

# A comparative case study of face recognition: The contribution of configural and part-based recognition systems, and their interaction

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## ABSTRACT

Understanding the interaction between the configural and part-based systems in face recognition is the major aim of this study. Specifically, we established whether configural representation of faces contribute to aspects of face recognition that depend on part-based processes, such as identifying inverted or fractured faces. Using face recognition tasks that require part-based or configural processing, we compared the results of CK—a man who has object agnosia and alexia [Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience*, 9(5), 555–604] but normal upright face recognition, to those of DC—a man who has prosopagnosia but normal object recognition. CK was normal at recognizing faces if configural processing was sufficient, but poor at recognizing faces that were modified so as to alter their gestalt, and require part-based processing (Moscovitch et al.). DC was impaired at recognizing upright faces and his performance declined in all tasks involving recognition of modified faces, including those that depend on part-based and on configural processing. Nevertheless, DC was normal on tasks involving perception of generic faces and face imagery. These results show that although configural face perception can proceed without part-based processing, the reverse is not the case. Our results suggest that the configural system is always necessary for face recognition, and appears to support what remains of face identification even in prosopagnosic people who have an intact part-based system.

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## 1. Introduction

It has long been known that a double dissociation exists between recognition of faces and objects, such that some individuals are impaired in one but not the other. Some investigators have ascribed the source of this double dissociation to dissociation between configural and part-based processing with the former implicated primarily in face recognition and the latter in non-expert object recognition. Despite this possible dissociation, it is known that both configural and part-based processes can contribute to different aspects of face recognition. It is not known, however, whether there is a double dissociation between the configural and part-based face processing in face recognition. To address this question, we assessed

configural and part-based aspects of face recognition in a man with acquired prosopagnosia, DC, and compared his performance to that of an already well-known agnosic individual, CK who has great difficulty recognizing objects and words. CK has dissociation between configural face recognition and part-based face recognition, being normal at the former but impaired at the latter. Whether DC shows the reverse dissociation will be determined. Before addressing a possible dissociation and/or interaction between the part-based and configural face processing, a definition of each is here provided.

Part-based processing typically is conceived as dependent on piecemeal analysis of stimulus features and their subsequent integration. By contrast, configural processing is concerned with the particular relation that features bear to one another, as much as on the features themselves. Configural processing leads to the formation of a holistic or gestalt representation of the stimulus such that the parts or features are integrated into the whole structure of which they are a part, making it difficult to process and recognize any feature in isolation. Our study is based on the distinction between these two types of processes, though we are aware that their precise characterization remains a matter of debate. McKone (2004) believes that configural processing is “what makes faces

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special" (p. 193), that it occurs in parallel to part-based face processing, and that within it, the whole face has an entity greater than the sum of its parts (e.g. McKone, 2004; McKone, Martini, & Nakayama, 2003). Maurer, Le Grand, and Mondloch (2002) state that configural processing is divided into three types: "(1) sensitivity to first-order relations—seeing a stimulus as a face because its features are arranged with two eyes above a nose, which is above the mouth; (2) holistic processing—glueing together the features into a gestalt; and (3) sensitivity to second-order relations—perceiving the distances among features". (p. 255). McKone believes that the nature of configural processing is probably holistic more than relational.

For the purpose of this paper, there is no reason to distinguish among the various types of configural processing or representations. (Our view will be described in light of our results in Section 4.) Indeed, we do not examine the nature of part-based and configural/holistic processing in our paper, but rather use these serviceable definitions to characterize the operation of face and object-recognition systems. We begin with the assumption that recognition of upright faces that retain their normal configuration are processed configurally or holistically, whereas recognition of objects of which we are not expert is part-based. The question we ask is what processes are needed to recognize faces that depart from their typical configuration and orientation? Previous studies have shown that under many such circumstances, recognition of faces is also dependent on part-based processing; we do not know, however, whether it also relies on access to intact configural processes or representations. In particular, we wish to determine whether part-based face processing is dissociable and independent from configural processing, and, if so, what is the nature of the interaction between them. In the end, we speculate whether the part-based analysis involved in face recognition is the same as the one involved in object recognition.

CK is an integrative object agnostic and a pure alexic or letter-by-letter reader. His deficits in the two domains resemble one another in that he has difficulty integrating parts into a whole: He can draw the very pictures he cannot identify perceptually, and write the words he cannot read normally. His face recognition was studied extensively by Moscovitch, Winocur, and Behrmann (1997) and by Moscovitch and Moscovitch (2000) to determine what effect damage to the part-based system involved in object and word recognition had on recognition of faces. They found that CK could recognize intact, upright faces normally, but was disproportionately impaired in recognizing faces that were inverted or "fractured" by breaking the facial gestalt. Based on these results, they concluded that recognition of those types of face stimuli depend on the part-based system needed for recognizing objects and words.

It is not known, however, whether part-based processing of these non-configural face stimuli is sufficient for recognition, or whether it always needs to be supplemented by configural processing. Using many of the same face recognition tasks performed by CK, we now compare his results to DC—a prosopagnosic man with intact object and word recognition. Studying different aspects of the face recognition of a patient with prosopagnosia will allow us to determine the limits of face recognition when it depends only on part-based processes needed for object and word recognition. All tasks administered to DC are also administered to age- and education-matched controls.

Studies with CK, a person with preserved upright face recognition, but with visual object agnosia and pure alexia, and with normal people indicate that recognition of upright, intact faces can be accomplished by relying on configural information without recourse to processing information about individual parts separately (see McKone, 2004; McKone et al., 2003, for a summary). McKone and colleagues concluded that not only is configural processing essential to upright face recognition, it can also be sufficient.

The question remains whether part-based processing can be sufficient for recognizing faces lacking their full gestalt (e.g. inverted, fractured) or does it ultimately depend on gaining access to a recognition system that represents faces configurally? In other words, can part-based face recognition, as it is believed to occur in prosopagnosia or in normal people when faces are inverted or their gestalt is altered, be accomplished without recourse to internal configural representation or processing?

Using perceptual, face-matching tasks, a number of investigators noted that people with prosopagnosia, whose configural processing is impaired, perform better with faces whose configuration is altered by inversion or other means, than with upright, intact faces (e.g. Boutsen & Humphreys, 2002; de Gelder & Rouw, 2000a; Delvenne, Seron, Coyette, & Rossion, 2004). The implication is that for perceptual face matching, part-based processing is sufficient. Matching faces, however, is different from recognizing or identifying them. The former can be accomplished by comparing features, whereas the latter typically cannot. Here, we wish to test the limits of part-based processing in face recognition or identification.

There are reasons to believe that configural processing is always needed for identification, except in those rare cases in which a feature or combination of features uniquely distinguishes one individual from all others. de Gelder and Rouw (2000b) suggest that, even when inefficient, configural processing can be invoked by upright, intact faces and will interfere with part-based processing. Moreover, studying the effects of inversion in a series of visual search tasks, Murray (2004) showed that "although inversion disrupts holistic encoding of configural information, inverted faces retain some information about configuration that prevents immediate access to individual feature information, even when constituent information is all that is required by the task." (p. 395). She concluded that, in "intact" observers, some information is encoded holistically even for inverted faces. More evidence is needed, however, to support the hypothesis that normal part-based face-recognition system typically depends on interaction with a configural face system.

Moscovitch et al. (1997) noted that, when identification or recognition is required rather than perceptual matching, prosopagnosic individuals, without object agnosia (e.g. Bauer, 1984; Farah, 1990; Farah, Levinson, & Klein, 1995) typically perform more poorly than healthy controls even with inverted or fractured faces—stimuli that primarily require part-based analysis. They fare much worse than the 60–80% accuracy typically achieved by neurologically intact participants on part-based face-processing tasks. A parsimonious explanation is that in normal people, the part-based system must be interacting continuously with the configural face system to support a level of performance that far exceeds that in prosopagnosic people whose face configural system is damaged (Moscovitch & Moscovitch, 2000).

Thus, results from studies of healthy controls and prosopagnosic people converge on the same conclusion: on its own, part-based processing does not lead to normal or efficient face recognition. Indeed, recognizing inverted faces, scrambled faces, faces misaligned along the horizontal mid-line, and faces with other altered configurations, is slow and less accurate for normal individuals than recognizing intact upright faces. And from previous observations, it is proposed that prosopagnosic people will do even worse than normal people on part-based face recognition.

The exact nature of an interaction between the part-based and configural face recognition systems, however, is unclear and needs investigation. A few theories on face recognition suggest that the configural and part-based systems are constantly interacting to lead to normal recognition of both upright and altered faces (de Gelder & Rouw, 2000b, 2000c; Moscovitch & Moscovitch, 2000). Moscovitch and Moscovitch (2000) propose an interactive-activation model in which the part-based system forms a representation of a face based

on parts and local relations. This facial counterpart of the configural representation interacts with an internal representation of the latter to achieve a proper identification of the altered face. Thus, face identification, but not face matching, depends on part-based information having access to internal, configural representations and interacting with them (even when ill-functioning).

Our study will shed light on these issues by examining the performance of a pure prosopagnosic man (DC) at face recognition tasks that depend primarily either on configural or part-based processing (e.g. inverted, fractured, split faces). Decreased performance in DC, whose configural face-processing system is damaged, in comparison to controls on tasks that require part-based processing, would indicate that even part-based face recognition relies on an interaction between the part-based and configural systems. It would rule out the possibility of a double dissociation between the configural and part-based face-processing system.

To address these issues, we documented DC's recognition abilities including his recognition of upright individual faces and his recognition of categorical objects. To determine whether part-based face processing ever is sufficient for face recognition we compared DC (and his age- and education-matched controls) to CK (and his controls) on different aspects of face recognition, some of which require part-based face processing (Set 1), and some for which configural face processing is sufficient (Set 2). In order to rule out the possibility that DC's recognition impairment is mainly due to poor internal long-term representation of faces, his mental imagery of faces and categorical objects is evaluated (Set 3), as is his ability to process and represent generic faces to determine whether first-order representations are preserved (Set 4). Following this diagnostic procedure allows us infer the nature of face representations and processing in DC and what, if any, interactions there are between the configural and part-based systems.

## 2. Method

### 2.1. Participants

Because DC is the focus of this paper, his case presentation is given in detail, and it is followed by a summary of CK's.

#### 2.1.1. DC: prosopagnosic individual

**2.1.1.1. Case history.** DC was born in 1948. He has the equivalent of 15 years of education, and worked as a detective for the homicide division of a Police Force between 1976 and 1997. He now is on disability. He participated in our study in 2000.

In 1996, DC was found to have a colloid cyst in the third ventricle that was obstructing both foramina of Monro. This obstruction led to hydrocephalus and increased intracranial pressure. In addition, structural MRI showed evidence of a bilateral posterior cerebral artery infarction. He had a surgical shunt, a craniotomy and a resection of the cyst.

Shortly after his surgery, DC mainly complained of fatigue, and of not recognizing faces. In addition, he mentioned: "colors were too vibrant". He lacked sensation (or experienced hyper-sensitivity) on both his left arm and leg, and his left hand sometimes had "a mind of its own" where it would act in opposition to his right hand. He had a mild gait disturbance. DC went on working disability but continued to take care of his personal, familial, and financial activities. At the time of his full neuropsychological assessment (1998), and participation in this research (2000), DC did not report the alien-hand syndrome, or difficulties with his color vision. He was actively engaged in doing physiotherapy to regain his physical strength. He continued complaining of face recognition difficulties.

**2.1.1.2. Brain imaging.** Magnetic Resonance Imaging (1997) was obtained with a 1.5-T MR unit (Signa, General Electric Medical Systems, Milwaukee, WI). Magnetic resonance scanning was conducted using a spin echo sequence (TR/TE 2000/30–80), which yields 48 3 mm thick interleaved slices. A T1-weighted 3D volumetric sequence (TR/TE 5/24/1, 35° flip angle and 1.3 mm slice thickness) was also performed. 3D-MRI was realigned parallel to the anterior–posterior commissure line [1] using ANALYZE AVW™ Software (Biomedical Imaging Resource, Mayo Foundation, Rochester, MN) on a Sun workstation (Sun Microsystems, Mountain View, CA).

Lesion localization was determined in Talairach space (Talairach & Tournoux, 1988) from AC-PC aligned 3D-MRI. T1-weighted and spin echo images showed bilateral medial occipital lesions with enlargement of the adjacent lateral ventricles, consistent with encephalomalacia. The bilateral occipital lesions involved most of lingual gyrus, Brodmann Area (BA) 18 and 19 (Fig. 1). The right frontal white matter

damage from the surgical intervention subtends BA 8 and also includes BA 32. After the 3D-MRI was realigned parallel to the long axis of the hippocampus (Gao et al., 2003) producing a longitudinal view of the temporal lobe structures, encephalomalacia was also found in the right fusiform gyrus, BA 36. The right fusiform gyrus was also extremely shrunken, compared to the left.

**2.1.1.3. General intellectual capacities and memory.** DC's verbal and non-verbal intelligence [Wechsler Adult and Intelligence Scale-III (WAIS-III); Verbal and Performance subtests] is superior. While being accurate on all performance subtests, DC has borderline speed of processing (WAIS-III). His verbal and visual memory is average to high average (California Verbal Learning Test, and Rey-Osterrieth Complex Figure test recall, respectively).

**2.1.1.4. Visuo-spatial, perceptual and reading abilities.** Except for having a limited visual field, DC has normal visuo-perceptual abilities. His Goldman perimetry test shows superior field losses with macular sparing. His neuro-ophthalmology examination shows normal eye exam, normal acuity, normal retinal exam, and normal color vision (confirmed by our evaluation with the Farnsworth-Munsell 100 Hue-test). His conceptual visual reasoning (WAIS-III; Matrix Reasoning subtest), and his visuo-constructional skills (WAIS-III; Block Design, Object assembly subtests; ROCF copy) are high average. His space perception is very superior [Perfect scores all space perception subtests of the Visual Object and Space Perception Battery (VOSP); Judgement of Line Orientation; Symbol cancellation]. His object perception is normal (average performance in the VOSP, Object Perception subtests; and in the Hooper Visual Organization Test; very superior performance in the Boston Naming Test). (DC's recognition of buildings and dogs was assessed in details; it is normal. The results are presented later in the paper.) His reading is normal (Wide Range Achievement Test).

#### 2.1.2. CK: object agnostic and alexic individual

CK was born in 1962. He suffered from a closed-head injury after being hit by a car while jogging. Following his insult, he could no longer recognize objects and words, but remarkably could recognize upright familiar faces; he had object agnosia and alexia but no prosopagnosia. His insult led to bilateral thinning of the occipito-temporal region. CK has about 16 years of education; he completed his M.A. degree after incurring brain damage. Since graduating, he has held a position in a government ministry that requires a high-level of responsibility. Except for a scotoma in the upper, right visual field, CK's visual acuity, and his other perceptual abilities are normal. Indeed, he can copy and draw from memory objects he cannot identify visually. CK is classified as having an integrative visual object agnosia (Riddoch & Humphreys, 1987) presumably related to an impairment of part decomposition and synthesis (Farah, 1990) (for more details, see description in Behrmann, Moscovitch, & Winocur, 1994; Behrmann, Winocur, & Moscovitch, 1992, and Moscovitch et al., 1997).

#### 2.1.3. Age- and education-matched controls

DC's performance on all face recognition tasks is compared to that of four age- and education-matched neurologically intact males [(one is his brother); mean age: 53.4 years old, S.D.: 2.2; mean years of education: 16.0, S.D.: 2.1]. DC's recognition of objects and imagery were compared to that of nine different age- and education-matched neurologically intact individuals [seven males (one is his brother), two females mean age: 52.3 years old, S.D.: 2.3; mean years of education: 15.3 years, S.D.: 2.2].

The results of CK are compared to those of 12 age- and education-matched neurologically intact individuals (six males and six females). All were assessed by Moscovitch et al. (1997).

## 2.2. Ethics

All participants provided written informed consent to be part of this study, which was approved by the Research Ethics Committee of the Office of Research Services at York University, and at the University of Toronto.

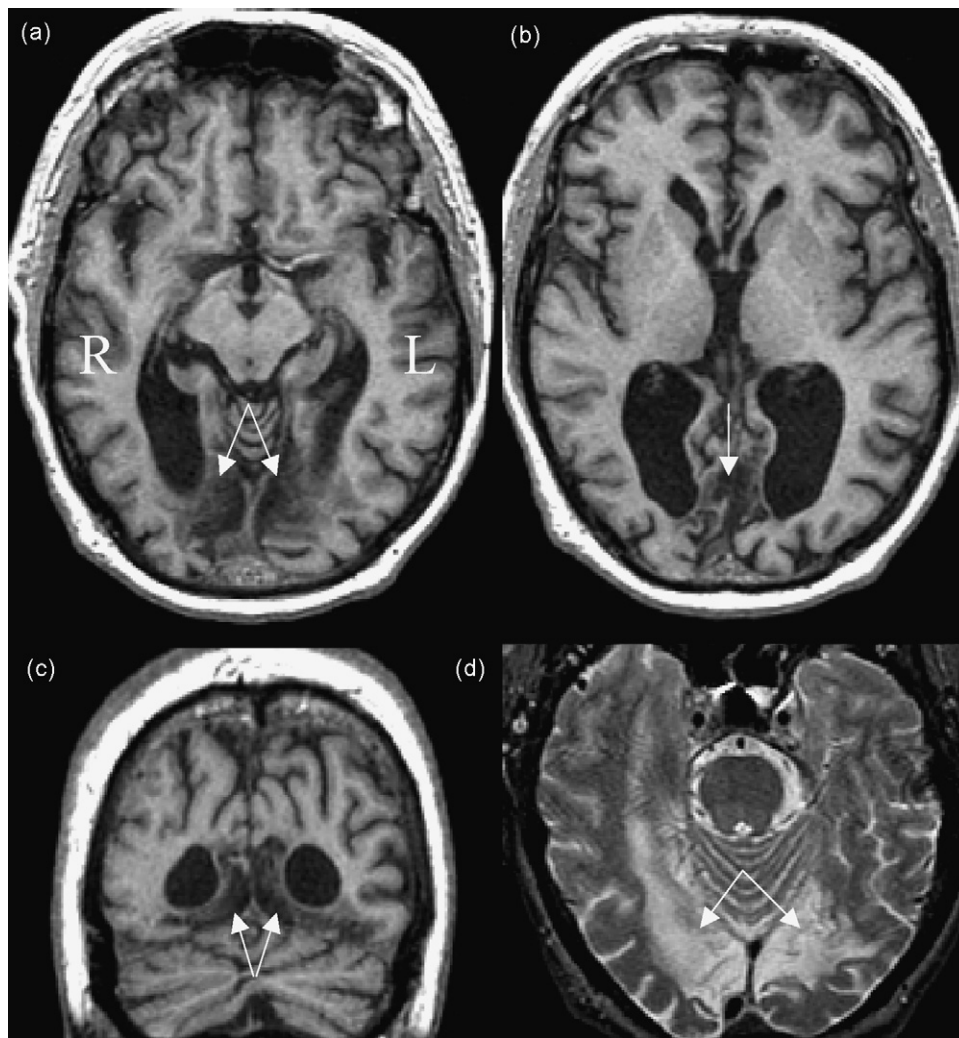
### 2.2.1. Recognizing faces of famous people

Seventy different color photographs of famous actors, politicians, and athletes (pictures from Set A from Moscovitch et al., 1997) were presented. In all face recognition tasks, participants are asked to identify the persons whose face is shown by either providing their names or giving important facts about them so that there is no doubt as to whether they recognize the individual or not. Participants were given 10 s to identify each picture. All participants were tested individually. See details about the procedure and stimuli in Moscovitch et al. (1997).

DC's results show an impairment of upright face recognition. DC recognized 26 faces out of 70 whereas, on average, controls recognized 52.75 out of 70 (S.D.: 5.63; range 47–62). Clearly DC's performance is impaired ( $z = -4.75$ ) showing that his face recognition system is damaged.

CK's recognition of upright faces (mean: 53;  $z = -0.08$ ) is not different from that of normal control group (mean: 54; S.D.: 13; range: 33–68) (Behrmann et al., 1994; Behrmann et al., 1992; Moscovitch et al., 1997). These results show that his severe recognition deficits for objects and words do not extend to upright face recognition. They suggest that the configural face system is sufficient for upright face recognition.





**Fig. 1.** DC's brain images. (a and b) Axial 3D-T1-MR images parallel to the AC-PC line and (c) A coronal section perpendicular to the AC-PC line. They showed bilateral lesions in the lingual gyri, BA 18 and 19 (arrows). (d) T2-weighted MR axial image that showed hyperintensity bilaterally in the medial occipital regions in the posterior cerebral artery territory (arrows).

### 2.2.2. Matching faces from different views and under different lighting conditions

We administered *The Face Recognition Test*, developed by Benton and van Allen (1973 and Benton, Hamsher, des Varney, and Spreen (1978). In this test, participants must match faces either under the same viewing conditions as the targets, or under different orientation and illumination.

DC's result [scaled score (SS): 40] is at the 2nd percentile (borderline impaired) compared to norms, and is impaired ( $z = -3.18$ ) compared to that of his matched controls (mean SS: 51; S.D.: 3.46; range: 47–53). DC could match faces presented under identical viewing conditions at 83.3% accuracy, and faces presented under different orientation, and lighting at 72.9% accuracy. These findings are consistent with those from a recent study showing that DC's face discrimination was also worse when trying to match faces across different orientations (Lee, Wilson, & Rivest, 2003).

The results of CK are from Behrmann et al. (1994). CK performed (SS: 49) slightly above neurologically intact individuals (mean SS: 45.6).

In sum, CK appears to represent faces normally and use this information in discriminating one face from another under all conditions, whereas DC is impaired once reliance on sensory matching does not suffice.

### 2.2.3. DC's recognition of sub-ordinate objects (exemplars) in a category

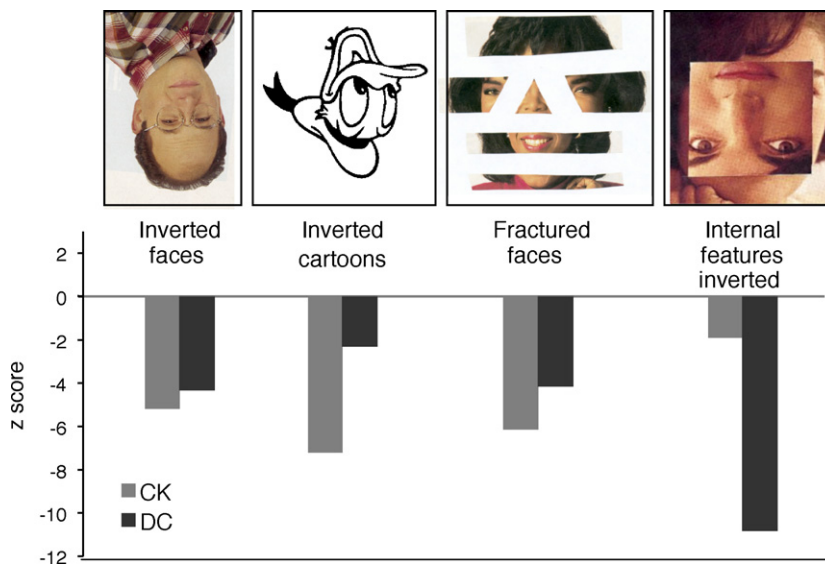
Whether DC's impairment at recognizing faces represents a general difficulty at recognizing different objects within a larger category was tested next. People with a problem of individuation of sub-ordinate stimuli that has many exemplars will likely exhibit the same symptoms as a pure prosopagnosic individual when tested on face recognition (e.g. Damasio, Tranel, & Damasio, 1990). It is still a matter of controversy whether the association of deficits in face and non-face domains always holds and, in particular, whether the reverse is true—namely impaired face recognition with relatively preserved individuation in other domains. There are reports of profoundly prosopagnosic patients who have no problem recognizing other sub-ordinate objects, such as animals or cars (De Renzi, 1986a, 1986b; Farah, Levinson, et

al., 1995; McNeil & Warrington, 1993; Sergent & Signoret, 1992). The reverse is also true; some patients cannot recognize some sub-ordinate objects other than faces, but have no difficulty with faces per se (e.g. Assal, Favre, & Anderes, 1984; Moscovitch et al., 1997).

In order to evaluate whether DC's impairment at recognizing faces represents a general difficulty at recognizing different objects within a larger category, we tested whether he could recognize different dog breeds and different famous buildings from around the world. These two categories of objects are most well known to DC. He is a dog owner and has a genuine interest in different dog breeds. In addition, dog breed stimuli are orientation specific, have faces and specific features. Buildings have been used as a standard control stimulus in research on face perception (e.g. Avidan, Hasson, Malach, & Behrmann, 2005; O'Craven & Kanwisher, 2000) because, like faces, they are always perceived in the same upright orientation, almost always present the same key features (e.g. windows and doors) more or less arranged in a similar configuration, and they are identified at an individual level.

Pictures of the 30 most common dog breeds (as published by the American Kennel Club Top 150 Most Popular Dog Breeds, [www.akc.org/breeds/regstats2001.cfm](http://www.akc.org/breeds/regstats2001.cfm), 2002, and of the top 30 most popular buildings, as voted by users on the [www.greatbuildingsonline.com](http://www.greatbuildingsonline.com), 2003) were selected, and shown to DC and nine age- and education-matched neurologically intact individuals (one is DC's brother). They were asked to identify the dog breed and the buildings. If they did not know the exact name of the stimuli, they were asked whether they could give information (e.g. the location, the use) that would help clarify whether the participant recognized the stimuli. All items presented were known to the participants.

DC recognized 68% of the different dogs and buildings [controls recognized an average of 75% (S.D.: 15%, range: 43–91%), and an average of 79% (S.D.: 12%, range: 56–93%), respectively]. Thus, his results are not significantly different from that of controls (i.e.  $z = -0.47$ , and  $-0.92$ , respectively). These results show that DC's recog-



**Fig. 2.** Comparative recognition performance (z score) of CK and DC at the face recognition tasks in which the stimuli did not preserve configural information. For each task, an example of a stimulus is provided, and the z score is calculated using the percentages of modified faces correctly recognized calculated from the ratio of the number of modified faces correctly recognized over the number of corresponding upright faces correctly recognized. From left to right, the examples of stimuli are Jason Alexander, Donald Duck, Oprah Winfrey, and Jacqueline Kennedy.

tion impairment is restricted to faces and does not extend to exemplars of other complex visual categories.

Next, we looked at whether his face recognition when depending on part-based processing would also be normal or whether it would be impaired. If it exclusively depends on the part-based object system, it should be normal, and certainly not worse than his upright face recognition, since DC's object recognition is normal even at identifying within-category exemplars.

### 3. Set 1: recognizing modified faces that do not preserve internal, configural relations, and their processing

We already know that CK, having visual agnosia and pure alexia indicative of a part-based damaged system, is impaired at the part-based face recognition tasks (Moscovitch et al., 1997). The question we wished to address is whether DC, who is prosopagnosic but recognizes objects and reads normally, will recognize these modified faces normally relative to his upright face recognition. If intact object and word recognition is sufficient for processing on these part-based face recognition tasks, DC's performance should be normal. If, however, recognition of these modified faces also requires interaction with the configural face system, then DC should be impaired.

DC and CK's standardized results for all tasks related to faces that do not preserve their configural information are summarized in Fig. 2. Participants always saw the modified faces before they saw their corresponding upright and intact faces. First, the participants tried to recognize all modified faces, and second, they tried to identify them when presented upright and unmodified. Once the two tasks were completed, the trials related to the faces that were never identified (neither when upright, nor when modified) were removed from the modified faces tasks. This was done in order to make sure that the performance at recognition of modified faces was always compared to correct recognition of upright faces. Details about each task and the results follow in the text.

#### 3.1. Recognizing inverted faces of famous people and inverted faces of cartoons

CK, DC, and controls were asked to identify the faces of 70 famous people whose photos were inverted. They were also asked to identify 31 famous inverted cartoons faces, such as Mickey Mouse's (see

examples in Moscovitch et al., 1997). If a face was not recognized when inverted and when upright, the result to the inverted face was dismissed. If only the part-based system drives his upright face recognition, and if the part-based system alone determines inverted face recognition, DC's impairment with inverted faces should not exceed his performance with upright faces.

CK is impaired at recognizing inverted faces ( $z = -5.18$ ). When inverted, CK recognized 14% of the 53 famous people faces that he identified when upright. [Controls recognized an average of 71% (S.D.: 11%, range: 42–82%) of the average of 54 famous people faces that they identified when upright.] Likewise, on inverted cartoons, CK recognized 17% out of the 30 faces that he identified when upright. [Controls recognized 96% (S.D.: 11%) out of the average of 28 (S.D.: 2.6; range: 23–31) cartoons faces that they identified when upright]. He clearly is impaired at recognizing inverted face cartoons ( $z = -7.2$ ).

When faces were inverted, DC recognized 9.1% of the 26 famous people faces that he identified when upright [controls recognized 52% (S.D.: 10%) out of the average of 53 (S.D.: 6.5) faces that they identified when upright]. When cartoons were inverted, however, DC recognized 75% out of the 27 cartoons faces that he identified when upright [controls recognized 90.8% (S.D.: 7.0%) out of the average of 27 (S.D.: 3.0) cartoons faces that they identified when upright]. DC who has no difficulty recognizing objects, or words, is impaired at recognizing inverted faces ( $z = -4.29$ ), and inverted cartoons ( $z = -2.26$ ), over and above his deficit in recognizing upright faces (see results in Fig. 2).

DC's results suggest that recognition of inverted natural, and cartoon faces, does not involve the object part-based recognition system exclusively. His performance suggests that, most likely, inverted face recognition depends on the interaction between the object-recognition system and the recognition system for upright, intact faces (e.g. Moscovitch & Moscovitch, 2000). If this is the case, DC should also be impaired on other part-based face recognition tasks. This possibility is assessed in the next tasks.

#### 3.2. Recognizing faces with their internal features inverted, and fractured faces

Recognition of faces with their internal features inverted (Gauthier, Skudlarski, Gore, & Anderson, 2000; Young, Hay,

McWeeney, Flude, & Ellis, 1985; Young, Hellawell, & Hay, 1987), and fractured faces, has been attributed to a part-based approach (Moscovitch & Moscovitch, 2000; Moscovitch et al., 1997). Indeed, it has been postulated that neurologically intact individuals have difficulty recognizing fractured faces because they must rely on a part-based approach. Without access to his part-based system, CK is worse than controls at these tasks. CK correctly recognized 34 upright faces out of 40; he correctly recognized only 38% of them when fractured ( $z = -6.14$ ). His controls correctly recognized an average of 33.1 (S.D.: 6.8; range 21–39) upright faces out of 40; they recognized an average of 81% (S.D.: 7.0%; range 68–92%) of them correctly when fractured. CK correctly recognized eight upright faces out of 11; he correctly recognized only one of them when their internal features were inverted ( $z = -1.9$ ). His controls correctly recognized nine (S.D.: 2.2; range: 4–11) upright faces out of 11; they correctly recognized six of them (S.D.: 2.7; range: 3–11) when their internal features were inverted. These results confirmed that the upright face recognition mechanism is most sensitive to internal face features, and their spatial relationship, even when the first-order relation (arrangement among the forehead, eyes, nose, mouth and chin) is retained among the features.

The results of CK were compared to those of DC on tasks requiring recognition of fractured faces and faces with their internal features inverted. If the part-based system is self-sufficient at performing these tasks, DC should perform normally on the tasks conditional upon upright face recognition. If, however as results from the previous experiment suggested, normal performance depends on an interaction between a part-based and configural face-recognition systems, DC should be impaired.

DC correctly recognized 21 upright faces out of 40; he correctly recognized 29% of 21 when the faces were fractured. His controls correctly recognized an average of 33.8 (S.D.: 4.8) upright faces out of 40; when fractured, they correctly recognized an average of 69.8% of the 33.8 (S.D.: 9.9). DC is impaired at recognizing fractured faces ( $z = -4.12$ ). DC correctly recognized four upright faces out of 11; he did not recognize any of them when their internal features were inverted. His controls correctly recognized 9.8 (S.D.: 0.5) upright faces out of 11; they correctly recognized 6.5 of them (S.D.: 0.6) when their internal features were inverted. Since DC recognized none of the four upright faces when their internal features inverted ( $z = -10.8$ ), it is concluded that he is impaired at recognizing faces with inverted internal features (see results in Fig. 2). These results suggest that although recognition of these modified faces is challenged when the part-based object-recognition system is damaged, an intact part-based recognition system alone is not sufficient for normal performance. Instead, it needs to interact with an intact system for configural face recognition if performance is to be fully normal and efficient.

#### 4. Set 2: recognizing modified faces that preserve internal, configural relations, and their processing

Moscovitch et al. (1997) showed that CK not only recognized upright familiar faces normally, but also those faces that have been modified by procedures that preserved the configuration of internal features, and could be processed configurally. These included inversion of external features, adding disguises, such as fake moustache, misaligning faces along a vertical axis, caricaturing them, and deleting a single feature, such as the eyes or nose. Moscovitch et al. postulated that because these modifications preserved internal configurations and allowed them to be processed configurally, they are mostly mediated by CK's preserved face-recognition system.

We administered these faces to DC to determine the limits of the face-system and object-recognition system. Since DC is impaired

at recognizing even upright faces; he should be impaired, but the crucial question is whether his impairment on these tasks, like that on the tasks attributed to the part-based analysis, exceeds the impairment he has in recognizing upright faces which have not been modified. If it does, it would suggest that the part-based, object-recognition system, cannot compensate, on its own, for any distortion of the face, even that which affects non-configural information.

The description of all tasks related to modified faces that preserve their configural information and their results follow. For all tasks, examples of stimuli, and corresponding DC and CK's standardized results are presented in Fig. 3.

##### 4.1. Recognizing disguised faces, and faces with their external features inverted

Neurologically intact individuals can be as impaired at recognizing disguised faces, as at recognizing inverted faces, but for different reasons. Recognizing inverted faces appears to rely on part-based recognition, whereas recognizing disguised faces simply adds noise to configural processing of faces. Though the detrimental effect is not as severe, inverting the external features of faces (e.g. hair and jaws contour) has similar effects on face recognition as do disguises, and probably for similar reasons. CK, whose face recognition depends primarily on configural processing, is no more impaired than controls on these tasks. When disguised, CK recognized 68% of the 35 famous faces that he identified correctly ( $z = 0.13$ ) [controls recognized 66% (S.D.: 16%; range: 35–88%) of the average of 54 they identified correctly (S.D.: 13; range: 33–68)]. Out of the 11 faces that CK recognized when upright (from a total of 12), he recognized 10 of them when their external features were inverted ( $z = 0.12$ ). [His controls recognized an average of 9.2 faces (S.D.: 2.5; range: 5–12) with inverted external features out of the 10.5 (S.D.: 1.8; range: 7–12) that they recognized when presented intact and upright.]

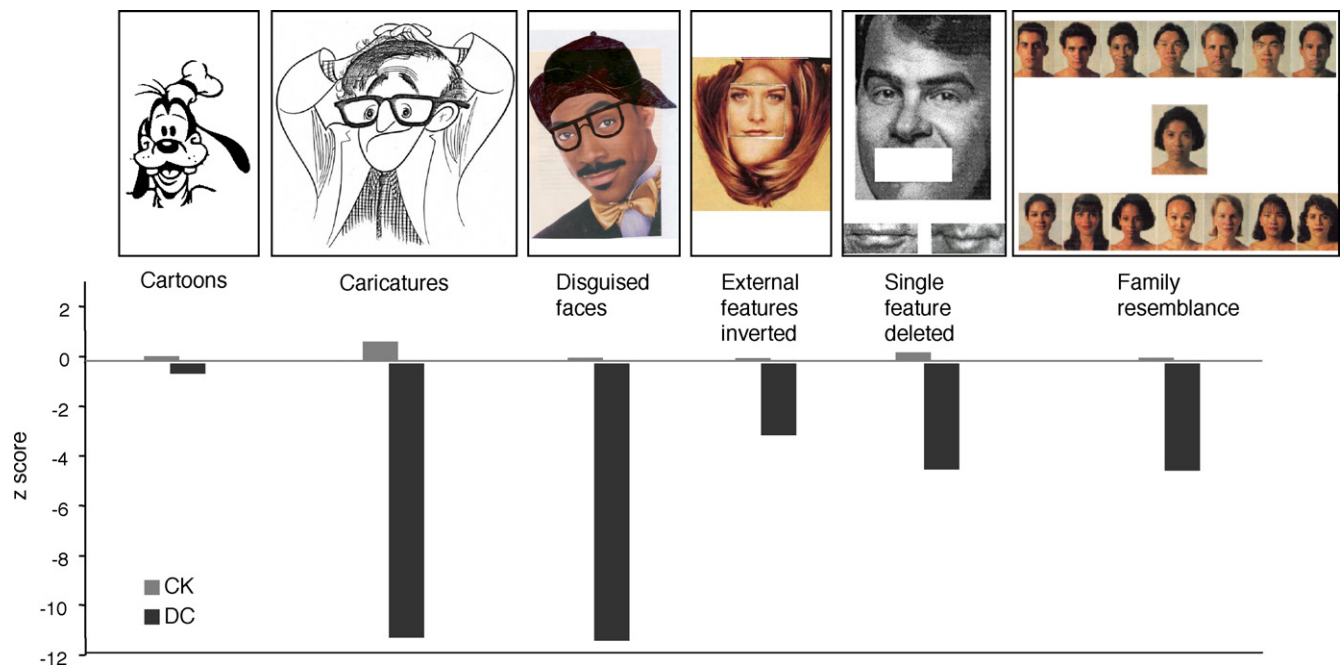
It is difficult to predict how DC would perform. Because configural face processing is impaired in DC, one can argue that simply adding noise to an already impaired system should not lead to a greater than normal deficit. Alternatively, it may be the case that if face recognition depends to a great extent on part-based processing, altering the parts, as these tests do, should lead to greater than normal impairment with upright faces.

When the faces were disguised, DC recognized 27% out of the 15 faces that he identified when upright (out of a total of 35) [his controls recognized 92.1% of the 35 faces (S.D.: 5.6%; range: 84.0–96.2%)]. DC is impaired at recognizing disguised faces ( $z = -11.6$ ).

Although tested on only few trials, DC also appeared impaired at recognizing faces when their external features were inverted. Out of the five faces that he recognized when they were upright (from a total of 12), he recognized only one face when its external features were inverted ( $z = -2.86$ ) [His controls recognized an average of 9.8 faces (S.D.: 2.6; range: 6–12) out of the 12 that they all recognized when presented intact and upright.] (see examples of stimuli and results in Fig. 3).

Disguising faces and inverting their external features leads to greater than normal deficits in DC, supporting the hypothesis that his face recognition is part-based. Altering the parts has disproportionate effect on his ability to recognize faces. Alternatively, it may be the case that a damaged configural system has fewer resources to cope with any perturbation and leads to a catastrophic deficit. If either interpretation is correct, it provides a clue as to the limitations of a part-based system as substrate face recognition. By relying on features, rather than on their configuration, any change is accorded great significance, and classified as unfamiliar with respect to the original representation.





**Fig. 3.** Comparative recognition performance (z score) of CK and DC at the face recognition tasks in which the stimuli preserved configural information. For each task, an example of a stimulus is provided, and the z score is calculated using the percentages of modified faces correctly recognized over the number of corresponding upright faces correctly recognized. From left to right, the examples of stimuli are Goofy, Woody Allen, Eddie Murphy, Meg Ryan, Dan Aykroyd, and stimuli for the “parents/offspring” test. The photos of seven men and seven women at the top and bottom, respectively, were the “parents” of the “offspring” photo in the center. In this case, the parents are the male in the sixth position, and the female in the third position from the left.

#### 4.2. Recognizing caricatures and cartoons

CK recognized caricatures and cartoons without any difficulty ( $z = 0.77$ , and  $z = 0.18$ , respectively) (Moscovitch et al., 1997). He recognized 30 caricatures out of 31 [controls recognized an average of 28 (S.D.: 2.6; range: 23–31)], and he recognized all cartoons presented (29/29) [controls recognized an average of 28.3 (S.D.: 3.9; range: 17–29)]. Based on these results, it has been postulated that both these types of stimuli engage the face recognition system. Caricatures enhance the distinctive characteristics of veridical faces. It has been shown that our memory of faces with distinctive features is best (e.g. Bartlett, Hurry, & Thorley, 1984; Benson & Perrett, 1994; Cohen & Carr, 1975; Going & Read, 1974; Light, Kayra-Stuart, & Hollander, 1979; Valentine & Bruce, 1986a, 1986b), and that caricatures sometimes are identified better than veridical line drawings of faces and anti-caricatures (e.g. Carey, 1992; Rhodes, Brennan, & Carey, 1987). The processing advantage of caricatures may be related to the involvement of the face recognition system.

The fact that CK recognized cartoons as well as caricatures suggests that the face recognition system that relies on configural information can be accessed by face stimuli that are not veridical representation of human faces without recourse to part-based recognition systems. We do not know, however, whether the part-based systems alone also code faces in this manner. By testing DC, we can determine whether recognition of caricatures and cartoons can also be efficient when recognition relies primarily on part-based object-recognition systems.

DC recognized 18 out of the 29 caricatures presented; each of his controls recognized them all. These results show that DC is impaired at recognizing caricatures ( $z = -11$ ).

By contrast, DC's recognition of cartoons is normal. DC recognized 27 out of 31 cartoons ( $z = -0.4$ ). Cartoons have their own identity and can be identified either by their distinctive features or configurally when upright, but rely more on the part-based system when inverted. Thus, though recognition of upright cartoons is normal in both DC and CK, recognition of inverted cartoons is impaired

in both, though much more so in CK who lacks the part-based, object-recognition system (see examples of stimuli and results in Fig. 3).

DC's results compared to CK's suggest that the processes and mechanisms responsible for the identification of caricatures and those for cartoons are different; the configural, face-recognition system appears to be essential for the recognition of caricatures, but not for that of cartoons. Because caricatures exaggerate the distinctive features of veridical faces, access to those representations is needed for identification. That DC's deficit exceeds that seen in recognition of upright veridical faces suggests that veridical face representation cannot be based only on these distinctive features, but on additional configural information that make these features distinctive. Having poor configural representations, DC cannot interpret the exaggerated features of caricatures and his performance suffers as a result.

The results of the experiments on recognition of caricatures and of upright and inverted cartoons suggest that optimal performance depends on the interaction of configural processes associated with face recognition and part-based processing associated with object recognition. Although one or the other system may suffice to support some aspect of faces recognition, to perform normally on all the tasks, the systems need to interact with one another.

#### 4.3. Face recognition with one part missing and recognition of the isolated part

The results of the previous experiments, and their interpretation, suggested that individual face parts or features are represented in the part-based recognition system. If that is the case, DC should be more than normally impaired at recognizing faces with a missing part, but insofar as DC can recognize the face, he should also be able to recognize its individual parts. Alternatively, individual face parts, like their configuration, may be represented by the configural face-recognition system. CK's normal performance in choosing the correct missing feature in faces he recognized supports the latter

interpretation. To see which of these interpretations is correct, DC was asked to recognize faces with one feature missing, and then to pick the missing features from between two alternatives.

Fifteen faces, each with one face part removed (i.e. a third had the nose removed, a third, the mouth, and a third, the eyes), had to be recognized. Recognition of the isolated missing face parts was also evaluated by a two-alternative forced choice method. First, participants were asked to identify a face without a missing part. Second, they had to choose the missing part out of two given choices.

CK performed no differently from controls ( $z=0$ ). He identified ten faces out of the 15 presented with a missing part; his controls identified an average of 10.0 of them (S.D.: 2.9). CK correctly chose all the missing parts of the ten faces that he identified.

DC is impaired at identifying faces with a missing part: He identified only four faces out of the 15 presented with a missing part. His controls identified an average of 11.3 of them (S.D.: 1.7; DC's  $z$ -score =  $-4.26$ ). In contrast to CK, DC correctly chose only one missing part of the four faces that he identified. DC's controls correctly recognized an average of 6.5 missing parts (S.D.: 3.3) out of the 11.3 faces that they identified correctly. DC's results must be interpreted with caution since they are based on only a few recognized faces, and since his controls were not good at identifying missing parts. Nevertheless, the results clearly show that while DC struggled with these tasks, CK did not (see examples of stimuli and results in Fig. 3).

These results suggest that the part-based recognition system is not sufficient for recognizing faces with a missing crucial part, nor is it sufficient for recognizing the missing part itself. The configural face-recognition system appears to be essential for both tasks, and the results suggest that it represents information about parts and their configuration, a conclusion supported by studies by Yovel and Kanwisher, 2004, 2005. Applying these results to those of the experiment on part-based recognition suggests that the impairment observed when faces are disguised, or their external features are inverted, probably results more from an impaired configural system's ability to cope with those changes than from poor matching to feature representations in a part-based system.

#### 4.4. Judging family resemblance

To test the hypothesis that recognition of individual parts depends on configural representations, even when long-term memory is not implicated, we tested performance on a family resemblance task that requires one to focus on facial features embedded in different configurations. Moscovitch et al. (1997) used a family resemblance task in which participants must examine one target face ("offspring") morphed from the top and bottom halves of a male and female face ("parents"), and choose the two faces (parents) that were used to create the target face. In other words, participants must pick the "parents" of computer-generated "offspring" faces. Despite his impaired word and object recognition, CK was normal at performing this task, showing that an intact part-based system is not necessary for it, and that the configural face recognition system does not preclude matching features even when embedded in a different configuration. We did not know, however, whether this task could also be executed normally by reliance only on the part-based system. If it could, then DC should also perform normally. If, however, DC is impaired it would support the hypothesis that feature matching, when targets are embedded in non-identical facial stimuli, depends more on an intact configural face system than on a part-based system.

In Moscovitch et al. (1997), CK identified 79.6% of the "parents" of the 49 "offspring" faces presented ( $z=0.13$ ), a level equivalent to that of controls.

DC, and his controls were tested with only eleven "offspring" faces, respectively. DC identified 40% of the "parents" faces from the photos of the "children" faces. His controls identified 76.8% (S.D.:

8.5%) of them. These results show that DC is impaired at finding the parents of the target offspring ( $z=-4.32$ ); confirming that the part-based system is neither necessary, nor sufficient, for matching facial features embedded in different configurations (see examples of stimuli and results in Fig. 3).

These results, and those of the previous study, suggest that matching features of different faces (as compared to identical ones) and retaining facial features in memory depend on an intact configural face system. Surprisingly, the part-based system does not appear sufficient for doing either. In the next set of experiments, we evaluated whether DC has an intact memory of faces that he knew pre-morbidly by evaluating his face imagery.

### 5. Set 3: mental imagery for faces, and other categorical objects in DC

The aim of the following experiments is to evaluate whether DC has intact face imagery despite his impaired face recognition. If DC's long-term visual memory is spared, he may be able to form good images of well-known faces despite his deficit in identifying them. Such a finding would suggest that his internal representation of faces is spared and that the locus of his face recognition deficit is in gaining access to it from perception. It would also suggest that he has access to an intact visual buffer where face information can be held and examined despite his deficit of recognition.

Common representations for visual perception and imagery has been postulated in light of their functional equivalence (e.g. Farah, 2001; Finke, 1985; Kosslyn, 1987; Kosslyn et al., 1993; Saariluoma, 1992), correlated neural substrates (e.g. Farah & Peronnet, 1989; Goldenberg, Steiner, Podreka, & Deecke, 1992; Kosslyn et al., 1993; O'Craven & Kanwisher, 2000), and associated deficits in individuals with brain damage (Bisiach & Luzzatti, 1978; Farah, 2001; Goldenberg, 1992; Levine, Warach, & Farah, 1985). Despite this compelling evidence, double dissociations between perception and imagery have been documented. In some individuals with brain damage, imagery is impaired and perception is intact (e.g. Farah, 1988; Farah, Levine, & Calvanio, 1988; Goldenberg, 1993; Riddoch, 1990), in others, the reverse is true. Individuals experience object agnosia without deficits in generating images of objects (e.g. Barton & Cherkasova, 2003; Behrmann et al., 1994; Servos & Goodale, 1995). Others suffer from concurrent recognition deficits (i.e. object agnosia, alexia, achromatopsia, and prosopagnosia) without imagery impairment in any recognition domains (e.g. Bartolomeo et al., 1998; Young, Humphreys, Riddoch, Hellowell, & de Hann, 1994).

If DC is normal at face imagery, it can be argued that DC's prosopagnosia would resemble CK's visual object agnosia in that CK could also have good imagery for objects he could not identify perceptually. Such a finding would add further evidence to support the dissociation between imagery and perception. For the sake of completeness, and in order to see if there could be dissociation between imagery for different types of visual stimuli, we also evaluated his imagery of dog breeds and famous buildings. The same participants as in the experiments on the recognition of categorical objects (DC, nine other controls, including his brother) were tested.

#### 5.1. General visual imagery

In order to make sure that a potential impairment of face imagery would not simply be due to an overall difficulty with imagery in general, the participants' general imagery abilities were tested with the high/low visual imagery task (Eddy & Glass, 1981), and a mental image manipulation task designed by Behrmann et al. (1994). In the former, participants must answer a series of 30 true or false statements that either can be easily imaged visually (high imagery items: e.g. The stars on the American flag are



white—True) or not (low imagery items: e.g. The prince will one day be queen—False). In the latter, participants must form mental images of common shapes (e.g. letters) from step-by-step verbal instructions (e.g. Take the letter V, turn it upside down, put a horizontal line through the middle of it—A).

At the Eddy and Glass Test, DC was correct on 94% of the High Imagery items [controls were correct on an average of 89% (S.D.: 9.0%, range: 67–100%)]. DC was also correct on 94% of the Low Imagery items [controls were correct on an average of 93% (S.D.: 12.0%, range: 71–100%)]. At the Behrmann et al. Test, DC had 83% correct responses [controls had an average of 84% (S.D.: 10.0%, range: 67–100%)]. These results show no difference between DC and other controls (High Imagery items:  $z = 0.55$ ; Low Imagery items:  $z = 0.08$ ; Behrmann et al. Test:  $z = 0.10$ ). DC's ability to perform mental operation on various symbols (e.g. letters, objects) is normal. Thus, a difficulty in imagery of faces, buildings or dogs (evaluated next) could not be attributed to a general inability to perform mental operations.

### 5.2. Face imagery

For the face imagery tasks, questions were created about the faces of 60 famous individuals well known to DC. The questions were based on the pictures of the faces that he was asked to recognize previously—30 questions related to faces that he did not recognize from their pictures, and 30 related to faces that he did recognize. If DC can access his visual memory of faces, his face imagery should be intact, and there should be no difference in his results between the two sets of recognized and unrecognized faces. If imagery and recognition share a common damaged buffer, imagery for his previously unrecognized faces should be worse than that for recognized faces.

Each questionnaire is composed of 30 true or false statements based on either specific face parts, on their relationship, and on the overall physiognomy of faces (e.g. Clint Eastwood has very thick large lips—False; Helen Hunt has a wide and short nose and an elongated face—False; Rodney Dangerfield has small eyes in relationship to his face—True). Different types of imagery statements were used to rule out different possible mental image generation deficits (e.g. activation of visual memory of global patterns, or of parts and their relationship to each other) that have been postulated to rely on distinct imagery mechanisms (Kosslyn, Behrmann, & Jeannerod, 1995).

There were at least 5 months between the administration of the recognition and imagery tests for DC and his brother. For all other controls, imagery questionnaires were given at least 48 h after administration of their related recognition tests.

DC obtained 77% correct responses for the faces that he previously recognized and those that he did not [controls: 68% correct for the faces previously recognized by DC (S.D.: 14.0%; range: 46–87%) and 68% for the faces not previously recognized by DC (S.D.: 12.0%; range: 52–90%)]. DC's performance is within the high average range for both sets of faces—those that he previously recognized and those he did not (faces previously recognized:  $z = 0.64$ ; faces previously not recognized:  $z = 0.75$ ). Despite his face recognition impairment, DC is able to form images of faces of well-known individuals. In fact, this imagery task appears to be difficult for many normal controls. DC is better than many of them. This finding shows that a pure face identification deficit can exist without imagery difficulties in which accessing the semantic system from long-term visual memory is spared.

### 5.3. Categorical objects imagery

True or False questionnaires were also created based on the pictures of the dog breeds and famous buildings used in the recognition

tests. Thirty questions were designed for each type of object. (Since DC's recognition was not different from that of controls, no distinction was made between objects that were previously recognized or not.) Again questions about parts, their relationship, and the overall impression of the objects were created (e.g. Cocker Spaniels have redder hair than Great Danes—True; Compared to Notre-Dame-de-Paris, Westminster Abbey appears thinner and taller—True).

DC obtained 63% correct responses in the Buildings Imagery task (controls: average 69%; S.D.: 11%; range: 45–78%), and 79% correct responses in the Dog Breeds Imagery task (controls: average: 75%; S.D.: 13%; range: 53–87%). The results show no difference between DC and other controls (Buildings Imagery:  $z = -0.54$ ; Dog Breeds Imagery:  $z = 0.31$ ). DC has no difficulty above those of normal controls forming images of different well-known dog breeds and buildings. This was expected, as his recognition of them was normal.

## 6. Set 4: face processing without identification

In the next experiments, we evaluated whether DC who is impaired at face identification, but who appears to have a normal face imagery, has difficulties with different aspects of basic face processing, what Carey (1992) calls first-order representation—where identification is not required. These studies also provide some evidence on the interaction between shape processing and depth segregation.

### 6.1. Depth segregation and recognition of overlapping faces

Whether depth segregation (or figure-ground perception) precedes or follows recognition has been debated for many years (Palmer & Rock, 1994; Peterson, 1994a, 1994b). Recently, Peterson and Skowe (2008) have argued that depth segregation is the outcome of competition for internal representations of shapes with the winner emerging as a figure. In our previous study with CK we showed that he is impaired at depth segregation of objects, but not of faces. When shown overlapping objects, CK was severely impaired at tracing their outlines, and of course, at recognizing them. In contrast, he could trace the outlines of overlapping faces normally, and he could identify some of the overlapping faces and easily recognize each one when required to choose it among others. His results suggest that identification and recognition contribute to depth segregation—depth segregation is impaired when the stimuli being segregated cannot be recognized. These results show that recognition contributes to depth segregation, a finding that is consistent with the precedent or competition model.

In the next set of experiments, we asked what type of face processing or access to what kind of representation is needed for depth segregation. Would DC, whose identification of faces is impaired, be able to show depth segregation for them? Would he recognize overlapping faces, and could he trace their contours? On one hand, depth segregation should be impaired if it depends on the face configural system which is necessary for face identification and at which DC is impaired. On the other hand, depth segregation should be possible if it depends only on access to first order representations. Indeed, a demonstration of depth segregation for faces would be evidence that first-order face representation is relatively preserved in DC.

Participants were presented with three overlapping caricatures of famous people. In total, they were shown nine sets of three overlapping faces. They first were asked to identify each face. If they failed, they were asked to choose the target caricatures out of five free-standing caricatures. After completing the recognition and matching tasks, they were asked to trace the outlines of each face [see Moscovitch et al. (1997) for details about stimuli and procedure].

DC identified only two overlapping caricatures out of 27 (controls: average: 10; S.D.: 8.2; range: 2–21), though he correctly matched 26 out of the 27 caricatures when they were presented separately (controls: average: 26; S.D.: 1.9; range: 25–27). (DC was always perfect at identifying overlapping outlines of objects.) Compared to controls, his identification of overlapping faces is the worst within the normal range. [CK recognized the overlapping faces normally (14/27).] Thus, not only did DC have no difficulty tracing the outlines of the overlapping faces, he could also match them to the given choices, presumably on the basis of sensory features.

DC's performance shows that depth segregation for faces can be intact even when face identification is severely impaired, indicating that depth segregation for faces is not dependent on the configural face system. Being able to trace their outline of faces that he cannot identify indicates further that first-order representations are preserved in DC, suggesting that these also are not dependent on an intact configural face system. Whether the latter are dependent on part-based processing, as would be required for generic recognition of objects, or on some minimal processing that is preserved in a damaged configural system remains to be determined.

### 6.2. *Recognizing Mooney faces and objects*

Recognizing Mooney figures depends on closure. This is a case of depth segregation where the dark regions must be attributed either to surfaces or shadows, and where the light and dark regions must be assigned to the figure or the ground. While CK was unable to recognize any Mooney object, he had no difficulty recognizing Mooney faces. These results lead to the conclusion that figure completion is separate for face and object processing, and confirmed that depth segregation occurs in parallel to recognition. We asked DC to describe the Mooney faces and objects. Based on his results in the previous experiment, we expected that he would be normal at seeing both.

Participants were shown seven Mooney faces and nine Mooney objects. They had to describe what each figure represented.

DC was normal at recognizing Mooney faces; faces emerged easily for him. [He recognized 6.5 Mooney faces compared to an average of 6.6 (S.D.: 0.7; range 5–7) for controls.] He also recognized all objects but with less spontaneity. [He recognized 9.0 Mooney objects compared to an average of 7.2 (S.D.: 1.7; range 3–9) for controls.] He needed a few cues before they would emerge for him. By comparison, CK performed normally in recognizing Mooney faces (seven out of seven), and was impaired at recognizing Mooney objects (zero out of seven). These results suggest that despite his face identification impairment, DC has intact face depth segregation and completion for both faces and objects.

### 6.3. *Recognition of the Arcimboldo composite faces (and of the objects of which the faces are composed)*

We next assessed whether faces made up of objects (such as a face with cherries for eyes, a pear for a nose and a banana for a mouth) could be recognized as faces, and how well the objects were recognized. In *Moscovitch et al. (1997)*, CK had no difficulty seeing the faces when presented upright. For most faces (six out of eight), he could not tell that the internal features were made up of arrangement of various objects (naturally, neither could he identify the objects). When the composite faces were inverted, CK could tell that the pictures were made of an arrangement of various objects (eight out of eight), but he could not identify all the objects, and never reported that they collectively represented faces. These results supported a modular organization of faces and objects, such that, when activated, the face recognition system interferes with the operation of the damaged system used to identify objects.

Participants were shown eight composite faces created by the artist Arcimboldo (see *Moscovitch et al., 1997*). They were asked to describe everything that they saw. If they saw a face, they were required to provide details about what type of face it was (e.g. sex, emotion expressed). If they also saw objects, they were asked to identify each object. All participants saw the faces upright.

DC and all normal controls identified all eight faces and the objects from which they were made. These results support our previous conclusion that what is impaired in the prosopagnosia exhibited by DC is the ability to use configural processes to identify individual faces. Apprehension of the structural representation of a (generic) face, namely its first-order representation, and the processes needed to derive such a representation, are generally intact. It must be noted that this conclusion is limited by the fact that the Arcimboldo and Mooney faces tasks were very easy for the controls, thus leading to a ceiling performance in all participants, including DC. A subtler deficit in utilizing first-order information for face detection may thus be missed by these experiments.

## 7. Discussion

The major aim of this study was to determine whether there is a double dissociation between the part-based system and configural system to face recognition, and if not, to establish which aspects of face recognition depend on an interaction between the two. To do this we compared performance on a variety of face-recognition tasks in two patients with dissociable visual disorders: DC, who has prosopagnosia but can read and recognize objects normally, and CK, who has pure alexia and visual object agnosia, but can recognize faces. The results lead to the general conclusion that while there is a clear dissociation in CK between his part-based and configural face recognition – he cannot recognize faces isolating part-based processing, but can recognize faces that have preserved configural information –, and there is no evidence of this dissociation in DC; he is impaired at recognizing all faces, those with, and without configural information.

More specifically, the results show that despite his profound object and word agnosia, CK was normal at recognizing upright whole faces, but poor at recognizing faces that were inverted, fractured, or modified so as to alter their gestalt. From these results it was concluded that face recognition that depends on part-based processing was impaired, whereas that which depends on configural processing was spared. This idea had been corroborated many times in healthy people by a number of investigators, including *McKone et al. (2003)*, and *McKone (2004)* who also showed that face categorization, and identification, are possible when only the configural system is available. CK's results further showed that the domain specific information necessary for activating the configural face recognition system is: (a) orientation specific (i.e. it requires upright faces, and not inverted ones); (b) dependent on spatial relations among the internal features of faces only (not the external features); (c) not dependent on any single feature (see also *Robbins & McKone, 2003*); and (d) not dependent on particular elements of which a face is composed as long as the required configural properties of the face are preserved—any configural, face like stimulus will do whether it is a cartoon, simple line drawing or caricature. Using fMRI, *Tong, Nakayama, Moscovitch, Weinrib, and Kanwisher (2000)* confirmed that many configural face-like stimuli are as capable of activating the fusiform face areas as faces are.

By comparing the performance of DC to that of CK, we can establish further which aspects of the face identification systems are challenged in DC's prosopagnosia where face recognition must rely mostly on the intact part-based system used to recognize objects and words. Except for identifying upright cartoons, a finding that will be discussed later, DC was impaired at all face recognition tasks, even those in which faces were modified to emphasize part-based

processing. Indeed, any modification led to even worse recognition on DC's part than for upright faces, which already was severely impaired. Overall, DC can recognize upright normal faces at about 40% accuracy, and his performance decreases when he attempts to identify any modified faces. These include both those typically processed by a part-based approach, such as inverted, and fractured faces, and those which can be handled by the intact face-recognition system alone, such as facial disguises and inversion of external features.

Before attempting to account for DC's deficits in face recognition, it is important to appreciate what aspects of face and object processing are spared. DC performs normally on tests of object identification, and can identify normally exemplars of sub-ordinate categories of objects, such as famous buildings and breeds of dogs. DC also had no difficulty with face tasks not requiring identification, such as depth segregation necessary for identifying Mooney faces, nor in apprehending faces made of objects, such as Arcimboldo faces. The latter set of results suggests that DC retains a good structural description of the general or generic characteristic of faces, what [Diamond and Carey \(1986\)](#) call first-order representations, but has difficulty only with identifying individuals which depends on second-order representations.

As with CK's imagery for objects and words, DC's imagery for faces appears intact despite his recognition impairment. This dissociation can be added to a series of many others already reported in the domains of recognition (e.g. [Bartolomeo et al., 1998](#); [Barton & Cherkasova, 2003](#); [Behrmann et al., 1994](#); [Farah, 1988](#); [Farah et al., 1988](#); [Goldenberg, 1993](#); [Riddoch, 1990](#); [Servos & Goodale, 1995](#); [Young et al., 1994](#)). Our finding of intact imagery suggests that his long-term internal representation of faces is preserved, though we cannot specify exactly what underlies such a representation (see discussion below).

Together, these findings suggest strongly that DC's prosopagnosia occurs at mid-level perception: his face identification is impaired while his generic face processing and representation, and ability to maintain structural images of familiar faces, are preserved. The impairment occurs at a stage of extracting information necessary for synthesizing or integrating the elements into a whole and/or mapping the elements to an internal structural representation.

Although any relationships drawn can only be speculative, the bilateral involvement of BA 18 and 19 in DC's objects and faces processing abilities ought to be considered. It should be noted that this involvement must be related to DC's lost of superior visual fields (with macular sparing) and, minimally, to some hesitation and lack of spontaneity with identification of silhouette-objects. While these difficulties lead to significant perceptual decline, it is clear from his visuo-perceptual, constructional and recognition abilities that they are not sufficient for explaining his recognition deficits which is restricted to faces. Indeed, DC is normal at reading and at recognizing objects presented in natural settings, and his visuo-perceptual and constructional abilities were remarkably good attaining scores in the high average to superior. It must be noted that, although all normal, his results to some object-recognition tasks suggest a weakness at identifying objects depicted by black and white silhouettes presented in an unusual point of view, such as in the silhouettes subtests of the VOSP and the Mooney objects. Indeed, DC obtained low average to average scores at these recognition tasks and was, at times, hesitant while answering. These scores are slightly lower than expected and his attitude is much less assertive than that found in all other visuo-perceptual tasks. However, unlike his performance at any face recognition tasks, these results do not represent an impairment. Moreover, whatever difficulty he experiences does not hinder his recognition of objects not presented as silhouettes (e.g. black and white line drawings, dogs, and buildings). Consequently, we believe that the involvement of BA 18 and 19 may

contribute to some difficulties with identification of silhouette-objects, but just as these difficulties are not sufficient to hinder his normal object recognition, they cannot be sufficient to explain his face recognition impairment. Speculations on the involvement of BA 18 and 19 in face recognition are presented in the next part of the discussion.

### 7.1. Interaction between part-based and configural face processing

While it was expected that DC would be impaired at recognizing faces processed configurally, it is surprising, given his intact word and object recognition, that he would also be impaired at recognizing faces whose identification requires part-based processing, such as faces which are inverted or fractured. Clearly his object part-based system is not sufficient to support part-based face recognition. An interaction with the configural face system appears necessary, showing that it is required for all face recognition tasks—even those for which part-based processing has been shown to be essential for recognition. These results indicate clearly that the part-based system alone is not sufficient to support face identification; it must interact with the configural system if normal identification is to be achieved, as [de Gelder and Rouw \(2000a, 2000b\)](#) and [Moscovitch and Moscovitch \(2000\)](#) have suggested.

While our results allow us to establish that an interaction between the configural and part-based system is essential for face recognition, they do not indicate whether the part-based processing arise from systems implicated in word or object processing. Indeed CK is impaired at recognizing both objects and words. We had the opportunity to determine whether part-based processing of faces relies on the object system only, or on both the object and word systems by comparing CK's face processing to that of an alexic man, CM<sup>3</sup> whose recognition impairment is restricted to that of words. CM is a man with pure alexia with intact object and face recognition. Studying his face recognition can help us to determine whether damage to processes implicating recognition domains other than those concerned with objects, also affects recognition of part-based face stimuli. All face recognition tasks (from [Moscovitch et al., 1997](#)) administered to CK and DC were also administered to CM. His results are consistent and unequivocal: he performs normally on all face recognition tasks, whether part-based or configural, showing that damage to the word recognition system alone does not interfere with face recognition. We conclude that CK's impairment at part-based face processing co-occurs with damage to the object-recognition system; damage to the word-system alone is not sufficient. Whether the part-based face and object systems are actually two separate systems interacting with each other, or whether it is the object-recognition system that governs part-based face analysis ([de Gelder & Rouw, 2001](#); [Farah, Wilson, Drain, & Tanaka, 1995](#); [Moscovitch et al., 1997](#)) is a matter of open to debate.

The interaction of the part-based and configural face systems appears to require optimal natural face input in order to be activated. It does not appear to be engaged when dealing with cartoons

<sup>3</sup> CM was born in 1970. He was a heavy drug user and suffered from a closed head injury. Three weeks after his injury, CM went into a coma, and temporal occipital abnormalities were found on Electro-Encephalograph. Following his insult, CM could no longer recognize words, but could recognize objects and upright familiar faces; he had pure alexia (letter-by-letter reading) but no object agnosia, nor prosopagnosia. CM has about 15 years of education; he works in computer programming business. His pre-morbid estimated IQ is high average. Based on his neurologist, CM's visual acuity, and his other perceptual abilities are also normal. His performance at the Boston Naming Test was normal showing that his object recognition and naming are normal. We cannot provide more details about his general cognitive profile. Nevertheless, we believe that his data on face processing are informative when compared to the other two cases, as his deficit is limited only to visual word recognition.



faces whose features are exaggerated, salient and unique. Apparently, the part-based system is sufficient for cartoons recognition just as the isolated configural system in CK was sufficient in this case. Alternatively, recognition in this case may solely depend on a partially damaged configural system that still can cope with the minimal demands that cartoons make on it. That DC recognizes upright cartoons is consistent with both alternatives.

When confronted with inverted cartoons, DC is impaired relative to normal controls, though he still performs better than CK. This finding suggests that for recognition of even simple face-like stimuli, such as inverted cartoons, neither an intact configural system, as in CK's case, nor an intact part-based system, as in DC's case, can by itself support normal performance. That DC performs better than CK on this task suggests either that the part-based approach is more important than the configural in recognizing inverted cartoons, or that in DC, the configural system is only partly damaged and can still interact with his preserved part-based system to a limited extent.

The interaction between the part-based and configural systems cannot tolerate any deviation from optimal inputs. It appears to be very rigid. Indeed, despite having a preserved part-based system, DC was extraordinarily sensitive to any changes that would degrade or alter the face stimuli, such as disguising the face with hair and glasses, and those that have little effect on normal recognition, such as inverting external features. One possibility is that in a system in which faces are represented only in terms of their features, recognition depends on matching faces feature-by-feature. Consequently, introducing any new features (such as by disguising a face with glasses or mustache) or altering old ones, such as by inversion, makes it difficult to find an appropriate match. Any modification to the face features, and their spatial arrangement, would tax the recognition process leading to a further decrease in efficiency. Another possibility is that DC's configural system is not totally destroyed, but merely malfunctioning and producing noisy output. In this case, his face recognition would be driven by a damaged configural system leading to poor performance. This damaged system may be particularly insensitive to faces that deviate from a comparison norm. *de Gelder and Rouw (2000b)*, and *Boutsen and Humphreys (2002)* suggested that prosopagnosia could result from trying to achieve recognition using a damaged configural system. Again, recognition of the part-based face stimuli (e.g. inverted faces) would be worse because the part-based system not only would not benefit from an interaction with a healthy configural system, but actually be hampered by input from a damaged system.

The interaction between the part-based and configural systems appears necessary to face identification only. Our results suggest that it is not essential for object recognition. In agreement with repeated cases showing dissociation between face identification and identification of other sub-ordinate category of objects (e.g. *Assal et al., 1984; De Renzi, 1986a, 1986b; Farah, Levinson, et al., 1995; McNeil & Warrington, 1993; Moscovitch et al., 1997; Sergent & Signoret, 1992*), we continue to believe that face recognition is an ability relying on a unique process. This uniqueness may have evolved through the most sophisticated possible human expertise, or because, among all categorical objects, faces have the least distinctive features (and arrangement). The reason for the face uniqueness is beyond the scope of our study. We certainly recognize that DC's expertise with faces was incomparable with that related to any other objects as he had no specific object-related hobby, and was a detective within the criminal division of a police force. Given his added expertise with faces, it is still remarkable that only face recognition is impaired, but not recognition of exemplars in other categories. His face-recognition impairment and preserved recognition of exemplars in other categories contrasts with the opposite pattern shown by CK. This double dissociation suggests that it is unlikely that a single mechanism mediates processing of information necessary for identification of different sub-ordinate

categories, but rather that faces may depend on special mechanisms (*Kanwisher & Moscovitch, 2000; McKone & Kanwisher, 2005*).

DC's results on tasks other than those related to identification further inform us about the nature of the interaction between the part-based and configural systems and its limits. DC is normal at generic face representation as indicated by his performance on tests of Mooney faces, overlapping faces, and Arcimboldo figures. His facial imagery also is intact. These results suggest that his deficit lies at the interface between visual perception and his stored representation of faces, and that the interaction between the two systems is necessary at the level of this interface. Concluding that an interaction with the configural system does not appear necessary for generic face representation is consistent with *de Gelder and Rouw's proposal (2001)* stating that face identification relies on a different system or an additional system that represents generic faces.

The interaction between the part-based and configural system does not appear necessary for facial imagery either. However establishing the role of configural processing in preserved facial imagery is more problematic because DC seems able to individuate the faces he imagines though he cannot identify them perceptually. One cannot argue that he depends only on first order representations; the representation must contain sufficient information for him to perform normally on tests of imagery. Admittedly, such tests may not require the fine detail necessary for face identification. Thus, one can know that Cher's face is "longer" than Michelle Pfeiffer's and that the latter's eyes are farther apart than Cher's, but such information may not be sufficient to recognize either one from the myriad people one encounters daily. It is possible, therefore, that the configural representation that supports imagery is an impoverished one in comparison to the one that is needed for identification. This is likely since the results of our imagery tests show that normal individuals have relatively poor face imagery in comparison to their face recognition. Alternatively, they may be one and the same, and be highly detailed, but DC's deficits lies in creating configural representation from vision, not in retaining such representations once they had been formed. A third possibility is that the representations supporting imagery are part-based ones that retain some relational information (see *Moscovitch & Moscovitch, 2000*) adequate for imagery but not for identification. At the moment, there is no evidence to distinguish among these alternatives.

With respect to the neural substrates implicated in the interaction between the part-based and configural system, DC provides little new information, letting us only speculate about them. As in other cases of prosopagnosia (e.g. *Barton, Press, Keenan, & O'Connor, 2002; Damasio, Damasio, & Van Hoesen, 1982; Sergent & Signoret, 1992*), his bilateral occipital lesions involved most of lingual gyrus (with greater damage on the right than on the left), and BAs 18 and 19. Consistent with DC's impairment of upright and inverted face recognition, the FFA has been shown to be involved both in upright faces discrimination and in the face inversion effect where the signal is higher for upright faces (*Yovel & Kanwisher, 2005*). These areas, involved in face recognition (e.g. *Schultz et al., 2006; Sorger, Goebel, Schultz, & Rossion, 2007*), do not seem to be necessary for processing generic faces and for imagery of different individuals. DC's capacity to do these face tasks, and to recognize some upright faces may depend on more superior and anterior regions of the temporal lobe which have been implicated in face processing. The STS is sensitive primarily to eyes and perhaps motion of the face or facial features (e.g. *Puce, Allison, Bentin, Gore, & McCarthy, 1998*), this region, along with LOC, may subserve generic recognition of faces. Retention of well-learned representation of faces that supports imagery is likely dependent on anterior temporal cortex, most likely on the right (e.g. *Barton & Cherkasova, 2003; Sergent, Ohta, & MacDonald, 1992*), and their projection to other regions of cortex (e.g. *Avidan et al., 2005; Behrmann, Avidan, Gao, & Black, 2007*).

In conclusion, by studying the face recognition of dissociable agnosic individuals, we hoped to understand more precisely the contribution of different systems, and how they interact. Considering the performance from DC and CK together, we have shown the recognition of faces that preserve the orientation and face gestalt can be accomplished by the configural system without the contribution of the part-based system. By contrast, though the part-based system is needed for recognition of faces that do not meet these criteria, it cannot accomplish this task on its own without the involvement of the configural system. Previously we had speculated that the part-based system forms a part-based facial representation that is the counterpart of the configural face representation, and that this counterpart supports face recognition in prosopagnosic patients. Our data neither support, nor refute this hypothesis. Indeed, it is entirely possible that the part-based system serves only as a conduit of information about face features, and the local relations to one another to the configural system, and cannot on its own recognize faces at all, except those that are identifiable by single features, such as cartoons, and the rare individual. DC's performance can be attributed as much to the little that is preserved of his configural system as to operation of his intact part-based system. In short, we have provided no evidence in support of a double dissociation between the part-based and configural face recognition systems.

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