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Preservation of mouth region processing in two cases of prosopagnosia

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Although most adults are considered experts in face recognition, brain trauma can produce a selective loss in this ability, a condition referred to as prosopagnosia. This study examined the processing strategies of prosopagnosic patients LR and HH using the Face Dimensions Test. In this test, featural and configural information in the upper and lower halves of the face was parametrically varied and sensitivity to these changes measured. We found that relative to age-matched control participants, LR and HH exhibited an impaired ability to discriminate differences in the eye region, but a preserved ability to detect featural and configural differences in the mouth region. This pattern of impairment and sparing was demonstrated in tests of direct perception and immediate memory. The obtained findings demonstrate that prosopagnosia does not necessarily cause a global impairment to face perception, but a selective impairment to the perception of information in the upper half of the face.

Human adults are experts at recognizing faces. Most people can identify thousands of individual faces, even when the person is seen at a distance, under poor lighting conditions, from a novel viewpoint, or after 10 years of ageing (Bahrick, Bahrick, & Wittlinger, 1975; Bruce, 1988). This proficiency in face recognition is remarkable considering that all human faces have the same basic features (i.e. eyes, nose, and mouth), arranged in a similar configuration (i.e. the two eyes are above the nose, that is above the mouth). Successful face recognition must therefore depend on perceiving subtle differences in the featural information in a face, such as variations in the shape or size of the face parts (e.g. eyes, nose, and mouth) and differences in the spatial configuration of the features, such as the distance between the eyes or the distance between the nose and mouth (Diamond & Carey, 1986).

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The separate contributions of featural and configural dimensions to face perception can be tested using a same/different discrimination task. In this task, configural sensitivity is indexed by the participant's ability to detect differences in pairs of faces that differ only with respect to the spatial distance between individual features (e.g. the distance between the eyes). Changes in spatial distance alter the configural information in a face while preserving the information about its local features (provided that the spatial variation is not extreme). Changes in the featural information can be tested by manipulating the shape or size of the facial features, manipulations that have relatively little effect on the configural face information. Studies have manipulated featural and configural information to examine the face-processing strategies of normal individuals (Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; Mondloch, Le Grand, & Maurer, 2002) and clinical populations (Barton, Cherkasova, Press, Intriligator, & O'Connor, 2004; LeGrand, Mondloch, Maurer, & Brent, 2001). These studies have found that configural information is disproportionately affected by inversion relative to featural information. Because upright, but not inverted faces are believed to engage face-specific processes, it has been argued that configural information is more essential to expert face recognition than featural information (but see Malcolm, Leung, & Barton, 2004; Riesenhuber, Jarudi, Gilad, & Sinha, 2004; Yovel & Kanwisher, 2004).

Although adults are experts in face recognition (Carey, 1992; Tanaka, 2001), brain trauma can produce a selective loss in face recognition abilities, a clinical condition known as acquired prosopagnosia. Prosopagnosia is behaviourally characterized as a selective loss in the patient's ability to recognize faces. It is of compelling interest to cognitive scientists and neuropsychologists to understand the underlying cognitive processes that are compromised due to such brain injury. It has been suggested that recognition deficits in prosopagnosia are due to impaired perception of the spatial distances or the second-order configural information in a face (Levine & Calvanio, 1989; Sergent & Signoret, 1992; Sergent & Villemure, 1989). Other researchers (Caldara *et al.*, 2005) have argued that prosopagnosia causes impaired perception of specific regions of the face. Employing the Bubbles image classification technique (Gosselin & Schyns, 2001), Caldara *et al.* found that prosopagnosic patient PS utilized information in the lower half of the face in recognition and ignored information in the eye region.

Further evidence for a selective mouth bias and eye impairment was described in a study by Bukach, Bub, Gauthier, and Tarr (2006). They found that prosopagnosic patient LR performed worse than control participants in his configural and featural eye discriminations, but was within the normal range of performance for his featural and configural mouth judgments. Based on these results, the authors argued that the patient could not make fine-level perceptual discriminations on multiple regions of the face. When instructed to attend to the upper region of the face, the patient's eye performance improved, but at a cost to mouth discriminations.

To more precisely investigate the perception of featural and configural information, we devised the Face Dimensions Test – a psychophysical measure in which differences in featural and configural information of the eyes and mouth features were independently and parametrically varied across four levels of change. Featural changes were manipulated by incrementally adjusting the pixel size of the eyes or mouth features in the face stimulus. Configural changes were performed by incrementally varying the pixel distance between the eyes or distance between nose and mouth of the face stimuli. Perceptual sensitivity to these changes was assessed in a same/different matching task where participants were asked to make a 'same/different' response to two stimulus faces that were either identical or varied by 1, 2, 3, or 4 degrees of difference.

Variants of the Face Dimensions Test have been employed to investigate inversion effects in face perception (Tanaka, Kaiser, & Bub, in preparation) and the face-processing strategies of children with autism (Wolf, Klaiman, Brown, Tanaka, & Schultz, 2006). In the current study, the Face Dimensions Test was validated with neurotypical adults and then administered to patients with prosopagnosia and their age-matched control participants. The goals of this study were twofold: first, to examine the effects of prosopagnosia on the perception of featural and configural face information and second, to examine whether individuals with prosopagnosia are differentially affected by information in the top of the face versus information in the bottom. To follow is a description of the face-processing deficits of patients LR and HH.

CASE DESCRIPTIONS

Patient LR is a 51-year-old male who received a penetrating head wound in a motor vehicle accident at 19 years of age. CT scans revealed ablation of the anterior and inferior sections of the right temporal lobe, affecting the amygdala, but apparently sparing posterior regions including the fusiform gyrus (Bukach *et al.*, 2006). Visual acuity following the accident was 20/20 in both eyes with corrective lenses. Following the accident, LR was no longer able to recognize faces including highly familiar individuals like his own daughter (for a more detailed description of LR, see Bukach *et al.*, 2006). Patient HH is a 48-year-old right-handed male who suffered a closed-head traumatic brain injury in a motorcycle accident at 21 years of age. Structural MRI carried out on HH following the accident revealed no evidence of anatomical damage. However, after his accident, HH reported severe difficulty recognizing the faces of friends and family, and relies on cues such as hairstyle and clothing to recognize people. Both patients performed normally on standard tests of object recognition, and report no difficulty recognizing non-face objects in daily life. The results of neuropsychological testing for LR and HH can be found in Table 1.

Method

Assessment of face recognition ability

As shown in Table 1, both LR and HH showed significant impairments on clinical tests of face recognition. To better assess the extent of face recognition deficits, we administered a task that involved familiarity, identity, and name recognition judgments using current celebrity stimuli and unknown foils to LR and HH and five age-matched controls (four males; mean age = 46 years, range = 43–49 years). All participants received a small monetary compensation for their participation.

Stimuli

The stimuli were 70 prints of grey-scale high-quality digital images of faces. Half of the faces were of famous people and half were of unfamiliar people. The famous faces were of well-known individuals from a variety of professions including actors, athletes, musicians, and politicians (see Appendix). For the famous faces, we chose individuals who are highly familiar to Canadians in their 40s and 50s (the demographics of our participants). The non-famous faces were aspiring actors, models, and unfamiliar European politicians. Images from the two sets of faces were matched on age and gender. All the images were from the internet and were matched for photographic

Table 1. Result of standardized neuropsychological tests administered to LR and HH

	Prosopagnosic patient	
Neuropsychological tests	HH	LR
Intelligence (WAIS-R)	Superior (120)	High average (114)
Visual acuity	Normal (20/20)	Normal (20/20)
Colour perception (AO-HRR)	Normal	Normal
Line orientation (JLOT)	Normal	Normal
Object and space perception (VOSP)	Normal	Normal
Object recognition (SVOB)	Normal	Normal
Recognition memory for words (RMT)	Normal	Normal
Face recognition – timed (BFRT)	Impaired (37/54)	Severely impaired (12/54)
Recognition memory for faces (RMT)	Severely impaired (32/50)	Severely impaired (38/50)

Note. WAIS-R, Weschler Adult Intelligence Scale (third edition); AO-HRR, American Optical Handy Rand Rittler; JLOT, Benton Judgment of Line Orientation (Benton *et al.*, 1983); VOSP, Visual Object and Spatial Perception (Warrington & James, 1991); SVOB, Snodgrass & Vanderwart objects (Snodgrass & Vanderwart, 1980); RMT, Warrington Recognition Memory Test (Warrington, 1994); BFRT, Benton Face Recognition Test (Benton *et al.*, 1983).

quality. The faces were printed on white paper and were approximately 13 cm in width and 18 cm in height.

Procedure

Sorting task

The participant sat in a well-lit room in front of a table. They were shown pictures of faces, and asked to sort each face on the basis of whether it was a very famous individual or an unfamiliar individual. The faces were presented individually in a randomized order for an unlimited duration. We conducted this task as a measure of familiarity with the famous faces (even in the absence of being unable to identify the faces). Correct responses and time to complete the task were recorded.

Identity task

Upon completion of the sorting task, the participant was then presented with the famous faces sequentially for an unlimited duration and asked to identify each individual (irrespective of whether they had sorted the face correctly). A face was correctly identified if the name of the person was provided or if the participant provided accurate biographical details about the person.

Naming task

To ensure that the participant knew the famous people, a naming task was conducted. The participant was presented with the names of the famous faces previously unidentified, and was asked whether they knew of this individual and to provide some biographical information about them (e.g. career details). In the event that a famous person was unknown to the participant, the face was removed from the results. However, all the famous individuals used in the study were familiar to the patients.

Results and discussion

In the first phase of the task, images of faces were sorted according to whether they were of famous or non-famous individuals. Age-matched controls were fast (mean $= 2:54$ min) and highly accurate (mean $d' = 4.66$) at sorting famous and unfamiliar faces. The two acquired prosopagnosics performed extremely poorly on this task. LR correctly sorted only 60% of the familiar faces ($d' = 1.65$), and it took him 10:34 minutes to complete the task. Similarly, HH correctly sorted only 65% of the famous faces ($d' = 1.83$), and he was very slow at completing the task (11:34 minutes). In the second phase of the task, patients and age-matched participants were shown the famous faces and asked to identify them by name. LR correctly identified only 43% of the famous faces including faces that he sees on a regular basis (e.g. George Bush, Bill Clinton, and Tom Hanks). Similarly, HH was very poor at identifying the famous faces. He identified only 20% of the faces, and failed to recognize such well-known individuals as Elvis Presley, Arnold Schwarzenegger, and Pope John Paul II. Despite being unable to recognize the majority of the famous faces, the prosopagnosic patients were able to provide detailed biographical information on all these individuals when presented with their name.

EXPERIMENT 1: SIMULTANEOUS MATCHING TASK

Having established that LR and HH are severely impaired at recognizing highly familiar faces, we next investigated the source of their face-processing impairment by developing a psychophysical task that measured sensitivity to featural and configural information in the eye and mouth region. Featural information was manipulated by independently changing the size of the eyes or the mouth features. We chose to manipulate the size of the eyes and mouth features because scaling maintains the feature's overall shape while preserving its absolute spatial location in the face. Although size manipulations also alter the distances between features, these changes are relatively modest (Tanaka, Kaiser, & Bub, submitted). Configural information was manipulated by changing either the inter-ocular distance between eyes or the distance between the centre of the upper lip (i.e. the philtrum) and the bottom of the nose. As shown in Figure 1, five levels of featural and configural changes were manipulated to test '4 degrees of difference'. To establish the validity of the face manipulations, the measure was first administered to university students and then given to patients LR and HH and age-matched control participants.

Method

Participants

The participants were 32 (22 females; mean age = 23 years, range = 19–32 years) undergraduate students from the University of Victoria with normal or corrected to normal vision; patients LR and HH and five age-match participants (four males; mean age = 46 years, range = 43–49 years) also took part in Experiment 1. The patients and age-matched control participants received monetary compensation for their participation and the undergraduate students received course credit.

Stimuli

The stimuli consisted of grey-scale digitized photographs of four male and four female faces. The individuals had no jewellery, glasses or makeup, and facial markings

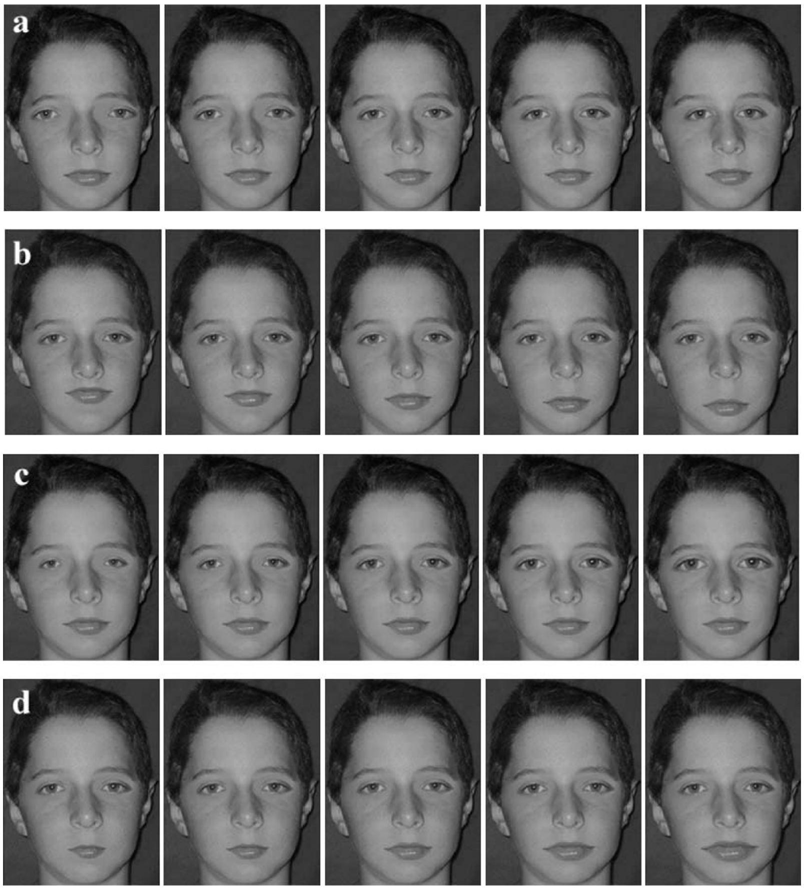

Figure 1. Example of a complete set of the face stimuli. a) Faces differing in the distances separating the eyes (configural/eyes manipulation). b) Faces differing in the distance between the nose and mouth (configural/mouth manipulation). c) Faces differing in the size of the eyes (featural/eyes manipulation). 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.

(e.g. freckles and moles) were removed digitally. Using the graphics software program Adobe Photoshop, we modified an original face along four dimensions: configural/eyes, configural/mouth, featural/eyes, and featural/mouth (see Figure 1). Each dimension consisted of five faces, the original face and four modified face images. The modified faces in the *configural/eyes dimension* were created by (1) moving each eye closer together on the horizontal axis by 5 pixels; (2) moving each eye closer together by 10 pixels; (3) moving each eye farther apart by 5 pixels; and (4) moving each eye farther apart by 10 pixels – 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 pixels; (2) moving the mouth closer to the nose by 10 pixels; (3) moving the mouth away from the nose by 5 pixels; and (4) moving the mouth away from the nose by 10 pixels – always relative to the original face (see Figure 1b). The modified faces in the *featural/eye dimension* were created by (1) increasing the size of the eyes by 10%; (2) increasing the size of the eyes by 20%; (3) decreasing the size of the eyes by 10%; and (4) decreasing the size of the eyes by 20% – always relative to the original face (see Figure 1c). The modified faces in the *featural/mouth dimension* were created by (1) increasing the size of the mouth by 10%; (2) increasing the size of the mouth by 20%; (3) decreasing the size of the mouth by 10%; and (4) decreasing the size of the mouth by 20% – always relative to the original face (see Figure 1d). Due to the nature of the manipulations in the featural condition, some degree of configural change was unavoidably introduced. For example, changing the size of the eyes while maintaining the position of the pupils necessarily alters the inter-ocular distance. The magnitude of these changes was as follows: Within the eye condition, the inter-ocular distance varied in increments of 4.2–4.8 pixels between each level of change; in the mouth condition, the philtrum length varied in increments of 1.4–2.0 pixels.

Eight original faces (four males and four females) 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

The participant sat in a darkened room with his/her eyes approximately 60 cm from a 15-inch Compaq Presario monitor on which the faces were presented by a Macintosh G4 computer and RSVP software (Tarr & Williams, 1996). On each trial, a fixation cross was presented for 150 ms, followed by the two faces presented side-by-side. The participant's task was to decide whether the faces were the 'same' or 'different'. It was clarified that a 'same' response indicated that the faces were physically identical. The faces remained on the screen until the participant signalled their response with a key press or 3,000 ms elapsed, whichever came first. Trials in which the participant did not respond within the allotted 3,000 ms were coded as incorrect. Accuracy and reaction time for correct trials was recorded.

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 were an equal number of trials from each of the eight face sets and the four dimensions (configural/eyes, configural/mouth, featural/eyes, and featural/mouth). Within each dimension, the degree to which the faces differed ranged from 1 degree of difference (the closest neighbouring face, e.g. the original face and the manipulation to each eye moved closer together by 5 pixels, Figure 1a), to 4 degrees of difference (the manipulations with the greatest difference, e.g. the face with each eye moved out by 10 pixels and the face with each eye moved in by 10 pixels). Each face pair was tested twice in the same and different conditions.

Results and discussion

The accuracy and reaction time data were submitted to $4 \times 2 \times 2$ ANOVA with degree of difference (1, 2, 3, and 4), information type (featural and configural) and region (top and bottom) as within-group factors. Undergraduate participants were faster and more accurate as the degree of difference increased ($F(3, 31) = 194.01; p < .001$). Sensitivity to configural ($d' = 1.72$) and featural ($d' = 1.82$) changes were very similar, but for the degree of difference of 2, participants were more accurate for the featural changes ($F(1, 31) = 9.63$, $p < .01$; see Figure 2). No other effects or interactions were significant. Response times were equivalent for configural (1,446 ms) and featural changes (1,439 ms; $F(1, 31) = .04$, $p > .1$). Undergraduates were equally sensitive to changes restricted to the eye ($d' = 1.82$; 1,422 ms) and mouth regions ($d' = 1.72$; 1,462 ms; $F(1, 31) = 1.76$, $p > .1$).

Accuracy and reaction time for LR and HH were compared with the age-match control group by a modified t test for comparing single-case studies to small samples as proposed by Crawford and Howell (1998). The formula for calculating the t test is $(x - \bar{x})/s\sqrt{((N + 1)/N)}$, where x is the patient's score, $\bar{x}$ and s are the mean and standard deviation of the control group, and N is the size of the control sample. The obtained t test value is compared with a critical value using $\alpha = .05$ (one-tailed) and $N - 1$ df, as the hypothesis tested (that the patient has a deficit) is directional.

The patients' reaction times were within the normal range with the exception of an abnormally long reaction time in the configural eye condition for LR ($M = 2,184$ ms, $t(4) = 2.93$, $p < .05$). Both prosopagnosic patients were much better at discriminating differences restricted to the mouth region than the eye region (see Figure 3 and Table 2). LR showed normal sensitivity to configural/mouth ($d' = 1.67$, $t(4) = -0.75$, $p > .05$) and featural/mouth ($d' = 1.93$, $t(4) = 0.22$, $p > .05$) differences. In contrast, for changes restricted to the eye region, LR was severely impaired (configural/eye $d' = 0.81$, $t(4) = -7.16$, $p < .01$ and featural/eye $d' = 0.94$, $t(4) = -5.00$, $p < .01$). HH demonstrated a similar pattern of results: he had normal sensitivity to the mouth region (configural/mouth $d' = 1.71$, $t(4) = -0.62$, $p > .05$ and featural/mouth $d' = 2.17$, $t(4) = 0.86$, $p > .05$), and severely impaired sensitivity to changes in the eye region (configural/eye $d' = 0.35$, $t(4) = -9.50$, $p < .01$ and featural/eye $d' = 0.42$, $t(4) = -7.06$, $p < .01$). The patients' d' scores were within normal limits for featural

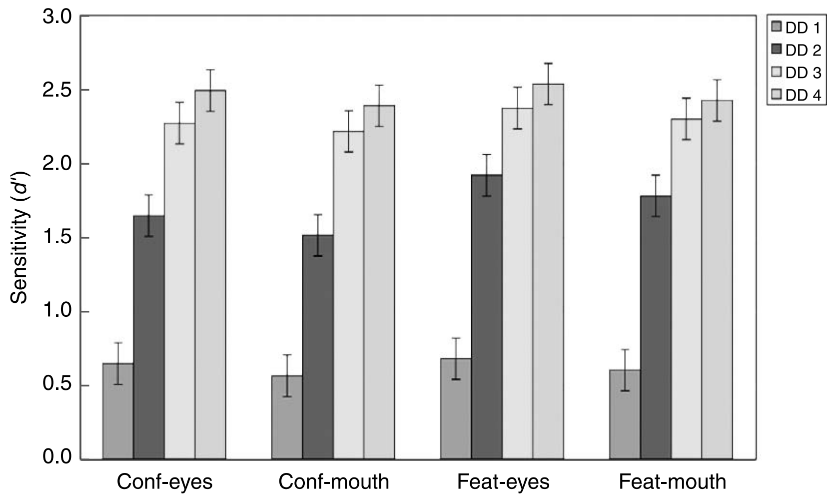

Figure 2. Performance (d') of adults on the simultaneous face-matching task. Solid bars show sensitivity to the 4 degrees of difference (dd) in each condition: configural/eye changes, featural/eye changes, configural/mouth changes, and featural/mouth changes. Error bars represent 95% within-participant confidence intervals.

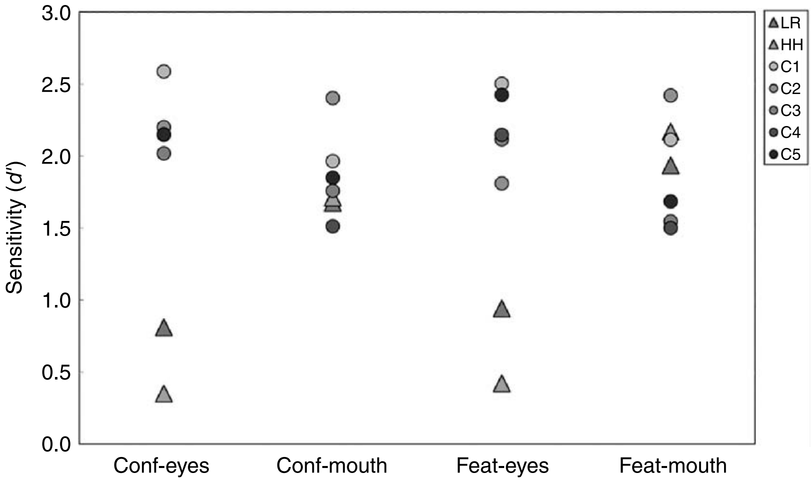

Figure 3. Performance of age-matched controls and prosopagnosic patients on the simultaneous face-matching task. Mean accuracy (d') for each of the five control participants (C1–C5) is represented by circles. Mean accuracy (d') for the two prosopagnosic patients (LR and HH) is represented by triangles.

and configural discriminations in the mouth region for every degree of difference. In contrast, they were impaired in their ability to discriminate featural and configural differences in the eye region at nearly every degree of difference. However, as shown in Table 2, the patients demonstrated d' scores above chance level of performance at more

Table 2. d' scores for patients LR, HH and age-matched control participants on the Face Dimensions Test according to region (eyes, mouth) and information type (configural, featural) in simultaneous matching task (Experiment 1).

		LR	HH	Controls
Eyes				
Configural	1 Degree	−0.20	−0.24*	0.64
	2 Degrees	0.06**	−0.24**	1.29
	3 Degrees	0.79*	0.75*	2.18
	4 Degrees	0.95**	0.10**	2.38
Featural	1 Degree	−0.20*	−0.24*	0.43
	2 Degrees	−0.20**	−0.24**	1.50
	3 Degrees	0.63**	1.15*	2.33
	4 Degrees	0.46**	0.75**	2.40
Mouth				
Configural	1 Degree	0.46	−0.24	0.43
	2 Degrees	0.27**	0.96	1.10
	3 Degrees	1.10	1.96	2.15
	4 Degrees	2.83	2.13	2.78
Featural	1 Degree	0.79	0.49	0.53
	2 Degrees	1.10	1.48	1.47
	3 Degrees	2.83	2.79	2.36
	4 Degrees	2.83	2.52	2.57

* = $p < .05$; ** = $p < .01$

extreme levels of 3 and 4 degrees of difference indicating a residual sensitivity to large-scale changes in the eye region.

To determine whether sensitivity to configural and featural changes was equivalent, we conducted z-test differences for each patient within each face region. Sensitivity to featural and configural information was equivalent in both the mouth and eye regions for both patients (LR: $z_{\text{diff}} = -0.61$ for the eye region and $z_{\text{diff}} = -0.74$ for the mouth region; HH: $z_{\text{diff}} = -0.36$ for the eye region and $z_{\text{diff}} = -0.95$ for the mouth region; $p > .1$).

The main finding of Experiment 1 was that prosopagnosic patients LR and HH demonstrated preserved perception of information in the mouth region and were selectively impaired in their detection of differences in the eye region. Critically, the pattern of preserved and impaired perception varied as a function of face region and was not affected by whether the difference was featural or configural. In direct perception, patients performed on par with age-matched control participants in their ability to process featural and configural information in the mouth region, but were significantly compromised in their ability to discern featural and configural differences in the eye region.

EXPERIMENT 2: SEQUENTIAL MATCHING TASK

Experiment 2 was designed to test the processing of featural and configural information in an immediate memory task. The Face Dimensions Test was administered in a sequential presentation format where a study face was shown for 500 ms, followed by a test face. The participant's task was to decide whether the test face was identical to the previously shown study face. The featural and configural discriminations were first tested and equated with university students and then administered to patients LR and HH and age-matched control participants.

Method

Participants

The participants were 32 (26 female; mean age = 20 years, range = 18–31 years) undergraduate students from the University of Victoria with normal or corrected to normal vision, patients LR and HH and the same age-matched control participants who took part in Experiment 1. The patients and age-matched control participants received monetary compensation for their participation and the undergraduate students received course credit for their involvement.

Stimuli

The same stimuli employed in Experiment 1 were used in the current study.

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.

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 were an equal number of trials from the eight faces, the four dimensions (configural/eyes, configural/mouth, featural/eyes, and featural/mouth) and 4 degrees of difference within each dimension. Each same and different condition was repeated twice. Percentage of correct and reaction time for correct trials was recorded. Reaction time on a trial was measured from the time the second study face was presented until the participant responded. Trials in which the participant did not respond within the allotted 3,000 ms were coded as incorrect.

Results and discussion

The accuracy and reaction time data were submitted to $4 \times 2 \times 2$ ANOVA with degree of difference (1, 2, 3, and 4), information type (featural and configural) and region (top and bottom) as within-group factors. As shown in Figure 4, the undergraduate participants were faster ($F(3, 31) = 47.13$, $p < .001$) and more accurate ($F(3, 31) = 187.47$, $p < .001$), as the degree of difference between faces increased. The main factor of region was also reliable showing that participants were faster ($F(1, 31) = 10.22$, $p < .01$) and more accurate ($F(1, 31) = 6.56$, $p < .05$) at detecting changes to the eye region (885 ms; $d' = 1.55$) than the mouth region (934 ms; $d' = 1.33$). No other effects or interactions were significant. Importantly, participants were equally sensitive to changes in configural changes in the spacing of the features (917 ms; $d' = 1.43$) as they were to changes in the size of the features (903 ms; $d' = 1.45$), $F(1, 31) = 0.2$, $p > .1$.

Modified *t* tests were used to compare the patients' performance with that of the age-matched controls. LR's reaction times for the eye region were significantly longer than the control participants for both configural (1,626 ms, $t(4) = 5.29$, $p < .01$) and featural (1,930 ms, $t(4) = -4.05$, $p < .01$) changes. In contrast, LR's response times were within the normal range for the mouth region. Response times for HH were within normal range and did not differ significantly from age-matched controls. Taken together, there was no

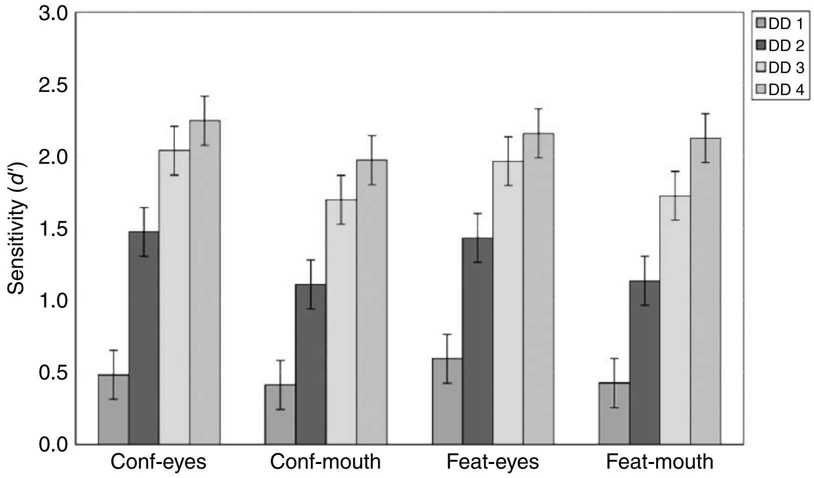

Figure 4. Performance (d') of adults on the sequential face-matching task. Solid bars show sensitivity to the 4 degrees of difference (dd) in each condition: configural/eye changes, featural/eye changes, configural/mouth changes, and featural/mouth changes. Error bars represent 95% within-participant confidence intervals.

evidence of a speed/accuracy trade off for patients LR and HH to the extent that their impaired discrimination of eye information was not a consequence of speeded responses.

LR showed normal sensitivity to featural and configural changes restricted to the mouth region (featural/mouth $d' = 1.89$, $t(4) = 0.29$, $p > .05$ and configural/mouth $d' = 1.17$, $t(4) = -1.21$, $p > .05$). In contrast, he was severely impaired at detecting both featural and configural differences restricted to the eye region (featural/eyes $d' = 0.17$, $t(4) = -5.41$, $p < .01$ and configural/eyes $d' = 0.40$, $t(4) = -3.08$, $p < .05$; see Figure 3). Similarly, HH showed normal sensitivity for featural/mouth ($d' = 1.82$, $t(4) = 0.16$, $p > .05$) and configural/mouth ($d' = 1.20$, $t(4) = -1.12$, $p > .05$), whereas he had great difficulty for the featural/eyes ($d' = 0.35$, $t(4) = -4.75$, $p < .01$) and configural/eyes ($d' = 0.09$, $t(4) = -3.85$, $p < .01$) discriminations (see Figure 5). With only one exception, the patients' d' scores were within normal limits for featural and configural discriminations in the mouth region for every degree of difference. In contrast, the patients were impaired in their ability to discriminate featural and configural differences in the eye region at nearly every degree of difference. However, at the 3 and 4 degrees of difference, their d' scores were above chance indicating that the patients showed a residual sensitivity to changes in the eye region.

To determine whether each patients' sensitivity to featural and configural information was equivalent, we used a z-test of differences in d' for both face regions (Marascuilo, 1970). Sensitivity to featural and configural information was equivalent in both the mouth and eye regions for each of the patients (LR: $z_{\text{diff}} = 0.67$ for the eye region and $z_{\text{diff}} = -1.63$ for the mouth region; HH: $z_{\text{diff}} = -0.71$ for the eye region and $z_{\text{diff}} = -0.95$ for the mouth region; ps $> .05$) (Table 3).

In summary, the results of the present experiment demonstrate that in an immediate face memory task, the patients were impaired in their ability to detect configural and featural differences located in the eye region of the face, but were normal in their ability to discriminate differences in the mouth region. Thus, LR's and HH's face impairments appear to stem from a deficit in processing information in the upper region of the face rather than an impairment to configural face information.

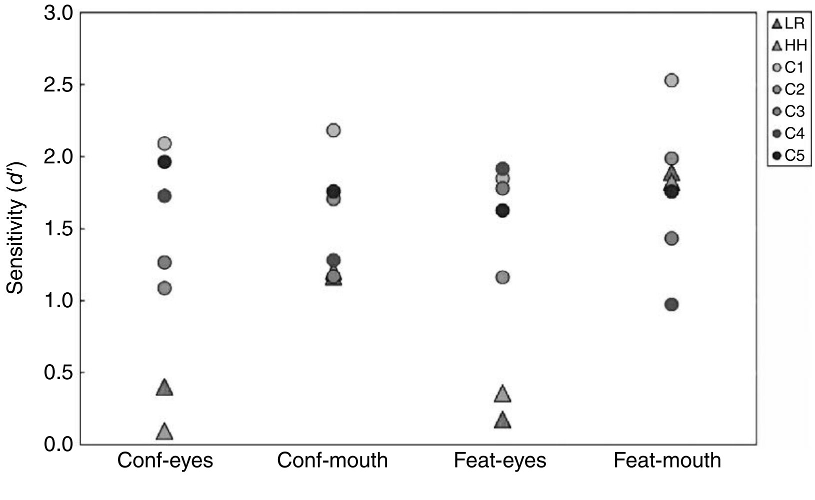

Figure 5. Performance of age-matched controls and prosopagnosic patients on the sequential face-matching task. Mean accuracy (d') for each of the five control participants (C1–C5) is represented by circles. Mean accuracy (d') for the two prosopagnosic patients (LR and HH) is represented by triangles.

Table 3. *d'* scores for patients LR, HH and age-matched control participants on the Face Dimensions Test according to region (eyes, mouth) and information type (configural, featural) in sequential matching task (Experiment 2).

		LR	HH	Controls
Eyes				
Configural	1 Degree	0.19	−0.31**	0.74
	2 Degrees	0.40**	0.17**	2.15
	3 Degrees	1.08**	0.69**	2.86
	4 Degrees	1.57**	0.84**	3.14
Featural	1 Degree	−0.80**	−0.69**	0.59
	2 Degrees	0.59*	0.69*	2.21
	3 Degrees	1.75**	1.00**	3.10
	4 Degrees	2.23	0.69**	2.91
Mouth				
Configural	1 Degree	0.59	0.36	0.51
	2 Degrees	0.92	1.73	1.43
	3 Degrees	2.23	2.38	2.45
	4 Degrees	2.96	2.38*	3.21
Featural	1 Degree	0.59	0.84	0.25
	2 Degrees	1.97	2.73	1.91
	3 Degrees	2.23	2.38	2.37
	4 Degrees	2.96	2.73	2.88

* = $p < .05$; ** = $p < .01$

GENERAL DISCUSSION

In the present study, we investigated the effects of prosopagnosia on regional differences in the processing of featural and configural face information. The Face Dimensions Test was developed to assess the sensitivity of participants to systematic changes in featural and configural information. After equating featural and configural discriminability with neurotypical individuals, this measure was administered to prosopagnosic individuals and age-matched control participants. It was found that relative to age-matched control participants, the patients performed normally in their ability to discriminate differences in the size and spacing of the mouth features. However, they were selectively impaired in their ability to detect featural and configural differences in the eye region whether tested in a perceptual (Experiment 1) or immediate memory (Experiment 2) task.

The foregoing results have several implications regarding the nature of prosopagnosia and its relevance to theories of normal face processing. First, the face deficits identified in our patients did not correspond to impairment of either featural or configural processes. Normal mouth performance for both configural and featural conditions demonstrates that these basic sensory and perceptual operations are essentially intact in both prosopagnosic patients. This result is somewhat surprising given that several studies have implicated impairment in configural processing as a source of face recognition deficits (Barton, Press, Keenan, & O'Connor, 2002; de Gelder & Rouw, 2000; Saumier, Arguin, & Lassonde, 2001).

Furthermore, the distinction between configural and featural processing has been highly influential in the development of normal face recognition theories. In fact, much of the research on face recognition involves attempts to dissociate these two processes. For example, inversion is thought to disproportionately disrupt configural processing of faces (Freire *et al.*, 2000; Leder & Bruce, 2000). However, inversion might have similar effects on configural and featural processing if the dimensions are matched for task difficulty (Malcolm *et al.*, 2004; Riesenhuber *et al.*, 2004; Yovel & Kanwisher, 2004).Consistent with this view, we found that brain-damaged individuals did not differ in their configural and featural judgments when the discriminations were equated in neurotypical populations. Although the computational requirements for featural and configural processing are unlikely to be identical, the finding that both featural and configural processing were impaired to an equal extent in the eye region suggests the existence of a mechanism that is common to both types of processes.

It has also been suggested that the perceived face configuration is more affected by vertical displacements of features than horizontal displacements. For instance, Barton and colleagues (2001; 2003) compared the sensitivity with horizontal displacement of the eyes separately from vertical displacement of the mouth. They observed larger decrements for mouth displacements, i.e. vertical relations, than eye displacements, i.e. horizontal relations. Goffaux and Rossion (2007) also found larger decrements of performance for vertical configural changes on the same feature, the eyes, than for horizontal changes. Paradoxically, we found that patients LR and HH were more sensitive to changes in vertical displacements between the nose and philtrum than horizontal displacements between the eyes.

The consistency of LR's and HH's pattern of spared and compromised face processes is perhaps the most intriguing aspect of the results presented here. It is significant that LR and HH did not demonstrate a global impairment of face-processing abilities, but exhibited a deficit that was restricted to the upper eye region of the face with normal sensitivity to information in the mouth region. The upper region deficit extended to judgments involving both featural and configural discriminations. This spatial limitation is not likely due to simple attentional neglect, as performance for the eye region improved for both participants when differences in the size and spacing of the eyes were sufficiently salient (as shown in Tables 1 and 2).

This finding corroborates the earlier results reported by Bukach *et al.* in which they found that LR showed intact perception of featural and configural discriminations of the mouth and impaired perception of the eyes. The present results extend these findings by showing that when the discriminability of the featural and configural information is equated, the patients are impaired in their processing of eye information. The mouth preference is also consistent with the study of prosopagnosic patient PS as reported by Caldara *et al.* (2005). Employing the Bubbles technique in which portions of the face are revealed at different spatial frequencies (Gosselin & Schyns, 2001), it was found that PS relied more heavily on the mouth and external contour regions for face recognition instead of the eye region. Here we report similar preserved mouth and impaired eye processing when viewing of an undegraded face shown in a simultaneous or sequential presentation format.

The recent prosopagnosic evidence demonstrating a preference for mouth information is paradoxical given that neurotypical individuals rely more on the eye features than the nose and mouth features during face recognition (Sergent, 1984; Tanaka & Farah, 1993; Walker Smith, 1978). The perceptual basis for this eye advantage has also been demonstrated using reverse correlation procedures that identified the eye regions as most diagnostic for both ideal and human observers (Sekuler, Gaspar, Gold, & Bennett, 2004; Vinette, Gosselin, & Schyns, 2004).

Why then do both prosopagnosic patients rely more heavily on information in the mouth region? It cannot be that eye changes in this particular task were perceptually more difficult to detect than mouth changes. Indeed, from a perceptual standpoint, normal participants showed a slight advantage in their ability to discriminate eye changes than mouth changes in the sequential version of the task. Nor can the mouth bias be explained by an upper visual-field deficit, because LR showed an upper-field advantage in another study using homogeneous novel objects and for inverted faces (Bukach *et al.*, 2006).

Several possibilities remain. One possibility is that the mouth bias is the consequence of impaired processing of information contained in the upper half of the face. It is feasible that information in the eye region (e.g. two eye features, the pupil, iris, and eyebrows) might be too visually complex for patients in which case resulting in a reliance on information in the sparser, lower mouth region. According to this account, the mouth preference is a simplifying strategy when patients have difficulty integrating information across the entire spatial extent of a face. Consistent with this view, 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).

A second possibility is that individuals with prosopagnosia may rely more heavily than normal on other types of information due to the dynamic motion information conveyed by the mouth (Knappmeyer, Thornton, & Bulthoff, 2003). Although we are unaware of any studies examining regional differences in the diagnosticity of dynamic motion, it is possible that movement in the mouth region may be particularly diagnostic for certain aspects of face processing, though it appears that this information alone is not sufficient for normal identification.

A third possibility is that the mouth bias may be due to impaired amygdala function. Although we have yet to uncover the nature of the neurological damage in HH, LR's CT scans reveal substantial damage to the right amygdala (Bukach *et al.*, 2006). A role for the amygdala has been implicated in detection of both eye-gaze (Kawashima *et al.*, 1999) and emotion information from the eyes (Morris, deBonis, & Dolan, 2002). Interestingly, a strong mouth bias has recently been demonstrated in a case of selective bilateral amygdala damage with selective impairment in detecting fear responses (Adolphs *et al.*, 2005). A mouth bias has also been shown in children with autistic disorders, a population who also has impaired amygdala function (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Although amygdala damage alone is unlikely to result in severe prosopagnosia (Adolphs, Tranel, Damasio, & Damasio, 1994), the amygdala may play an important functional role in directing attention to the eyes for further detailed processing.

In conclusion, this study illustrates the usefulness of the Face Dimensions Test as a diagnostic tool for identifying the impaired and preserved face processes of individuals with acquired prosopagnosia. This test revealed that patients exhibited preserved discrimination of information in the bottom mouth half of the face and impaired discrimination of information in the upper half of the face. Thus, the nature of prosopagnosia for patients LR and HH lies not in an impairment of their global perception of a face, but in a more selective, impaired processing of information in the eye region.

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References

Adolphs, R., Gosselin, F., Buchanan, T. W., Tranel, D., Schyns, P., & Damasio, A. R. (2005). A mechanism for impaired fear recognition after amygdala damage. *Nature*, *433*(7021), 68–72.

Adolphs, R., Tranel, D., Damasio, H., & Damasio, A. (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. *Nature*, *372*(6507), 669–672.

Bahrick, H. P., Bahrick, P. O., & Wittlinger, R. P. (1975). 50 Years of Memory for Names and Faces – Cross-Sectional Approach. *Journal of Experimental Psychology-General*, *104*(1), 54–75.

Barton, J. J., Cherkasova, M. V., Press, D. Z., Intriligator, J. M., & O'Connor, M. (2004). Perceptual functions in prosopagnosia. *Perception*, *33*(8), 939–956.

Barton, J. J., Keenan, J. P., & Bass, T. (2001). Discrimination of spatial relations and features in faces: effects of inversion and viewing duration. *British Journal of Psychology*, *92*, 527–549.

Barton, J. J., Deepak, S., & Malik, N. (2003). Attending to faces: Change detection, familiarization, and inversion effects. *Perception*, *32*(1), 15–28.

Barton, J. J., Press, D. Z., Keenan, J. P., & O'Connor, M. (2002). Lesions of the fusiform face area impair perception of facial configuration in prosopagnosia. *Neurology*, *58*, 71–78.

Benton, A. L., Hamsher, K. deS., Varney, N. R., & Spreen, O. (1983). *Contributions to neuropsychological assessment*. New York: Oxford University Press.

Bruce, V. (1988). *Recognizing faces*. London: Erlbaum.

Bukach, C. M., Bub, D. N., Gauthier, I., & Tarr, M. J. (2006). Perceptual expertise effects are not all or none: Spatially limited perceptual expertise for faces in a case of prosopagnosia. *Journal of Cognitive Neuroscience*, *18*(1), 48–63.

Caldara, R., Schyns, P., Mayer, E., Smith, M. L., Gosselin, F., & Rossion, B. (2005). Does prosopagnosia take the eyes out of face representations? Evidence for a defect in representing diagnostic facial information following brain damage. *Journal of Cognitive Neuroscience*, *17*(10), 1652–1666.

Carey, S. (1992). Becoming a face expert. *Philosophical Transactions Royal Society of London B*, *335*, 95–103.

Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *Clinical Neuropsychologist*, *12*, 482–486.

de Gelder, B., & Rouw, R. (2000). Paradoxical configuration effects for faces and objects in prosopagnosia. *Neuropsychologia*, *38*, 1271–1279.

Diamond, R., & Carey, S. (1986). Why faces are not special: An effect of expertise. *Journal of Experimental Psychology: General*, *115*, 107–117.

Freire, A., Lee, K., & Symons, L. A. (2000). The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception*, *29*(2), 159–170.

Goffaux, V. & Rossion, B. (2007). Face inversion disproportionately impairs the perception of vertical but not horizontal relations between features. *Journal of Experimental Psychology Human Perception and Performance*, *33*(4), 995–1002.

Gosselin, F., & Schyns, P. G. (2001). Bubbles: A technique to reveal the use of information in recognition tasks. *Vision Research*, *41*(17), 2261–2271.

Kawashima, R., Sugiura, M., Kato, T., Nakamura, A., Hatano, K., Ito, K., *et al.* (1999). The human amygdala plays an important role in gaze monitoring – A PET study. *Brain*, *122*, 779–783.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry*, *59*(9), 809–816.

Knappmeyer, B., Thornton, I. M., & Bulthoff, H. H. (2003). The use of facial motion and facial form during the processing of identity. *Vision Research*, *43*, 1921–1936.

Leder, H., & Bruce, V. (2000). When inverted faces are recognized: The role of configural information in face recogntion. *Quarterly Journal of Experimental Psychology A*, *53*, 513–536.

LeGrand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2001). Early visual experience and face processing. *Nature*, *410*, 890.

Levine, D. N., & Calvanio, R. (1989). Prosopagnosia: A defect in visual configural processing. *Brain and Cognition*, *10*, 149–170.

Malcolm, G. L., Leung, C., & Barton, J. J. (2004). Regional variation in the inversion effect for faces: Differential effects for feature shape, feature configuration, and external contour. *Perception*, *33*(10), 1221–1231.

Marascuilo, L. A. (1970). Extensions of the significance test for one-parameter signal detection hypotheses. *Psychometrika*, *35*, 237–243.

Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception*, *31*(5), 553–566.

Morris, J. S., deBonis, M., & Dolan, R. J. (2002). Human amygdala responses to fearful eyes. *Neuroimage*, *17*(1), 214–222.

Riesenhuber, M., Jarudi, I., Gilad, S., & Sinha, P. (2004). Face processing in humans is compatible with a simple shape-based model of vision. *Proceedings of the Royal Society of London B*, *271*, S448–S450.

Saumier, D., Arguin, M., & Lassonde, M. (2001). Prosopagnosia: A case study involving problems in processing configural information. *Brain and Cognition*, *46*, 255–259.

Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J. (2004). Inversion leads to quantitative, not qualitative, changes in face processing. *Current Biology*, *14*(5), 391–396.

Sergent, J. (1984). An investigation into component and configural processes underlying face perception. *British Journal of Psychology*, *75*, 221–242.

Sergent, J., & Signoret, J. L. (1992). Functional and anatomical decomposition of face processing: Evidence from prosopagnosia and PET study of normal subjects. *Philosophical transactions of the Royal Society of London B*, *335*, 55–62.

Sergent, J., & Villemure, J. G. (1989). Prosopagnosia in a right hemispherectomized patient. *Brain*, *112*(Pt 4), 975–995.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology [Human Learning]*, *6*(2), 174–215.

Tanaka, J. W. (2001). The entry point of face recognition: Evidence for face expertise. *Journal of Experimental Psychology: General*, *130*, 534–543.

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *Quarterly Journal of Experimental Psychology, 46A*, 225–245.

Tanaka, J. W., Kaiser, M., & Bub, D. (in preparation). Comparing apples and oranges: The role of featural and configural information in face recognition.

Tarr, M. J., & Williams, P. (1996). RSVP: A software package for experimental psychology using the Apple Macintosh OS: Department of Cognitive and Linguistic Sciences, Brown University, Providence, RI.d.

Vinette, C., Gosselin, F., & Schyns, P. G. (2004). Spatio-temporal dynamics of face recognition in a flash: It's in the eyes. *Cognitive Science*, *28*(2), 289–301.

Walker Smith, G. J. (1978). The effects of delay and exposure duration in a face recognition task. *Perception and Psychophysics*, *24*(1), 63–70.

Warrington, E. K. (1984). *Warrington Recognition Memory Test*. Windsor (UK): NFER-Nelson.

Warrington, E. K., & James, M. (1991). A new test of object decision: 2D silhouettes featuring a minimal view. *Cortex*, *27*(3), 370–383.

Wolf, J., Tanaka, J., Klaiman, C., & Schultz, R. (2006). *A computer-based battery to test the face processing skills of children with autism*. Paper presented at the International Meeting for Autism Research, Boston, MA.
Yovel, G., & Kanwisher, N. (2004). Face perception: Domain specific, not process specific. *Neuron*, *44*, 889–898.

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Appendix
List of famous names used in the famous face-sorting task

(1) Tony Blair
(2) George W. Bush
(3) Marlon Brando
(4) Humphrey Bogart
(5) Jimmy Carter
(6) Jean Chrétien
(7) Bill Clinton
(8) Hillary Clinton
(9) Winston Churchill
(10) Prince Charles
(11) Tom Cruise
(12) Princess Diana
(13) Elvis Presley
(14) Albert Einstein
(15) Clint Eastwood
(16) Harrison Ford
(17) Bill Gates
(18) Wayne Gretzky
(19) Tom Hanks
(20) Bob Hope
(21) Mick Jagger
(22) John F. Kennedy
(23) Paul McCartney
(24) Marilyn Monroe
(25) Brain Mulroney
(26) Paul Martin
(27) Richard Nixon
(28) Dolly Parton
(29) Pope John Paul II
(30) Elizabeth Queen of England
(31) Ronald Regan
(32) Frank Sinatra
(33) Arnold Schwartzenegar
(34) Margaret Thatcher
(35) Pierre Trudeau