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Whole not hole: Expert face recognition requires holistic perception

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ABSTRACT

Face recognition is an important ability of the human brain, yet its underlying mechanisms are still poorly understood. Two opposite views have been proposed to account for human face recognition expertise: the ability to extract the most diagnostic local information, feature-by feature (analytical view), or the ability to process all features at once over the whole face (holistic view). To help clarifying this debate, we used an original gaze-contingent stimulus presentation method to compare normal observers and a brain-damaged patient specifically impaired at face recognition (prosopagnosia). When a single central facial feature was revealed at a time through a gaze-contingent window, normal observers' performance at an individual face matching task decreased to the patient level. However, when only the central feature was masked, forcing normal observers to rely on the whole face but the fixated feature, their performance was almost not affected. In contrast, the prosopagnosic patient's performance decreased dramatically in this latter condition. These results were independent of the absolute size of the face and window/mask. This dissociation indicates that expertise in face recognition does not rest on the ability to analyze diagnostic local detailed features sequentially but rather on the ability to see the individual features of a face all at once, a function that is critically impaired in acquired prosopagnosia.

1. Introduction

Human observers are generally remarkably accurate and fast at recognizing previously encountered people from their face (Sergent, 1989). They can store hundreds, or perhaps thousands of faces in memory (Bahrick, Bahrick, & Wittlinger, 1975) despite the fact that different individual faces are extremely similar, and that a given face never appears twice under the same viewing condition. This observation has inspired researchers from different scientific disciplines, psychology, neuroscience and computational science in particular, to investigate the processes subtending expertise in face recognition (Bruce & Young, 1998; Sinha, Balas, Ostrosvky, and Russell, 2006; Young & Ellis, 1989). Nevertheless, there remains much debate regarding how a person's face is perceived and recognized by the human brain.

Traditionally, there have been two main views on how humans recognize faces: the analytical and the holistic view (Davies, 1978; Ellis, 1975; Sergent, 1986). Both views start from the observation that faces are visually complex stimuli, composed of multiple elements or features (e.g., external and internal features such as chin, hair, eyes, mouth, nose, etc.) that can be diagnostic of facial identity by varying in shape (as defined by the bone structure of the head) and in their surface properties (reflection of light on the skin, defining color, contrast, and texture variations) (Bruce & Young, 1998; O'Toole, Vetter, & Blanz, 1999). According to the analytical view (e.g., Bradshaw & Wallace, 1971; Davies, 1978; Tversky & Krantz, 1969), observers explore a face by scanning local features in order to extract the most diagnostic information to individualize the face. This view has been supported by classical eye movement recording studies, showing that human observers indeed concentrate on localized internal elements of the face (i.e., eye, mouth; Yarbus, 1967), and are capable of recognizing individuals based on only a limited amount of information from the face (e.g., eyes and eyebrows: Davies, Ellis, & Sheperd, 1977; Gosselin & Schyns, 2001; Haig, 1985; Sadr, Jarudi, & Sinha, 2003; Sheperd, Davies, & Ellis, 1981). In contrast, the holistic/configural view is based originally on early insightful observations about face perception and reflects the idea that "*a face is perceived as an undecomposed whole, at a single glance, rather than as a collection of individual features*" (Galton, 1883). This holistic view of face recognition does not ignore or dismiss the fundamental role of local features in face recognition, but contrary to the analytical view (Tversky & Krantz, 1969),

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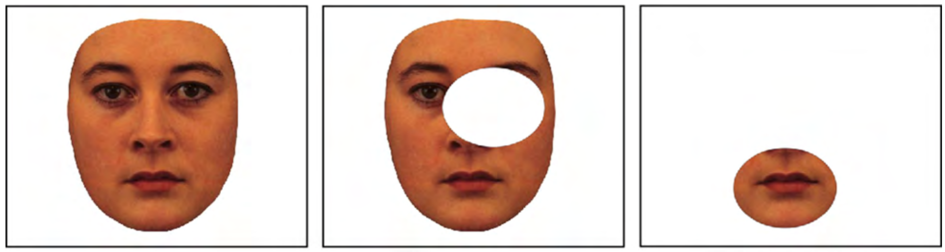

Fig. 1. Illustration of the different viewing conditions in the experiment. The size of the window/mask was adjusted to reveal/cover roughly one main internal feature of the face at a time only (one eye, the nose or the mouth). The position of the mask/window was synchronized on-line with the observer's fixation position.

it states that these features are not perceived and represented independently of each other, the face being perceived as an integrated whole (Farah, Wilson, Drain, & Tanaka, 1998; Maurer, Le Grand, & Mondloch, 2002; McKone, 2004; Rossion, 2008; Sergent, 1986; Tanaka & Farah, 1993, 2003). The holistic view has been supported by behavioural studies showing that the recognition of a given facial feature (e.g., a local element such as an eye, or a distance between two elements, or even half of a face) is influenced by the position and identity of other facial features (in an upright face; Farah et al., 1998; Sergent, 1984, 1986; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Young, Hellawell, & Hay, 1987; for neural evidence, see Schiltz & Rossion, 2006).

However, since the holistic view is based essentially on demonstrations of interactivity of processing between distant features (e.g., eyes and mouth), current evidence supporting this view of holistic face perception remains somewhat indirect. A direct demonstration that the observer's *perceptual field*, or *functional visual field* (i.e., the area of vision where diagnostic visual information can be extracted, Rossion, 2008, 2009) encompasses the whole face, rather than one single feature at a time, is still missing.

Moreover, it would be important to demonstrate that holistic perception is not only at play when dealing with individual faces, but that it is in fact *critical* to the human expertise at recognizing individual people from their face.

In the present study, we addressed these two issues and directly contrasted the two theories of face recognition with an original method in which visual stimulation was contingent on the observer's gaze location (van Diepen, De Graef, & Van Rensbergen, 1994; for the origin of the method in reading research, see Rayner, 1975, 1998). In an individual face matching task, we compared a baseline condition in which a full face was displayed to two conditions in which access to information was restricted in a systematic way, depending on the observer's gaze position. In one condition, we constrained the available visual information to the centre of vision by means of a gaze-contingent window (Fig. 1). This way, we forced observers to process the face stimulus feature-by-feature, i.e., analytically. In the other condition, we did the exact opposite: we occluded the fixated feature by means of a gaze-contingent mask, forcing observers to rely on information from the rest of the (non-fixated) face, which was clearly visible (Fig. 1).

To our knowledge, this kind of gaze-contingent manipulation has never been applied before to test face recognition. Importantly, the gaze-contingent manipulation does not reflect a mere manipulation of foveal/peripheral vision: the information provided/masked to the observer depending on his/her fixation is adjusted to reveal/cover one feature at a time on the face stimulus, irrespective of the absolute size of the face stimulus (an issue directly addressed in experiment 2).

To test the hypothesis that holistic face perception is a critical function of the human brain, we compared the performance of normal observers in these viewing conditions to that of a unique neuropsychological patient (PS, Rossion et al., 2003) who suffers from acquired prosopagnosia, the inability to recognize faces (Bodamer, 1947) following brain damage. While it has been shown that acquired prosopagnosic patients do not process facial features interactively (e.g., Boutsen & Humphreys, 2002; Joubert et al., 2003; Levine & Calvanio, 1989; Sergent & Villemure, 1989), including recent evidence on the patient PS (Ramon, Busigny, & Rossion, 2010), there has yet to emerge any empirical evidence that these patients focus on one feature at a time, and thus have a constrained perceptual field, which prevents them from perceiving the multiple features of an individual face all at once.

Here we compared the patient PS′ performance across these viewing conditions, and to normal observers. We hypothesized that if normal observers perceive faces holistically, they should be relatively less affected by the presence of a mask covering the facial feature they focus on (mask condition), compared to the situation where their perception is limited to that single feature (window condition). In contrast, and most importantly, if the brain-damaged prosopagnosic patient PS perceives faces feature-by feature, or analytically, and is unable to perceive a face holistically, her performance should be much more affected in the mask than in the window condition.

2. Experiment 1

2.1. Methods

2.1.1. Case description

The patient PS (born 1951; 59 years old) is a well-documented case of prosopagnosia following brain damage as the result of closed head injury about 17 years ago. The neurofunctional aspects of her prosopagnosia have been described in detail in previous studies (e.g., Busigny & Rossion, in press-a; Caldara et al., 2005; Rossion et al., 2003). Briefly, PS has her main lesions in the right inferior occipital cortex and in the left middle fusiform gyrus (see Fig. 2), but her right middle fusiform gyrus is intact (see Sorger, Goebel, Schiltz, & Rossion, 2007 for all details). This area shows a preferential response to faces (e.g., Rossion et al., 2003), but an absence of sensitivity to individual faces (Schiltz et al., 2006).

PS′ low level vision is largely preserved, with a visual acuity of 8/10 in both eyes, as well as full field vision, apart from a small left paracentral scotoma (1/8th of the central visual field, along the lower horizontal meridian, extending over 3.5°, for illustrations see Sorger et al., 2007), and her color vision is low, but still in the normal range (Sorger et al., 2007). Reading is preserved, and object recognition, even for within-category discrimination is also preserved (Schiltz et al., 2006), so that patient PS is one of the rare cases of selective face agnosia following brain damage (see also De Renzi, 1986; Henke, Schweinberger, Grigo, Klos, & Sommer, 1998; Riddoch, Johnston, Bracewell, Boutsen, & Humphreys, 2008). The only function that remains significantly impaired, according to the patient's complaints and neuropsychological investigations, is face recognition.

PS can categorize a visual stimulus as a face, but she has pronounced difficulties in identifying people from their face, including highly familiar people (friends, family members) or herself in a photograph. This recognition impairment concerns the faces of people either known before or after her lesion. Like other cases of acquired prosopagnosia (e.g., Davidoff & Landis, 1990; Delvenne, Seron, Coyette, & Rossion, 2004; Farah, 1990), she is impaired and slowed down at matching/discriminating pictures of unfamiliar faces (e.g., Busigny & Rossion, in press-a; Ramon et al., 2010; Rossion et al., 2003; Schiltz et al., 2006).

To recognize familiar faces, or to match different pictures of unfamiliar individual faces, PS relies on external (non-face-inherent) cues such as hair style, glasses, facial hair, or the voice, posture, gait, etc. Previous investigations have shown that

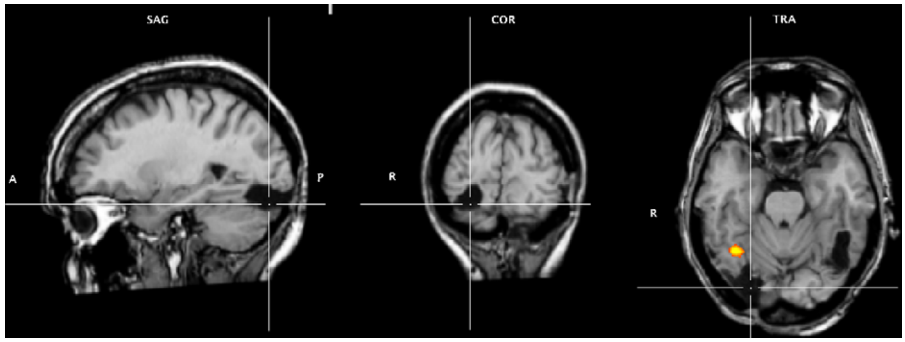

Fig. 2. PS has damage to the left middle fusiform gyrus and a small lesion to the right middle temporal gyrus, but her main lesion, thought to be instrumental in causing her prosopagnosia, concerns the right inferior occipital cortex (line crossing). This lesion does not prevent a preferential activation for faces in the right middle fusiform gyrus ('FFA'; here as the result of a combined analysis of 6 functional localizer runs, contrasting faces and object pictures in a face localizer contrast, see Sorger et al., 2007 for details). Although this region responds preferentially to faces, it does not show the normal release to adaptation to different facial identities, in line with the difficulties of the patient in individualizing faces.

PS also tends to focus and rely on specific elements of the face, in particular the mouth, to identify faces and to match different pictures of the same unfamiliar persons (Caldara et al., 2005; Orban de Xivry, Ramon, Lefèvre, & Rossion, 2008; see also Bukach, Le Grand, Kaiser, Bub, & Tanaka, 2008 for similar observations on another case of acquired prosopagnosia) and she does not have any advantage when processing upright over inverted faces (Busigny & Rossion, in press-a).

2.1.2. Control participants

PS′ performance was contrasted with the performance of 8 age and gender matched control participants with normal or corrected to normal visual acuity and with no complaint of face recognition impairments.

2.1.3. Stimuli

A delayed matching task was conducted in which a photograph of an unknown adult reference face was followed by a side by side presentation of photographs of two faces, one of which (target) was of the same identity as the reference face, but the picture taken at a different moment in time and therefore was slightly different from the reference photograph. The participant's task was to indicate which of the two faces corresponded to the reference face.

Stimuli were displayed on a 22″ Iiyama Vision Master Pro 514 monitor at a viewing distance of 53 cm with a spatial resolution of 1280 by 1024 pixels and a refresh rate of 100 Hz. The height of the faces was 15°, the distance between the inner borders of the faces was approximately 10°. and the elliptical window and mask subtended 8.5° horizontally by 6.5° vertically. The stimulus set contained 10 male and 10 female faces (KDEF database, Lundqvist, Flykt, & Öhman, 1998) from which the external features were cropped but head shape was largely preserved. The faces were randomly combined in pairs of two males or two females. Both stimulus display and response registration were handled by an Intel Pentium 4 PC. Eye movements were registered with the SR Research Eyelink II head-mounted eye tracker at a sampling rate of 250 Hz and with gaze position error smaller than 0.5°. Head movement was restricted by a chin and head rest.

2.1.4. Procedure

The course of a trial is presented in Fig. 3. A drift correction with a central fixation cross was followed by the presentation of a blurred face, which was the grey-scale average image of all faces, indicating the position of the reference face and a fixation cross on the left of that face. Participants were instructed to fixate the fixation cross. Upon steady fixation by the participant, the cross disappeared. From the moment the participant fixated the blurred face, it changed into the reference face, which participants were instructed to memorize. After 4 s, the reference face was replaced by two faces, one on each side of the screen. The participant could freely explore both faces during an unrestricted time period. The stimuli and the timing of presentation

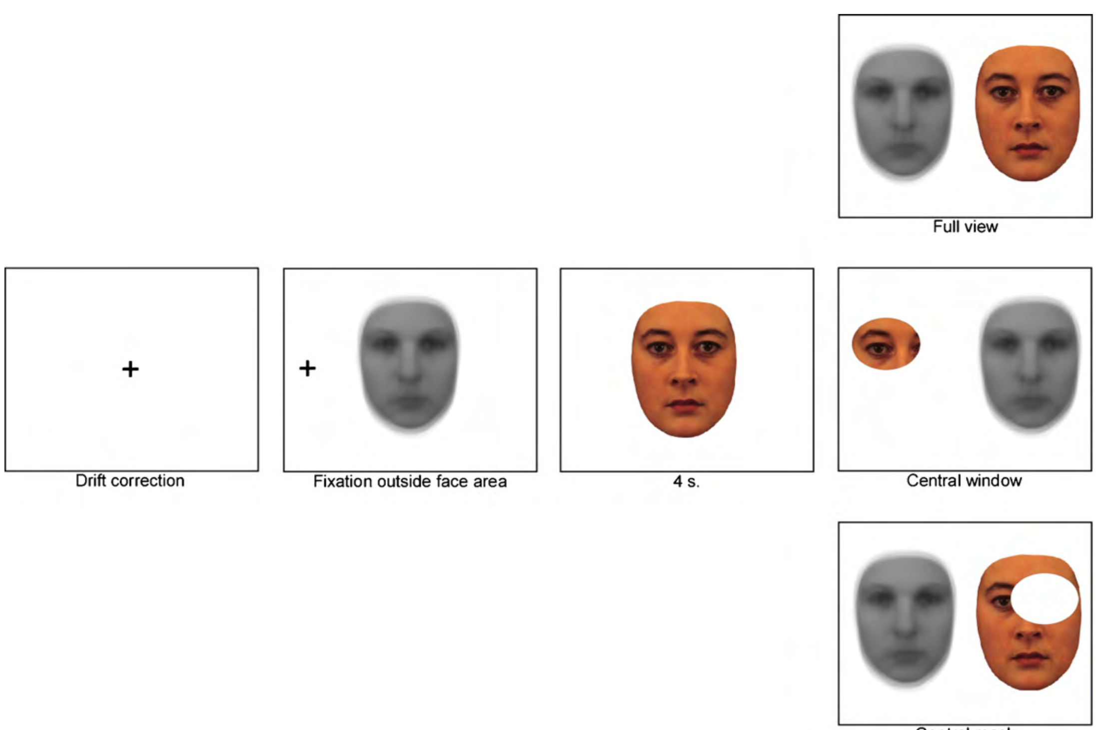

Fig. 3. Course of a trial. The greyscale face displayed is the average of all faces, which is displayed when the observer does not fixate on the face. In all condition, the non-fixated face was always replaced by the blurry average face. In the central mask and central window the fixated face was covered by the central window or mask.

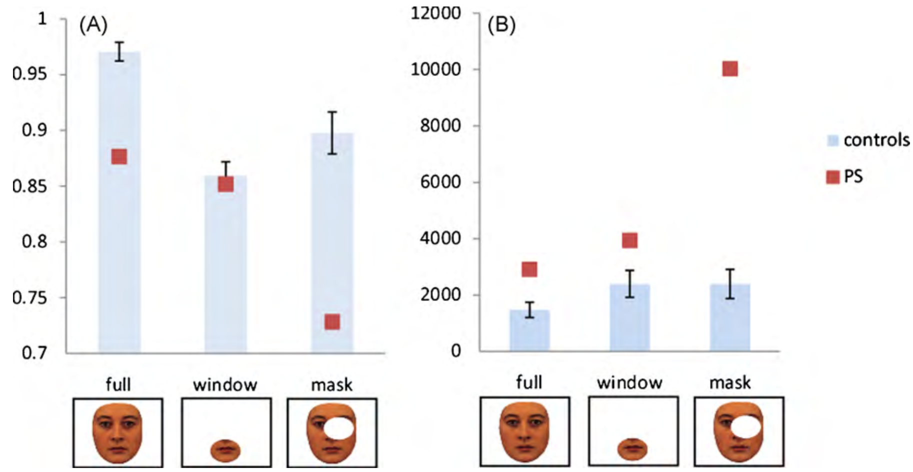

Fig. 4. Average accuracy (A) and response times in ms. (B) Of PS and the control participants for all viewing conditions. The error bars represent standard errors. Contrary to normal observers, PS′ performance is almost not affected in the window condition, but decreases substantially in the mask condition.

were adjusted from previous experiments with patient PS (e.g., Busigny & Rossion, in press-a; Schiltz et al., 2006) to ensure that despite her prosopagnosia, she could perform the task well above chance with full faces, so that her accuracy and response times data were meaningful and could be compared across conditions and to the data of the control participants.

In one third of the trials the faces were completely visible (full view). In another third of the trials a gaze contingent mask covered the fixated feature in the central part of the visual field (mask condition). In the remaining third of the trials only the fixated feature in the central part of the visual field was visible through a limited spatial window (window condition). In both experiments, the mask/window covered/revealed roughly one feature of the face at a time (eye, nose, or mouth), although it was large enough to cover/reveal the whole eye–eyebrow combination in the mask/window conditions, respectively.

During the exploration of the pair of faces, the face that was not fixated was replaced by the average face (Fig. 3), in order to provide a reference frame for saccade planning to the face in all viewing conditions. Furthermore, this way, the amount of information from one face during the exploration of the other face was similar in all three viewing conditions. The response was provided by pressing the left or right assigned key on the keyboard.

The experiment was subdivided in 9 blocks, each consisting of 27 trials, 9 for each of the 3 viewing conditions (for 81 trials/condition in total). The order of the viewing conditions within each block was randomized and the participant was unaware of the type of viewing condition during the exploration of the reference face.

2.1.5. Eye movements analysis

The eye fixation patterns were visualized using heat maps with the *Z*-values of the relative number of fixations per trial on a given position in the screen for each condition separately. Fixation positions were smoothed using a Gaussian filter with a sigma of 30 pixels, in order to account for the fixation position variability when fixating a certain point. Only trials resulting in a correct response were included. The cluster test proposed by Chauvin, Worsley, Schyns, Arguin, and Gosselin (2005) was used for the statistical analysis of the difference between pairs of heat maps. To this end, pixel-wise *t*-tests were conducted. Clusters of pixels with a *t*-value larger than 2.7 ($p < 0.05$) were considered as significant.

2.2. Results

2.2.1. Behavioural data

The effect of the viewing condition (full view, central mask, or window) on accuracy was analyzed using a logistic regression analysis. The effect on the response times was investigated with an analysis of variance (ANOVA), including only trials resulting in correct responses. The contrasts between the individual viewing conditions were assessed with a Tukey multiple comparisons analysis. The direct comparison between PS and control participants was assessed using Crawford and Howell's (Crawford & Howell, 1998) method for the analysis of single case neuropsychological data.

As shown in Fig. 4, normal observers responded faster and more accurately when they saw full faces than when there was a mask or window (main effect of viewing condition: $\text{Chi}^2(2) = 37.82$; $p < .0001$ for accuracy rates; $F(2, 14) = 18.29$; $p < .0001$ for response times). Accuracy was higher with the full view than when the central feature was masked, $\text{Chi}^2(1) = 22.00$; $p < .0001$, or when only the feature was available, $\text{Chi}^2(1) = 37.77$; $p < .0001$. There were also faster response times (RT) with the full view than with the central mask, $t(14) = 5.21$; $p = .0004$, or window, $t(14) = 5.25$; $p = .0003$. Observers performed more accurately with the central mask than with the window, $\text{Chi}^2(1) = 3.91$; $p = .048$, but there was no significant difference in speed, $t(14) = 0.05$; $p = .99$.

PS′ accuracy was lower, and her RTs were much higher with the central mask than with the full view (accuracy: $\text{Chi}^2(1) = 5.37$; $p = .02$; RT: $t(196) = 12.45$; $p < .0001$), but to a much larger extent than normal participants (see below). Consequently, and in direct contrast to normal observers, her performance was much lower with the mask than with the window (accuracy: $\text{Chi}^2(1) = 3.63$; $p = .057$; RT: $t(196) = 10.58$; $p < .0001$). In fact, compared to the full view, the central window condition did not cause any decrease in accuracy ($\text{Chi}^2(1) = 0.21$; $p = .65$, or increase in RTs, $t(196) = 1.87$; $p = .15$) for PS.

In summary, the data showed that, with full faces, the prosopagnosic patient PS performed the face identity matching task with less accuracy than normal observers, and was considerably slower than normal observers. This reflects her prosopagnosia, and is merely a replication of observations made in several previous studies. However, while normal observers were affected the most when attempting to match faces using diagnostic information that was revealed feature by feature in a small central window, PS′ performance and speed was completely unaffected in this condition (Fig. 4). This suggests that even when processing the full face, she uses a restricted window, analyzing each element in turn. This observation could not result from a floor effect (i.e., PS performing lower than controls in the full view condition) because, relative to full faces, her performance and speed were massively affected when central vision was masked (15% accuracy, about 7000 ms increase in RTs). In contrast, if anything, normal observers performed better in this central mask condition compared to the window condition.

The accuracy and response time patterns for all control participants were very similar (Fig. 5). All participants were affected both by the mask and by the window, but the decrease in accuracy was most pronounced in the window condition. In contrast, PS showed only a small decrease in accuracy in the window condition, almost the smallest of all participants, while her performance was completely out of range (lower performance and RT increase) in the mask condition. Statistical analyses confirmed these observations, showing that PS′ accuracy was lower both in the full view, $t(7) = 3.69$; $p = .004$, and in the central mask conditions, $t(7) = 4.53$;

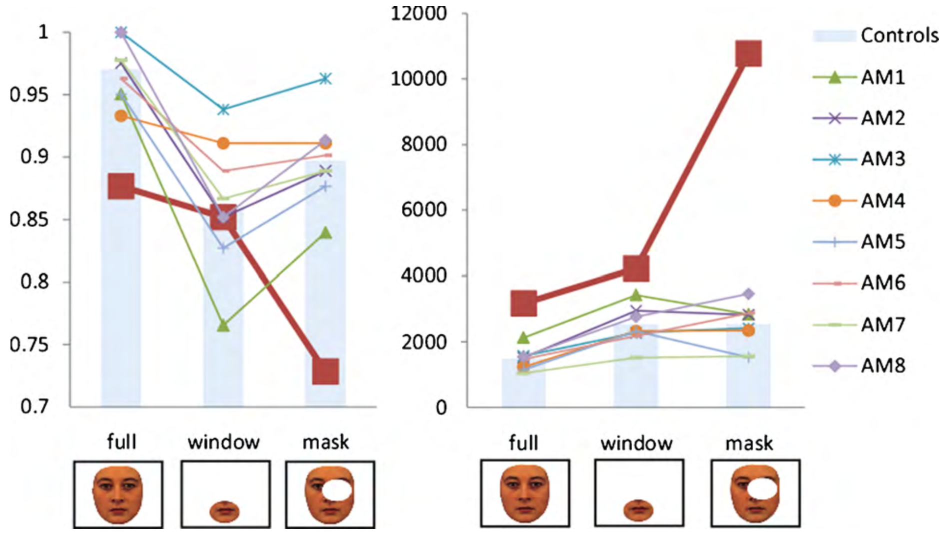

Fig. 5. Average accuracy (A) and response times in ms. (B) Of PS and the control participants individually for all viewing conditions. Contrary to every control participant, PS′ performance is almost not affected in the window condition, but decreases substantially in the mask condition.

p = .001, compared to normal observers. In the window condition, on the contrary, her accuracy did not differ from that of the control participants, $t(7) = 0.13$; $p = .45$. RTs showed almost the same pattern, with longer RTs for PS than for the control participants in full view, $t(7) = 4.69$; $p = .001$, and with the central mask, $t(7) = 11.57$; $p < .0001$. However, despite showing only a very small increase of RT in the window condition, PS was still slower than the control participants in this condition, $t(7) = 2.77$; $p = .014$.

Fig. 6 shows the size of the decrease in accuracy and increase in RTs for the mask and window conditions compared to the full view for all participants individually. Both the accuracy decrease, $t(7) = 2.50$; $p = .02$, and the RT increase, $t(7) = 12.13$; $p < .0001$, caused by the central mask were higher for PS than for the control participants. Furthermore, PS was one of the participants with the lowest accuracy decrease caused by the window, although not significantly lower than for the control participants, $t(7) = 1.47$; $p = .093$. The difference in accuracy decrease, $t(7) = 5.96$; $p < .0001$, and RT increase, $t(7) = 11.61$; $p < .0001$, between the mask and the window conditions was higher for PS than for the control participants, showing that her performance pattern was qualitatively different from that of normal observers.

2.2.2. Eye movements

The heat maps of PS and the control participants for all conditions separately were compared. As illustrated in Fig. 7, the largest difference between the control participants and PS in all three viewing conditions and for the reference face was that PS made much more use of the lower facial half than the control participants, while the opposite was true for the upper facial half. This is in agreement with previous findings that normal observers' fixations mostly fall in the region around the eyes (e.g., Althoff & Cohen, 1999; Henderson, Williams, & Falk, 2005; Walker-Smith, Gale, & Findlay, 1977; Yarbus, 1967), while PS′ fixations are centered on the mouth (Orban de Xivry et al., 2008).

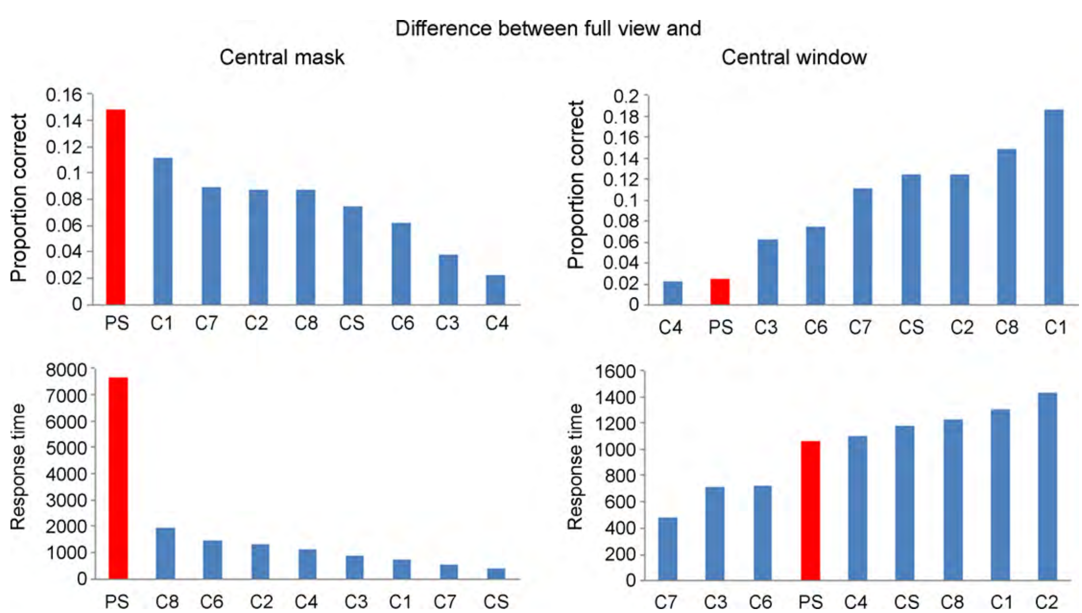

Fig. 6. Average accuracy decrease and response time increase in the mask and window condition compared to full view for PS and the control participants considered individually. With the central mask, PS′ performance relative to full view was the worse of all participants, while she was one of the participants showing the least decrease of performance with the window condition.

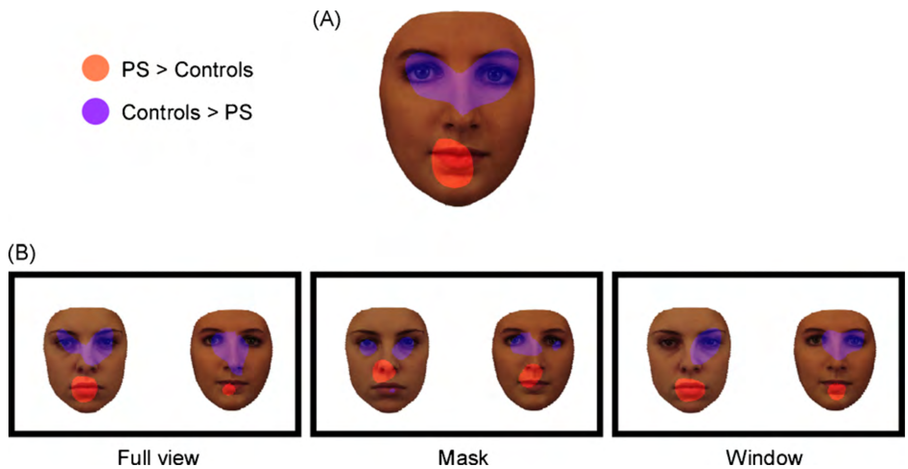

Fig. 7. (A) Areas that were fixated significantly more by PS than by the controls (red), or more by the controls than by PS (blue) for memorization of the reference face. (B) Areas that were fixated significantly more by PS than by the controls (red), or more by the controls than by PS (blue), in the mask condition, with a window or in full view (from left to right, respectively) for the pairs of faces to discriminate. Note that PS fixated the mouth in all conditions, but with the mask, for which she fixated as close as possible to the mouth. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

An interesting observation is that, while this eyes-mouth dissociation between normal observers and PS was true for all the conditions of the study, PS′ fixations were no longer on the mouth in the mask condition, but just above it (Fig. 7B). This suggests that while normal observers did not change their strategy in the mask condition, PS had to fixate an area that was close to the mouth to be able to rely primarily on a single diagnostic feature for her.

3. Experiment 2: increased viewing distance, smaller retinal size of window and mask

Experiment 1 showed that, while normal observers show greater impairment in the individual face matching task when they can only use the single feature that is fixated centrally compared to when this feature is masked, PS shows the exact opposite pattern. This suggests that PS is in great difficulty when she cannot easily use a feature-by-feature strategy. However, difficulties in the central mask condition for her might be merely caused by a reduced visual field rather than being due to the lack of holistic representation of the face. In other words, an alternative explanation for the pattern of results found here would be that PS′ pattern of performance results from a low level visual field problem (i.e., difficulty to see in the periphery) rather than a representational problem. This alternative explanation is not supported by ophthalmological exams, which shows that, apart from a small paracentral left scotoma, which rather falls in the window than outside of it (see Fig. 1 in Sorger et al., 2007; and Fig. 9), she has a full visual field. Nevertheless, we decided to rule out this low-level explanation directly by showing that the pattern of results found are independent of the absolute size of the window/mask used, but rather depend on their relative size (i.e., one feature covered on the face stimulus, irrespective of its size).

In order to investigate the specific influence of the retinal size of the stimulus, we increased the distance between the participant and the monitor, resulting in a decrease of the retinal size of the stimuli and the mask and window. If the performance pattern was caused by a narrower visual field for the patient, then we would expect her pattern of performance to change when the retinal size of the stimuli decreases. This would be particularly the case in the mask condition, where peripheral information is to be used, because decreasing the size of the stimulus results in an increase of the amount of information closer to the fovea and should therefore increase PS′ performance if her difficulty was caused by a low-level visual problem.

3.1. Methods

The experimental procedure and stimuli were identical to Experiment 1. The distance between the monitor and the participant was increased to 102 cm. The height of the faces then subtended 7.5°, the distance between the inner borders of the faces was 5°, and the size of the window and mask was 4.3 by 3.3°.

Both PS and 4 age- and gender-matched control participants each completed 3 blocks of 45 trials, 15 of each viewing condition in a random and therefore unpredictable order. All control participants had normal or corrected to normal visual acuity and no complaints of face recognition difficulties.

3.2. Results

As illustrated in Fig. 8, and in line with the data reported from the shorter viewing distance, the accuracy for the normal observers (main effect: $Chi^2(2) = 10.46$; $p = .0054$) was higher in full view than with the mask, $Chi^2(1) = 5.64$; $p = .018$, and the window, $Chi^2(1) = 10.44$; $p = .0012$. The accuracy in the mask condition did not differ from that with the window, $Chi^2(1) = 0.99$; $p = .32$. There were no significant differences between the response times in the different conditions (no main effect: $F(2, 6) = 1.13$; $p = .38$).

PS′ accuracy (no significant main effect: $Chi^2(2) = 3.38$; $p = .18$) was marginally higher with the full view than with the mask, $Chi^2(1) = 2.99$; $p = .084$, but did not differ between the full view and the window, $Chi^2(1) = 0.25$; $p = .62$. Her response times (main effect: $F(2, 97) = 50.06$; $p < .0001$) were significantly higher with the central mask than with the full view, $t(6) = 9.84$; $p < .0001$, or with the window, $t(6) = 6.93$; $p < .0001$. Response times with the window were also larger than those in the full view, $t(6) = 3.01$; $p = .0033$.

These results confirm the findings from Experiment 1. The accuracy and the response times of PS as well as the control participants for the two viewing distances show that for both groups, the performance pattern did not depend on the retinal size (Fig. 8). This was confirmed by statistical analyses comparing the two experiments. There was no main effect of distance on PS′ accuracy, $Chi^2 = 0.64$; $p = .42$, or for that of the control participants, $Chi^2 = 0.07$; $p = .79$. There was also no interaction between *viewing condition* and the *distance* for PS, $Chi^2 = 0.044$; $p = .98$, or for the control participants, $Chi^2 = 1.26$, $p = .53$. Also for the response times, neither for PS, $F(1, 293) = 1.03$; $p = .31$, nor for the control participants, $F(1, 10) = 0.78$; $p = .40$, was the main effect of distance significant. There was also no interaction between distance and viewing condition for PS, $F(2, 293) = 0.91$; $p = .40$, or for the control participants, $F(2, 20) = 0.51$; $p = .61$.

As with the shorter distance, PS′ accuracy was lower than the control participants in the full view, $t(3) = 3.61$; $p = .018$, and mask

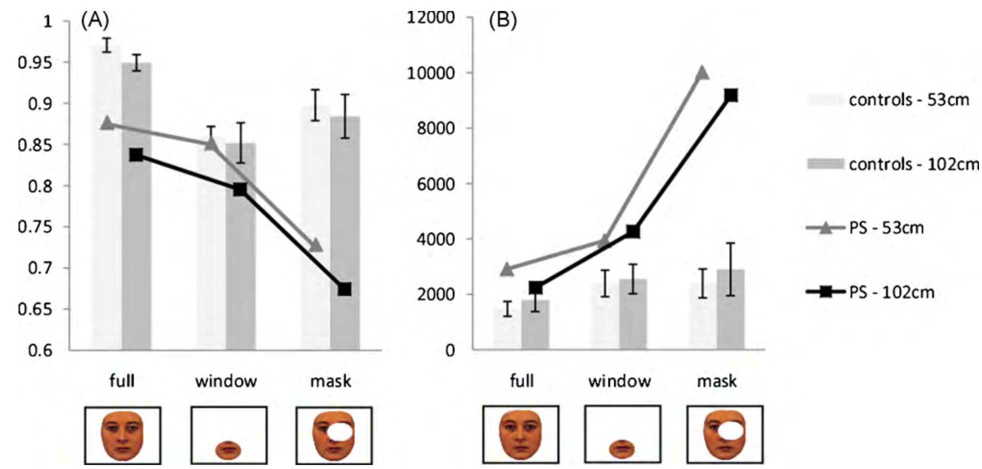

Fig. 8. Average accuracy (A) and response times in ms. (B) Of PS and the control participants in both retinal sizes for all viewing conditions. The error bars represent standard errors.

conditions, $t(3) = 2.50$; $p = .044$, but not in the window condition, $t(3) = 0.73$; $p = .26$. Her response times were higher with the mask condition only, $t(3) = 2.54$; $p = .042$.

PS′ accuracy decrease, $t(3) = 1.88$; $p = .079$, and response time increase, $t(3) = 2.52$; $p = .043$, with the mask compared to full view were again (at least marginally) larger than for the control participants (Fig. 8). The performance decrease caused by the window was not significant ($p > .1$ for accuracy and response times). The difference in performance decrease between the window and the mask was again larger for PS than for the control participants, both for accuracy, $t(3) = 2.40$; $p = .048$, and for response times, $t(3) = 2.36$; $p = .050$, confirming that the performance difference between PS and the control participants was not only a quantitative difference, but also a qualitative one, with a different performance pattern.

In sum, increasing the distance between the monitor and the observer, and therefore decreasing the retinal size of the stimulus and mask and window, did not influence the pattern of observations. PS still had more difficulties when information concerning the facial part under investigation (central mask) was covered, than when only the central information was present, while normal observers still showed a trend in the opposite direction. Furthermore, with smaller retinal size, we still observed that the performance difference between PS and normal observers was the largest with the central mask, and the smallest with a central window. These results indicate that the qualitative difference in performance patterns between PS and normal observers is not due to a low-level visual problem.

4. Discussion

In this study, we made two novel and potentially important observations for understanding human face recognition, and its specific impairment following brain damage.

First, if a normal observer has only one facial feature available at a time, at his/her own choice, even where visual acuity is maximal (Anstis, 1974), his/her face recognition ability is massively affected, as indicated by large increases in error rates (12%) and response times (about 900 ms, or an increase of ~60%) in a forced choice individual face recognition task which is performed almost at ceiling with full faces. This observation indicates that a forced feature-by-feature processing through a reduced spatial window is not at all optimal for face recognition, even when the window is large enough to cover at least an entire diagnostic feature at a given time. This observation strengthens previous evidence of reduced individual face recognition performance with a limited spatial window (Endo, 1986; Inui & Miyamoto, 1984), although these previous studies were performed without a gaze-contingent method that provides full control to the observer for extracting diagnostic local information online. The difficulty with the window condition cannot be attributed to the absolute size of the visual field, because Experiment 2 showed that the decrease in performance in the window condition relative to the full view condition was of about the same magnitude with a much smaller retinal stimulus size. Rather, it appears that the difficulty arises because the observer is forced to analyze each facial feature sequentially in the window condition.

When the fixated feature was masked, a new manipulation applied to face processing to our knowledge, there was also a drop in performance for normal observers, even though for accuracy rates this drop is significantly less pronounced than that in the window condition. This indicates that the fixated feature certainly contributes to face recognition, but that it is perhaps more critical to be able to see the remainder of the entire face for optimal face recognition. In this condition of masked central vision, the optimal strategy for the observer is to extract information simultaneously from the rest of the whole face, visible outside the mask (Fig. 1). Admittedly, one cannot exclude that normal observers concentrate on a single feature at the border of the mask (e.g., using the mouth only, not the eyes when the mask is on the nose) in this condition. However, the data suggest that normal observers did not do that. Indeed, such a piecemeal strategy in the mask condition would make them perform at the level of the window condition at best, but not better. In fact, if participants used only one feature at a time in the mask condition, their performance should have been lower than in the window condition, given that the single feature they would have used would have been presented outside of the fovea. Rather, the higher performance in the mask than in the window condition for normal observers suggests that, in the mask condition, observers extracted information from several features available simultaneously over the whole face.

Considering this, the second, and perhaps most important observation of the present study is that the prosopagnosic patient showed an opposite behaviour compared to the normal observers: She was almost unimpaired in the window condition, but found the mask condition extremely difficult, presenting large increases in error rates and response times in this condition. This is important because it further demonstrates that, following brain damage, a prosopagnosic patient does not simply perform less well, quantitatively, compared to normal observers. Rather, there appears to be a *qualitative* impairment in acquired prosopagnosia: while a particular way of processing the face, which is prevented in the

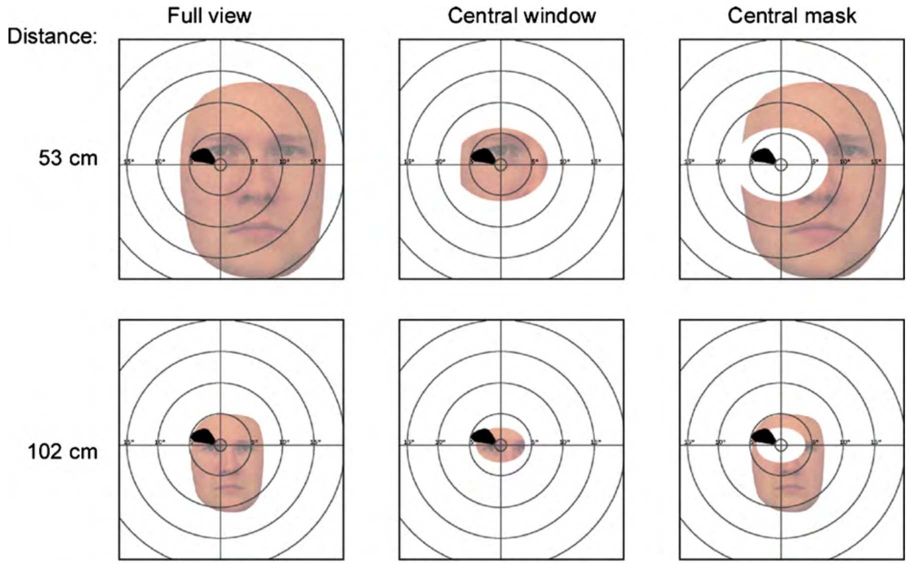

Fig. 9. Illustration of the size and location of PS′ parafoveal scotoma for both viewing distances and all viewing conditions.

window condition and required in the central mask condition, characterizes skilled human observers, this process is precisely what is dysfunctional in prosopagnosia.

In the window condition, the prosopagnosic patient was virtually unaffected as compared to a full view condition. This suggests that when she has a face presented in full view, she nevertheless processes the face feature by feature, over a small spatial window. Note that the small remaining difference in speed compared to the control participants in this window condition might be explained by PS′ small binocular paracentral left scotoma (see illustrations in Sorger et al., 2007) that was completely included in the window (Fig. 9) and therefore still slightly covered the fixated information. Alternatively, or in addition to this factor, it might be due to PS′ visual acuity or color sensitivity being slightly lower than control participants of the study (see Sorger et al., 2007). If anything, the fact that the greatest impairment of the patient relative to normal observers took place in the mask condition rather than in the window condition despite these potential (small) low-level difficulties reinforces the point of the present study. In future studies, one may want to present the patient and normal observers with a peripheral rather than a central window to fully clarify this point. In this situation, normal observers would be put in a situation where they would have to process the face feature-by-feature, but without being able to use the fixated feature. Presumably, this would correspond to the viewing condition of the patient in the mask condition of the present study.

Precisely, in the mask condition, the prosopagnosic patient had major difficulties, while normal observers were less affected than in the window condition. As a matter of fact, the patient complained heavily about the difficulty of this condition, and found it extremely hard to extract diagnostic information from outside of the central window of vision (which was masked), i.e., on the whole face that remained entirely visible. This difficulty of the patient in the mask condition indirectly indicates that her analytical mode of processing an individual face does not only reflect a peculiar and preferential strategy that she developed following her accident. In fact, it appears to be the most efficient way for her to resolve such a task in the full view condition. Indeed, if she is deprived of central featural information, she has great difficulties to use information from the whole face, visible around the mask, to perform the task. This suggests that, in contrast to normal observers, she is impaired at perceiving the remaining features distributed across the whole face.

The patient's inability to perceive the individual face as a whole cannot simply be accounted for by a low-level visual impairment, since her peripheral vision is preserved, and her small scotoma falls completely within the masked area of vision (Fig. 9). Moreover, her pattern of performance was virtually unaffected by a large change of retinal size of the central mask (and window) in Experiment 2. Thus, rather than an absolute loss of peripheral vision (tunnel vision), which may arise due to retinis pigmentosa, optic nerve damage or early visual cortex damage, this pattern of observations point to a high-level visual defect: the patient has normal sensitivity in her visual field, but appears to neglect the whole individual face and rather focus on a single feature at a time, over a small spatial window. To put it differently, while patients with tunnel vision should still be able to perceive faces holistically as long as the whole face is not greater than the tunnel diameter,[1] it seems that for the prosopagnosic patient it is the *perceptual* field (Rossion, 2008, 2009) that is constricted, being limited to one facial feature at a time when attempting to recognize a particular face.

Moreover, it is also important to point out that the prosopagnosic patient's impairment should not be confounded with a difficulty in perceiving the whole of a visual pattern in general, a function which may be impaired in patients with acquired prosopagnosia (e.g., Levine & Calvanio, 1989; Riddoch & Humphreys, 1987), or preserved only to some extent (Barton, 2009). Indeed, when dealing with complex objects or visual scenes, the prosopagnosic patient PS is able to use the whole visual field, providing that she does not have to identify a particular face. For instance, PS presents with an entirely normal response profile in a Navon hierarchical letter task (Navon, 1977): she is faster to identify global than local letters, and her sensitivity to global interference during identification of local letters is at least as large as normal observers (Busigny & Rossion, in press-b). She is also capable of per-

[1] Note that there is evidence that patients with retinis pigmentosa and tunnel vision have difficulties in symmetry perception (Szlyk et al., 1995) that cannot be explained by the simple loss of retinal functions themselves. According to these authors the alterations of the sensory input may have affected the perceptual encoding of the relationships among pattern elements which are involved in symmetry detection (see also a review by Wagemans, 1999). Thus, even though the impairment identified here with the prosopagnosic patient cannot be equated by tunnel vision, it would be an interesting suggestion to investigate whether these alterations of sensory input would have some impact on holistic face perception in patients with tunnel vision.

ceiving a face as a face ("face detection") when global perception is required (e.g., a Mooney or Arcimboldo stimulus, Dricot, Busigny, & Rossion, 2008). However, it is when dealing with *individual* faces that she does not present any evidence of holistic perception (Ramon et al., 2010). In other words, when the task requires identification of a specific individual face, normal observers appear to perceive the individual features of a face all at once, while the patient neglects the whole face and relies on a small, feature-based, constricted perceptual field.

The prosopagnosic's impairment in holistic face perception as demonstrated here is in agreement – and nicely complements – more indirect evidence of a lack of interactivity between facial features during her face identification. This is shown by the absence of inversion, part-whole, and composite face effects (Busigny & Rossion, in press-a; Ramon et al., 2010), her focus on specific local features, the mouth in particular rather than the centre of a face in recognizing familiar faces (Orban de Xivry et al., 2008), as well as her underreliance on regions of the face containing multiple features to process (the eyes) and relative distances between features across the whole face (Caldara et al., 2005; Ramon & Rossion, 2010). Since other cases of acquired prosopagnosia share some of these characteristics with the patient PS (e.g., Barton, Press, Keenan, & O'Connor, 2002; Bukach et al., 2008; see also Barton, 2008), we predict that these other patients may show the same pattern of performance as observed here in the window (preserved) and mask (impaired) viewing conditions. Considering that the right hemisphere is dominant in holistic face perception (e.g., Hillger & Koenig, 1991; Schiltz & Rossion, 2006; Sergent, 1988), this could particularly be the case if their prosopagnosia follows brain damage to face-sensitive areas of the right hemisphere, as is predominantly the case for the patient PS (Sorger et al., 2007) and cases of prosopagnosia in general (e.g., Barton et al., 2002; Bouvier & Engel, 2006; Hécaen & Anguelergues, 1962; Sergent & Signoret, 1992). Such findings would be important to strengthen and generalize the present observations, and would lead to a better understanding of the neurofunctional aspects of face recognition in the human brain.

To conclude, the combined set of original observations made in the present study strongly support the view that the impaired process in acquired prosopagnosia is also what makes normal observers particularly skilled at face recognition: the ability to perceive the individual face as a whole rather than to extract detailed information from particularly diagnostic localized features. Furthermore, besides providing novel clues about the nature of human face recognition, the gaze-contingent stimulus presentation method used here may prove to be a highly valuable tool for the diagnosis and characterization of face recognition difficulties in individuals with congenital prosopagnosia (Behrmann & Avidan, 2005; Duchaine & Nakayama, 2006), or autism (Langdell, 1978; Spezio, Adolphs, Hurley, & Piven, 2007), for which the nature of the face recognition impairments remains largely unclear at this stage.

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