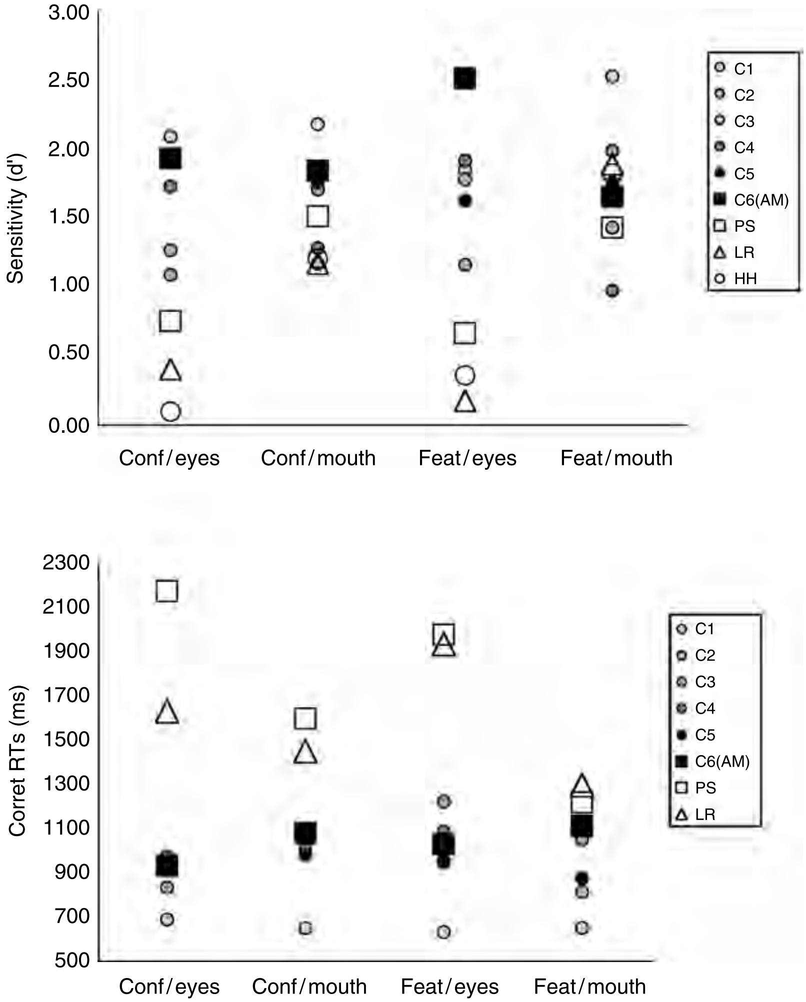

Figure 2. (a) Performance of age-matched controls and prosopagnosic patients (PS, LR, HH) on the delayed face-matching task. Mean accuracy (d') for each of the five control participants (C1–C5) are represented by circles. Mean accuracy (d') for PS and her age-matched control (AM) are represented by squares. For comparison with Bukach *et al.* (2008), the two prosopagnosic patients (LR and HH) are represented by triangles. (b) Correct RTs for PS and the controls, as well as patient LR. Data from HH are not displayed since they are not relevant: he did not succeed in any trials in the hardest levels of change in some conditions and thus his averaged RTs would be displayed for easier conditions than the controls.

Her response time data for the correct trials of the different conditions mirrored the performance data (Figure 2b). She was significantly slower for eyes trials than mouth trials ($t_{118} = 2.8$; $p < .01$). This difference was highly significant for featural conditions ($t_{57} = 3.54$; $p < .001$), but failed to reach significance for configural trials ($t_{59} = 1.37$; $p = .17$). For eyes, there were no differences between configural and featural trials ($t_{40} = 0.37$; $p = .71$), whereas PS was marginally slower for configural than featural trials on the mouth ($t_{76} = 1.81$; $p = .07$).

In summary, the results of the present experiment demonstrate that the patient PS was impaired in her ability to detect configural and featural differences located in the eye region of the face. However, she performed in the normal range for discrimination in the mouth region, whether these differences were configural or featural. Her response times data are consistent with the performance measures, even though she is also significantly slower than controls for the configural mouth condition.

Discussion

Similar to prosopagnosic patients LR and HH (Bukach *et al.*, 2008), PS performed within the range of age-matched control participants on the face dimensions task when required to detect differences in the mouth region, but was well below normal for discrimination in the eye region. This observation is in line with the lack of sensitivity to diagnostic information at the level of the eyes of familiarized faces for PS (Caldara *et al.*, 2005), and her dominant fixation on the mouth rather than the eyes when required to recognize personally familiar faces (Orban de Xivry *et al.*, 2008).

The commonality of the pattern of results between several cases of acquired prosopagnosia in this behavioural task is highly interesting, in particular when one considers that these patients have different lesion localization. While HH's anatomical damage following head-closed injury is unclear, LR presents a unilateral damage of the anterior and inferior sections of the right temporal lobe (Bukach, Bub, Gauthier, & Tarr, 2006), and PS's largest and most critical lesion involves the right inferior occipital cortex (see Sorger *et al.*, 2007). Hence, there is no overlap at all between the localization of structural brain damage in these prosopagnosic patients, even though one cannot exclude that identical regions would show abnormal neural activation that could be revealed only through functional neuroimaging investigations (see Sorger *et al.*, 2007). For instance, it is worth noting that all these cases have a structurally intact right middle fusiform gyrus. A preferential activation for faces in this region ('fusiform face area', 'FFA') has been reported for the patient PS (Rossion *et al.*, 2003), even though this area does not appear to code for individual faces (Schiltz *et al.*, 2006). Interestingly, all of these cases showing this eye processing impairment as a major characteristic of their prosopagnosia have well-preserved low-level visual abilities, and do not present impairments at object recognition (Bukach *et al.*, 2008; Rossion *et al.*, 2003; Schiltz *et al.*, 2006), unlike many cases of prosopagnosia (e.g. Barton, Cherkasova, Press, Intriligator, & O'Connor, 2004; Sergent & Signoret, 1992).

Why do prosopagnosic patients rely more heavily on information in the mouth region than the eyes? As discussed previously (Bukach *et al.*, 2008), it cannot be that eye changes in the task used here were perceptually more difficult to detect than mouth changes because normal subjects showed a slight advantage in their ability to discriminate eye changes than mouth changes. Nor can the mouth bias be explained by the small upper left visual-scotoma for PS (Sorger *et al.*, 2007) or any other low-level visual defects. Indeed PS is free to move the eyes in the present task and has ample time to inspect the faces for detecting differences. Moreover, the same pattern of results applies to patients LR and HH, who have a full visual field and no evidence of low-level visual defects.

In our previous reports (Bukach *et al.*, 2006, 2008; Caldara *et al.*, 2005; Orban de Xivry *et al.*, 2008), we raised and discussed several other potential explanations for this lack of sensitivity to the eyes of faces (e.g. avoidance of the eyes as in autism or bilateral amygdala damage, see Adolphs *et al.*, 2005; Klin, Jones, Schultz, Volkmar, & Cohen,

2002) but these are weakened by the observations made on cases of prosopagnosia with different lesion localization and behavioural profiles.

Among all these hypotheses, a strong candidate is that the impaired processing of information contained in the eyes region is a consequence of a general loss (or reduced) holistic perception in prosopagnosia, as also described in other cases (Barton *et al.*, 2001; Boutsen & Humphreys, 2002; Levine & Calvanio, 1989; Saumier *et al.*, 2001; Sergent & Signoret, 1992; Sergent & Villemure, 1989). Consistent with earlier theoretical proposals (Sergent, 1984; Tanaka & Farah, 1993), holistic perception can be simply defined here as a mechanism that allows perceiving simultaneously multiple facial features as a whole individual face representation. Presumably, if holistic face perception is impaired, the diagnosticity of a face region made of multiple features (two eye features, the pupil, iris, and eyebrows) will be most affected: each of these elements has to be processed individually and, as such, become less diagnostic than a single isolated feature such as the mouth. According to this account, when patients have difficulty integrating information across the entire spatial extent of a face, they chose to focus mainly on the mouth. If the mouth is diagnostic, they manage to achieve a similar level of performance as controls, who can detect these mouth changes while presumably being able to focus on other face features or on the center of the face, below and in between the eyes (see Orban de Xivry *et al.*, 2008). Consistent with this view, when PS is informed about the nature of the changes on the eyes during matching of unfamiliar faces, she can perform in the normal range (Ramon & Rossion, in preparation). More strikingly, when LR is explicitly instructed to focus on the eye region, his sensitivity to eye information improves, but at a cost to his discrimination of information in the mouth region (Bukach *et al.*, 2006). This hypothesis would also account for the fact that despite their performance in the normal range, the two patients PS and LR were significantly slowed for the mouth-configural condition here, but not for the mouth-featural condition: even when focusing on the mouth area, the former type of change (nose–mouth distance) is detected more slowly when one cannot integrate the two elements (mouth and nose) in the same perceptual representation. To sum up, the simple but consistent observation that acquired cases of prosopagnosia with well preserved low-level abilities and normal object recognition present a biased deficit in processing the eyes may thus reflect the holistic nature of our face processing system. The fact that the patients such as PS and LR do not present any impairment of object recognition, even for fine-grained discriminations (see Schiltz *et al.*, 2006), suggests that while holistic individual perception processes as defined here may be potentially recruited for nonface objects of expertise in the adult human brain (e.g. Gauthier & Tarr, 2002), they may be necessary for efficient processing of faces only.

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