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Neuropsychologia 42 (2004) 597–612

NEUROPSYCHOLOGIA

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Evidence for perceptual deficits in associative visual (prosop)agnosia: a single-case study

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Received 11 September 2003; received in revised form 22 October 2003; accepted 23 October 2003

Abstract

Associative visual agnosia is classically defined as normal visual perception stripped of its meaning [Archiv für Psychiatrie und Nervenkrankheiten 21 (1890) 22/English translation: Cognitive Neuropsychol. 5 (1988) 155]: these patients cannot access to their stored visual memories to categorize the objects nonetheless perceived correctly. However, according to an influential theory of visual agnosia [Farah, Visual Agnosia: Disorders of Object Recognition and What They Tell Us about Normal Vision, MIT Press, Cambridge, MA, 1990], visual associative agnosics necessarily present perceptual deficits that are the cause of their impairment at object recognition Here we report a detailed investigation of a patient with bilateral occipito-temporal lesions strongly impaired at object and face recognition. NS presents normal drawing copy, and normal performance at object and face matching tasks as used in classical neuropsychological tests. However, when tested with several computer tasks using carefully controlled visual stimuli and taking both his accuracy rate and response times into account, NS was found to have abnormal performances at high-level visual processing of objects and faces. Albeit presenting a different pattern of deficits than previously described in integrative agnosic patients such as HJA and LH, his deficits were characterized by an inability to integrate individual parts into a whole percept, as suggested by his failure at processing structurally impossible three-dimensional (3D) objects, an absence of face inversion effects and an advantage at detecting and matching single parts. Taken together, these observations question the idea of separate visual representations for object/face perception and object/face knowledge derived from investigations of visual associative (prosop)agnosia, and they raise some methodological issues in the analysis of single-case studies of (prosop)agnosic patients.

Keywords: Object recognition; Face recognition; Visual associative agnosia; Prosopagnosia

1. Introduction

Visual agnosia is a deficit in object recognition confined to the visual modality, despite intact elementary visual processes such as visual acuity, visual field, visual scanning and attention, and which is not due to general problems in language, memory or deficiency in intellectual abilities. Neuropsychological investigations have described cases of visual agnosia belonging to the two broad classes of disorders introduced by Lissauer (1890), namely visual *apperceptive*, and visual *associative* agnosia. As defined in the literature, apperceptive agnosics present visual deficits, which prevent them to elaborate a correct percept of the stimulus. Associative agnosics, on the other hand, are considered as being able to construct a normal visual percept that cannot be adequately associated with visual representations of objects stored in memory. This distinction has been extended to a particular type of visual agnosia, the inability to recognize faces, or prosopagnosia (Bodamer, 1947): *apperceptive prosopagnosics* cannot elaborate a correct percept of a face, whereas *associative prosopagnosics* are unable to give any meaning to a correctly elaborated visual representation of an individual face (De Renzi, Faglioni, Grossi, & Nichelli, 1991).

Humphreys and Riddoch (1987) have elaborated upon the basic distinction of apperceptive and associative agnosia, drawing a clear boundary between perceptual and mnesic processes involved in object recognition. Referring to a classical hierarchical cognitive architecture of visual object recognition, these authors have described different forms of apperceptive and associative agnosias, depending

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doi:10.1016/j.neuropsychologia.2003.10.008

on the stage at which the visual object processing is impaired.

A different view has been put forward by Farah (1990). Although this author also described a taxonomy of apperceptive agnosias and acknowledged the heterogeneity of associative agnosias,[1] a review of 99 cases of associative agnosias described over the century in the English-speaking literature led her to conclude that there was no clear evidence of the sparing of high-level visual processes in the cases of associative visual (prosop)agnosia[2] reported. She argued that all cases of associative visual agnosia present perceptual deficits that are the cause of their impairment at object recognition, and thus that perceptual and mnesic representations involved in object recognition were not clearly distinct. Farah's account is based on the observation that very few of the patients who have been described as associative agnosics have been adequately tested for perceptual abnormalities. In the rare cases where particularly demanding visual tasks have been presented to associative agnosic patients, their results have suggested some critical deficits at high-level visual processes (Farah, 1990).

Since these two theoretical proposals have been formulated, a number of acquired cases of visual agnosias for objects (e.g. Behrmann & Kimchi, 2003; Behrmann, Moscovitch, & Winocur, 1994; Behrmann, Winocur, & Moscovitch, 1992; Humphreys & Rumiati, 1998; Moscovitch, Winocur, & Behrmann, 1997; Turnbull & Laws, 2000) and for faces (e.g. De Renzi & di Pellegrino, 1998; De Renzi et al., 1991; Henke, Schweinberger, Grigo, Klos, & Sommer, 1998; McNeil & Warrington, 1991; Schweich & Bruyer, 1993) have been reported, that may be classified as the 'associative' type. However, these studies investigated a number of different theoretical questions related to object and face recognition, without explicitly testing the hypothesis of the necessary visual impairments in the 'associative' cases that they described.

Here we report the case study of NS, a case of acquired visual agnosia for objects and faces with intact knowledge of object function as well as object recognition through tactile and auditory modalities. NS' case is particularly interesting because he has no low-level visual deficits, and his performances at copying and matching objects appears remarkably normal. Furthermore, tested with a classical face recognition battery (Bruyer & Schweich, 1991), he was found to be normal at all tasks of perceptual processing of faces but dramatically impaired at recognition processes. In this report, we investigate NS' high-level visual processes in detail, in order to test the claim that a patient defined as a visual associative (prosop)agnosia, should necessarily show some visual impairments that are the cause of his/her deficit. Our investigation was motivated by recent studies of prosopagnosic patients and normal subjects, which have raised a number of issues regarding the conclusions that are usually drawn from analyses of patterns of errors alone, using classical object and face recognition tests. For instance, recent evidence indicates that normal subjects can perform reasonably well at the Benton facial matching test as well as at the face recognition test of Warrington (1984)—two standards in the literature—when they have to rely exclusively on external features, and the time to perform the test is not taken into account (Duchaine & Weidenfeld, 2003; see also Davidoff & Landis, 1990; Sergent & Signoret, 1992). Claims for normal abilities in object recognition have also been made in several cases in which the quality of the stimuli set used was poor, allowing the patient to attend to a single salient feature of the object or its background to perform the task (e.g. McNeil & Warrington, 1993). In addition to a lack of control in the use of stimuli, most studies report performance score only, without any precise information about the time taken by the patients to perform the object matching tasks, for instance. However, recent studies have shown that measuring response times was critical in revealing abnormal performances at object perception tasks in cases of visual agnosia and prosopagnosia (Gauthier, Behrmann, & Tarr, 1999).

Given these concerns, we tested our patient extensively with different visual tasks performed on computer, measuring accuracy rates and RTs. We compared the performance and RTs of our patient to normal subjects matched for age and level of education. Doing these tests, we were also particularly aware to the fact that apparently slight abnormal performances in tests of visual perception may arise of difficulties in accessing stored visual representations or to damage to these representations themselves. Accordingly, in addition to the use of RTs measures, a distinctive characteristic of the present study was the use of novel objects in several visual tasks. This strategy allowed us to cancel any support for matching tasks that could be extracted from prior knowledge of the stimuli for control subjects, and would thus make them perform relatively better than NS.

2. Case study

2.1. NS: clinical history

NS (born 1951) is a right-handed man who was 40 years old when he was hit by a car while cycling, and remained unconscious for 23 days. He was first evaluated in September 1991, a few days after recovery. The neuropsychological examinations revealed sensory transcortical aphasia, a severe dyslexia and dysgraphia, signs of apraxia, anterograde amnesia, anosognosia, a bilateral superior quadranopsia and a severe visual agnosia for objects, faces, colors and places. Over the next 2 years, NS underwent cognitive rehabilitation,

[1] Although Farah (1990, 1991) makes a clear distinction between visual associative agnosia, on the one hand, and on the other hand, the cases of visual modality-specific anomia ("optic aphasia") and the loss of general semantic knowledge (not confined to the visual modality). See Section 4.

[2] Since Farah's view concerns both visual agnosia for objects and prosopagnosia, and our patient suffers from clear deficit at both object and face recognition, we will use the term visual agnosia in the larger sense, i.e. including prosopagnosia.

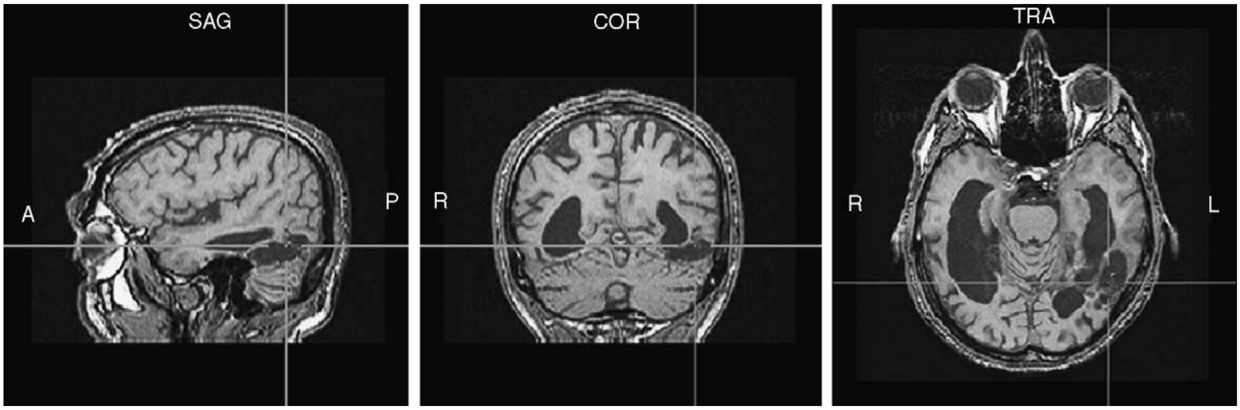

Fig. 1. T-1 weighted images (TR = 25 ms, TE = 6 ms, flip angle = 25°, slice thickness = 1.5 mm) were obtained in the bicommissural (AC-PC). 3D MRI anatomical data were also obtained on a GE 1.5 T unit using the spoiled grass (SPGR) technique. Orientation, coronal, transversal and sagittal slices showing the extent of the lesions in the occipito-temporal junction of NS' brain (transformed in Talairach and Tournoux's brain atlas in Brain Voyager 2000).

at a rate of 4 or 5 sessions a week. A recent MRI scanner of NS's brain showed NS lesions concern mainly the bilateral occipito-temporal junction (Fig. 1), but posterior regions of the occipital lobe appeared to be anatomically intact. Contusions were also found at left parietal and frontal sites.

2.2. Initial investigations of non-visual functions

The evaluation of the non-visual functions of NS 2 years after his accident has been reported in detail previously in a study investigating his calculation abilities (Pesenti, Thioux, Samson, Bruyer, & Seron, 2000), thus we will only summarize the main points here. In 1998–1999, NS was re-evaluated on all functions for which his performance was below the normal range a few years before, to describe the following summary.

Concerning his language and semantic abilities, NS' spontaneous speech is fluent and his aphasia has disappeared. His writing only presents a surface dysgraphia, and his reading aloud of words is correct but slower than normals. In order to assess more precisely whether NS is impaired in word reading, he was also asked to read some words presented one by one on a computer screen during a very short time (50 ms). Three types of words were used according to the number of letters making up them: short words (3 to 5 letters), intermediate words (6 to 8 letters), and long words (9 to 11 letters). Thirty-four familiar words were used for each type and the task was to read them aloud. The results revealed that NS was nearly able to read all words flawlessly. Among the 102 presented words, NS was not sure about only seven of them (one intermediate and six long words), but still gave in all cases the right answer. NS was in the normal range in a test of phonological fluency (NS: 17; controls: 22.55; S.D.: 7.04) but under the norms in a semantic fluency task (NS: 12; controls: 22.76; S.D.: 6.13) in which he had to give different instances of categories such as animals, fruits and furniture. NS does not show any evidence of semantic deficits in real life and he is able to give semantic information about famous persons from their names. He was perfectly accurate (30/30 decisions) at a task in which he had to match a target word to one of three possible words including a semantic and a non-semantic distractor, thus showing that he has no semantic impairments. His verbal short-term memory is in the normal range (see Pesenti et al., 2000). His visual short-term memory is below the normal range of performances as indicated by a *visual span test* using meaningless shapes (from Vanderplas & Garvin, 1959) (NS: 2; controls: 4.39; S.D.: 1.85), the *Benton multiple-choice recognition test* (80% correct; controls: 93–100%) and the *Corkin test* (below 3 S.D. in the full interval version of the test). He is also impaired in verbal long-term memory as assessed by the verbal learning of the *Buschke test* (average recalled words: 8.1; controls: 12.8; S.D.: 0.91; list learning score: 29.6%; controls: 79.8%; S.D.: 11.9). His long-term visual memory is also strongly impaired (*span and supra-span*: >15 trials, controls: 6; S.D.: 3.1; the doors part of the *doors and people test*: 8/12 and 4/12), but he has no deficits in attentional tests (see Pesenti et al., 2000).

2.3. Visual functions

NS has a full visual field, and the investigations of visual functions showed no deficits for elementary visual perception (normal scores on: the Cambridge low contrast grating test (Wilkins, Della Sala, Somazzi, & Nimmo-Smith, 1988); the Regan low contrast letter charts test (Regan & Neima, 1984); and the Pelli–Robson letter sensitivity charts test (Pelli, Robson, & Wilkins, 1988). His color perception is normal (Ishihara), and his visual acuity is excellent.

Tested with several sub-tests of the Birmingham object recognition battery (BORB; Riddoch & Humphreys, 1993) he performed well (normal range) at all perceptual tasks: *length match task* (test 2); *size match task* (test 3); *orientation match task* (test 4); *position of gap match task* (test 5); *minimal feature view task* (test 7); *foreshortened match task* (test 8). He apprehended correctly forms, volumes and

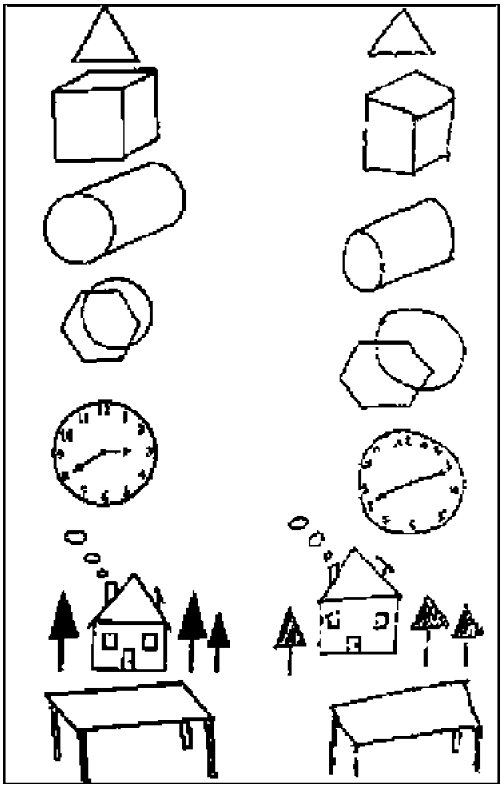

Fig. 2. Copy of geometric shapes and drawings (*test 1* from the BORB) by NS. Original drawings are on the left, copies are on the right.

perspective, making no errors when asked to judge two photographs of objects as exactly the same or different, and only a few for line drawings of geometrical forms. He made no error in a task of figure-ground segregation of geometrical forms (based on Gottschaldt hidden figure test; Gottschaldt, 1926). His drawing copy is very good also (Fig. 2, see also Pesenti et al., 2000), thus suggesting normal perceptual abilities at first glance. Although NS did all the visual tests of the BORB flawlessly, as a control, we administrated him three of these tests for which we checked his rapidity: the *overlapping letters task* (test 6, realized leisurely in 1995), the '*minimal feature view*' (test 7) and the '*foreshortened views*' (test 8). These last two tests require matching a prototypical view of a target object with one of two sample objects; one being the same object as the target but depicted from an unusual view; the other being a different object (distractor). In the '*foreshortened views*', the sample view of the target foreshortened the object's principal axis (see Riddoch & Humphreys, 1993); in the '*minimal feature view test*', the sample view reduces the saliency of the object's most distinctive feature. NS was 100% correct, and fast for these tasks.

2.4. Object and face recognition

By contrast to his normal visual abilities, NS has striking difficulties in tasks demanding access to visual semantic knowledge about objects in the BORB, being largely impaired at the *object decision task* (test 10), *item match task* (*class recognition*, test 11), *associate match task* (*semantic association*, test 12) and *picture naming*. He was also strongly impaired at an object decision task[3] performed on a computer (10 s presentation; 53.5% objects classified as objects, 2903 ms; 6 age-matched controls: 99%, 705 ms), and at a common object naming task (56.5% of correct response on drawings, 60% on photographs and 83% on real objects,[4] controls: 100% in all three conditions). He was also very consistent of his failure and success at object recognition: when given 100 objects from the Snodgrass and Vanderwart's object databank (Snodgrass & Vanderwart, 1980), he correctly and spontaneously named 30 of them, was in difficulty (i.e. he was often able to name them but only after a long and perilous effort) with 40 objects, and was unable to recognize 30 objects. Interestingly, when given the same 100 objects one month later, only one from the 30 objects previously recognized was not identified, and only three from the 30 objects previously unrecognized were, this time, correctly named, thus showing the stability of his visual recognition abilities.

Face processing was tested by the Bruyer and Schweich battery (1991) and NS performed flawlessly in the following tasks in which only score accuracy was measured: *facial decision* (to classify colored photographs as faces or non-face objects, 30 items), *visual analysis of facial features* (to find a target feature—mouth, eyes, nose—among four possibilities, nine items), *visual analysis of unknown faces* (find a target face from among a set of 10, despite a change of expression or pose, 24 items), *facial expression* and *lip-reading analysis* (to classify photographs of unknown people according to whether they express a feeling of happiness, sadness, or they pronounce the phoneme [o], 12 items). He was almost flawless on *sex decisions* (18/20, controls mean 19.6) and *age decisions* (27/30 correct, controls 29.1) on unfamiliar faces. He was however severely impaired at a *face recognition task*, classifying correctly as famous or unknown only 31/48 items (controls mean 46.2) but being unable to name any of the famous faces. When we presented a subset of these faces to him during a limited time (10 s maximum) and with all external cues, he was completely unable to discriminate a famous from an unknown face (1/25). Furthermore, he was largely below the normal range at the Warrington face recognition test (27/50). We administrated him also the Benton and van Allen face recognition test (Benton & Van

[3] Eighty-eight pictures of objects taken from the Snodgrass and Vanderwart (1980) battery, and 88 non-objects taken from the Kroll and Potter (1984) set.

[4] Even when he managed to name the object, this process was very slow for most of them: only 19% of all objects were correctly named in less than 2 s. For example, when having to recognize a saltshaker, NS started to describe what he saw: "*is that a little bottle? Hmm . . . one part of the object is like a glass and another part contains holes ... 15 holes . . . it might serve to mash fruits, to get orange juice . . . oh yeah, that's a saltshaker*".

Allen, 1968), and he had a pretty high score for a neuropsychological patient (40/54), a performance that would put him just below the normal range of normal subjects (‘mildly impaired’). However, he was particularly slow at doing the test (mean response time by item: 55 s).

2.5. Summary

Considering the extent of his neuropsychological deficits after the accident, NS has remarkably recovered 10 years later, to the point that he is now back to working full time as a researcher in a laboratory. Yet, he presents severe impairments in visual short-term memory as well as in long-term memory for verbal and visual material. However, the most striking impairment of NS is his inability to recognize common objects and people by their faces. His deficit cannot be defined in terms of optic aphasia since he does not have only object naming problems but he is also unable to mime the utilization gesture or to give a verbal description of the objects he cannot name. Likewise, an account in terms of semantic agnosia can be excluded since NS does not present any semantic deficits. His failure at a simple object decision task indicates that he does not have access to a proper visual structural representation of common objects. Regarding his perceptual processing of objects, he is flawless and fast at the two sub-tests of the BORB testing object matching under different viewpoints (tests 7 and 8). Furthermore, his copying of drawings is good, arguably better than some patients who have been defined on the same criterion as associative agnosics (e.g. Farah, 1990, p. 17; Humphreys & Rumiati, 1998). He was also reported normal at matching task on faces, as well as gender, age, and expression processing (although we do not have information about his response times), despite being largely impaired at recognizing famous and familiar people. Yet, he sometimes made one or two errors at object and face matching tasks where controls were correct without any hesitation and was slightly below the normal range (and slow) at the Benton face matching test. Furthermore, he was fast in the object perception tasks that we administrated to him, but was reported slow a few years before. In the following section, we report the testing of NS in a number of experiments (mostly on computer) aimed at testing the integrity of his high-level visual processing of objects and faces. Importantly, since we measured response times in many tasks during this investigation, we first ensured that NS was as quick as normal subjects at a phasic alert task (detecting a cross in the center of a computer screen), for which he scored in the normal range (231 ms, percentile 62).

3. Experiments

In all experiments, controls were matched for sex, age (between 45 and 55 years old) and level of education. These experiments used a binary decision task for which the subjects had to make their decision as accurately and quickly as possible and by pressing one of two keys on the computer keyboard. Stimuli were presented during 10 s maximum (or until response; 8 s for experiment 2).

3.1. Experiment 1: overlapping drawings detection task

Although associative agnosics such as NS are able to describe the visual appearance of objects they cannot recognize, previous investigations of such patients have revealed perceptual impairments not apparent in describing objects or copying drawings (Farah, 1990). The patient HJA (Riddoch & Humphreys, 1987), defined as an apperceptive agnosic, was also able of correct matching of objects and correct drawings, although particularly slow, but presented large difficulties at several tasks testing the integration of visual stimuli, and was characterized as a case of apperceptive integrative agnosia (see also the patients of Arguin, Bub, & Dudek, 1996; Butter & Trobe, 1994). HJA was disproportionately impaired at recognizing overlapping drawings, relative to normal subjects, a task that taps visual segmentation processes (Riddoch & Humphreys, 1987). Although NS is able to read overlapping letters perfectly, we tested his ability to cluster segments of line together properly by means of overlapping drawings (Fig. 3A). Two sheets of paper were presented to NS. Three overlapping drawings were located on one sheet, and six non-overlapping drawings were shown on the other one, of which three of them were identical to those from the first sheet. NS was simply asked to designate the three objects that overlapped, among the six presented individually. He was flawless (20/20) and fast in the extraction of three objects from the six overlapped figures. However, NS could have performed the overlapping objects simply using the features that are not superimposed such as the end of the key producing from the central mass. A variant of this experiment was thus administrated to the patient. In this task, the figures were not those from the three overlapped objects, but were created by putting together different parts of the overlapped objects (Fig. 3B). If the patient based his judgments on local features that are not superimposed, he should be impaired at this task. We built 90 overlapped figures and displayed one by one on the top of a computer screen. At the same time, one figure was displayed at the bottom of the screen and the patient was asked to decide, as fast as possible, whether this figure was one of the three overlapped. For half of the trials, the figure presented below matched one of the three overlapped figures. NS performed under normal range (86.67%; controls: 95.36%; S.D.: 21.05; $Z = 0.413$, $P = 0.660$)[5] and was not slower (5890 ms; controls: 3304 ms; S.D.: 2632; $Z = 0.983$, $P = 0.163$) compared to eight age-matched controls.

[5] The Z-score is the ratio of the difference between NS’ score and the normal controls average score by the standard deviations of the normals. A Z-score >2 means that NS’ performance is above or below 2 S.D. of the normals.

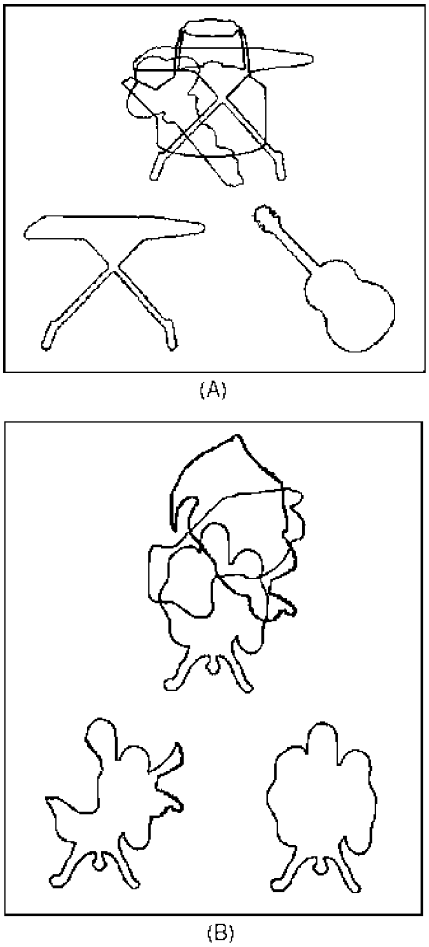

Fig. 3. Example of three overlapping drawings used in the first part (A) and the second part (B) of the overlapping drawings detection task (experiment 1).

3.1.1. Conclusion

Unlike other previously reported cases of visual agnosia, such as HJA, NS is not impaired at visual segmentation processes required to identify overlapping objects.

3.2. Experiment 2: object decision task with original drawings, silhouettes, and outlines

A distinctive characteristic of HJA is that he was paradoxically better at recognizing objects that were depicted in silhouettes than as line drawings, suggesting that he had troubles to perceive or integrate the internal details of a stimulus (Riddoch & Humphreys, 1987). Similarly, we tested NS at an object decision task on computer with objects in three formats: original drawing, silhouette, and outline (Fig. 4). There were a total of 240 stimuli: 40 objects taken from the Snodgrass and Vanderwart (1980) battery, and 40 non-objects taken from the Kroll and Potter (1984) battery, each in the three different formats. All of the stimuli were mixed and displayed in random order. The patient had to decide whether the stimulus represented a real object or not.

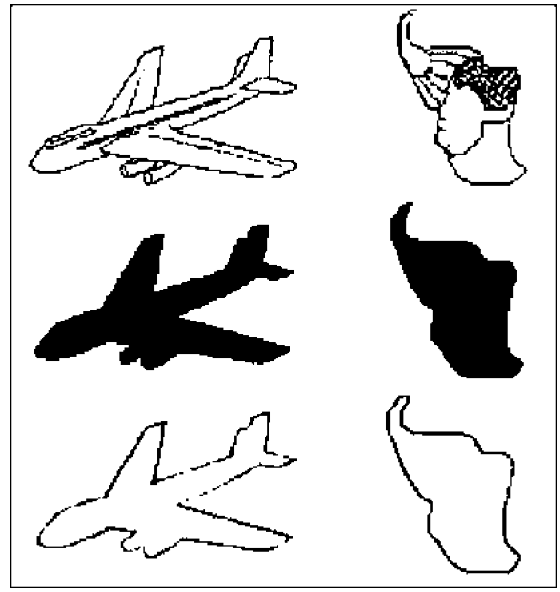

Fig. 4. Example of original drawing, silhouette and outline used in the object decision task with original drawings, silhouettes, and outlines (object on the left, non-object on the right) (experiment 2).

The results (accuracy and correct response latencies) are shown in Table 1. As expected, NS was strikingly impaired at this task compared to seven age-matched controls ($Z = 1.655$, $P < 0.5$ for the accuracy; $Z = 7.65$, $P < 0.001$ for the correct response latencies). There was a significant effect of *format* for the controls concerning both the accuracy and the correct response latencies ($F_{2,12} = 4.779$, $P < 0.05$, and $F_{2,12} = 8.583$, $P < 0.005$, respectively), with an advantage of the original drawings over the silhouettes for the accuracy ($P < 0.05$), and an advantage of the original drawings over the outlines and the silhouettes for the correct response latencies ($P < 0.05$ and 0.005, respectively). In contrast, despite a tendency to be better at original drawings, there was no significant difference between these three formats for NS in both accuracy ($F_{2,113} = 1.691$, $P = 0.189$) and correct response latencies ($F_{2,67} = 2.345$, $P = 0.104$).

3.2.1. Conclusion

Contrariwise to HJA, NS does not perform better with silhouettes or outlines. Instead, he tends to be even better at recognizing drawings with internal details.

Table 1
Accuracy and correct response latencies of NS and control subjects at the object decision task of original drawings, outlines, and silhouettes (experiment 2)

	NS		Controls ($n = 7$)	
	Correct (%)	RTs (ms)	Correct (%)	RTs (ms)
Original drawings	71.05	4417	99.25 (S.D. 08.65)	629 (S.D. 145)
Outlines	50	3630	94.96 (S.D. 21.93)	757 (S.D. 401)
Silhouettes	59.09	2810	92.21 (S.D. 26.85)	819 (S.D. 766)

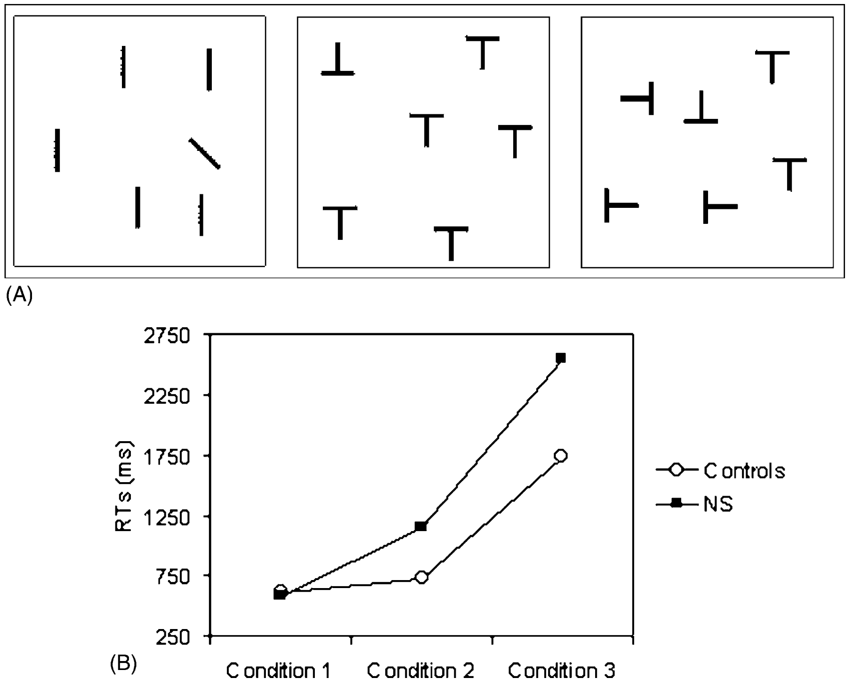

Fig. 5. The three conditions used in the visual search task (experiment 3) are shown in (A). In the first condition (on the left), the target is the 45° oriented line, whereas in the second (in the center) and the third condition (on the right), the target is the inverted "T". Results (correct response latencies) of NS and control subjects are shown in (B).

3.3. Experiment 3: visual search task

Although NS presented different patterns of performance than HJA at experiments 1 and 2, he might still have slight difficulties at integrating features in a coherent percept. The third experiment is a visual search task inspired from Treisman and Gelade (1980), and with which HJA also shown an abnormal pattern of performance (Riddoch & Humphreys, 1987). Three conditions were run (Fig. 5A): (1) detection of an oblique line (tilted 45°) among vertical lines; (2) detection of a combination of two lines forming an inverted "T", displayed amongst homogeneous distractors forming an upright "T"; and (3) detection of a "T" among heterogeneous distractors (upright, 90°and 270° "T"). Classically, normal subjects are quite efficient and relatively insensitive to the numbers of distractors presented when these distractors are homogenous (conditions 1 and 2) thanks to parallel grouping operations. In contrast, they are less efficient and sensitive to the numbers of distractors present when distractors are heterogeneous (condition 3) (Humphreys, Quinlan, & Riddoch, 1989). A selective deficit in feature integration, which prevents any parallel grouping, would foretell poor performances and/or increases in RTs particularly at the condition 2, for which items are combinations of two features, and distractors are homogeneous. In each condition, we used 80 trials in each condition for which the target was present in 50% of the trials. The number of distractors in an array was 5 or 9. Although they knew in advance the condition in which they were tested, the presence versus the absence of the target, as well as the number of distractors, was presented randomly.

Accuracy rates and RTs for correct trials for NS and six age-matched controls are presented in Table 2 and Fig. 5B. For the first and second task, control subjects were quick and insensitive to the number of distractors ($F_{1,4} = 0.036$, $P = 0.858$ and $F_{1,4} = 1.049$, $P = 0.364$, respectively) and to the presence or the absence of the target ($F_{1,4} = 1.262$, $P = 0.324$ in the first condition and $F_{1,4} = 0.518$, $P = 0.511$ in the second condition). Response times in the third condition, however, were slower and indicated an effect of the number of distractors ($F_{1,4} = 84.694$, $P < 0.001$, set size 5 < set size 9) and of the presence or the absence of the target ($F_{1,4} = 35.882$, $P < 0.005$, presence < absence). NS showed a different pattern of performance. His response times in the first condition were as quick as control subjects and were not affected by the number of distractors. However, in the second condition, he was significantly slower than controls ($Z = 4.87$, $P < 0.001$), especially when there were nine distractors and no target present in the display. In the third condition, he was also slower than control subjects ($Z = 2.95$, $P < 0.01$). However, as indicated by an analysis of the differential RTs between conditions 2 and 3, the increase of RTs between these two tasks was of the same magnitude for NS and for control subjects ($Z = 0.687$, $P > 0.05$).

This pattern of results is highly interesting. First, it confirms that NS is able to respond quickly in simple attentional tasks (task 1). But most importantly, although he

Table 2
Scores and correct response latencies of NS and control subjects at the visual search task (experiment 3)

	Distractors	Target	NS		Control ($n = 6$)	
			Scores	RTs (ms)	Scores	RTs (ms)
Condition 1	5	Yes	20/20	559	19–20/20	628 (S.D. 114)
		No	20/20	601	19–20/20	590 (S.D. 93)
	9	Yes	20/20	570	19–20/20	621 (S.D. 105)
		No	20/20	593	20/20	626 (S.D. 85)
Condition 2	5	Yes	20/20	999	19–20/20	699 (S.D. 80)
		No	20/20	1045	19–20/20	728 (S.D. 123)
	9	Yes	20/20	1061	19–20/20	711 (S.D. 73)
		No	20/20	1487	19–20/20	770 (S.D. 112)
Condition 3	5	Yes	18/20	1767	15–20/20	1064 (S.D. 158)
		No	20/20	2675	20/20	1829 (S.D. 327)
	9	Yes	13/20	2287	15–20/20	1531 (S.D. 272)
		No	20/20	3449	20/20	2557 (S.D. 443)

performed at ceiling, he was dramatically slowed down at the second task—which requires the integration of the two features—relative to the performance of control subjects. This was particularly the case with a larger number of distractors (9). Interestingly, this last effect cannot be attributed to a mere increase of task difficulty, because his increase of response times between the second and the third task—which does not require the integration but request a serial selection of stimuli one at a time—was of the same order of magnitude than control subjects (see Table 2).

3.3.1. Conclusion

Although NS performs in the normal range and relatively quickly, this experiment suggests that he may be in difficulty when having to integrate several visual features to form a coherent percept of an object.

3.4. Experiment 4: possible/impossible object decision task

Given the outcome of experiment 3, NS was tested in a task—inspired from Ratcliff and Newcombe (1982)—which required the integration of multiple lines in space, to form a coherent percept of a three-dimensional (3D) object. NS was presented with complex volumetric figures (Fig. 6), with the task to decide whether they were structurally possible (i.e. could exist in the real world as a 3D structure) or impossible. Thirty-five possible and 35 impossible figures were used (for the whole set of objects, see Williams & Tarr, 1997; http://www.cog.brown.edu/∼tarr/stimuli.html) and displayed one by one in the center of the screen. For normal subjects, the structural impossibility of some of these figures is perceived rapidly, without having to check every single line joints for any incoherence. NS was disproportionately impaired ($Z = 2.64$, $P < 0.01$) at this task, and slowed down (RTs: $Z = 2.36$, $P < 0.005$) compared to nine age-matched controls, scoring at 76% (significantly better than at chance: $P = 0.0018$) with a mean correct response time of 5477 ms (controls: 91%, 3003 ms ± 1048).

3.4.1. Conclusion

Although NS performed better than at chance at this computer task (with limited time presentation) whereas the patient of Ratcliff and Newcombe (1982) was unable to perform the task, he scored clearly below the normal range

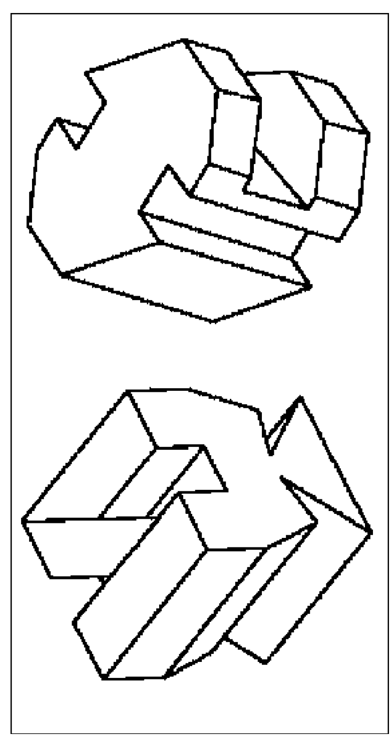

Fig. 6. Example of possible figure and impossible figure used in the possible/impossible figure decision task (experiment 4).

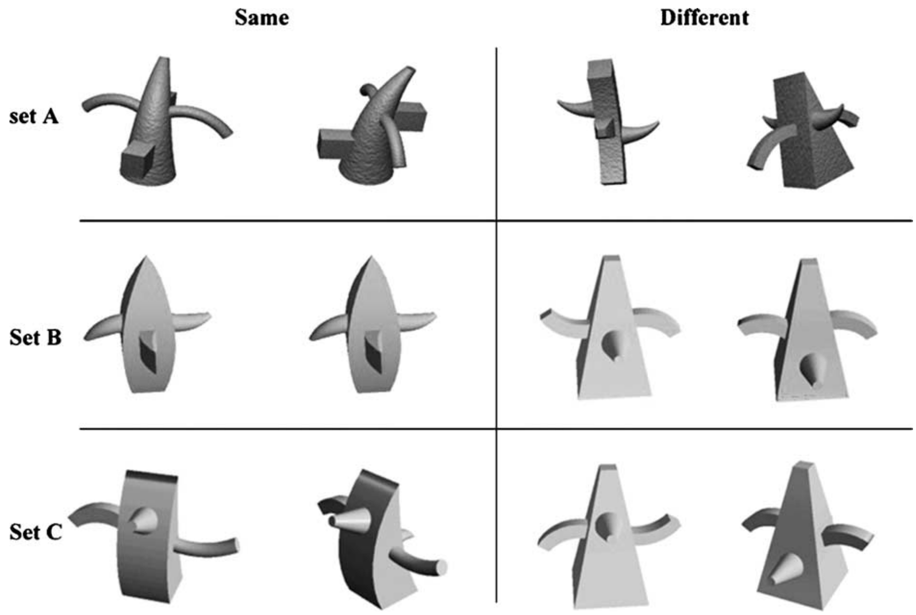

Fig. 7. The three conditions used in the structural encoding of novel objects task (experiment 5).

and was slowed down compared to controls. A deficit at this task suggests that the complex integration of object parts at the level of the three-dimensional structural description system (Schacter, Cooper, & Delaney, 1990) is at least partly damaged. Importantly, this task is performed on novel objects, and thus the control subjects were put in the same conditions as NS, unable to use any sort of prior knowledge about how these objects appear in real life to take their decision.

3.5. Experiment 5: structural encoding of novel objects

In order to test further the integrity of NS' structural encoding system, we tested him in simultaneous object matching tasks of structurally similar (but not identical) 3D novel objects[6] presented during a limited time. In contrast to the tasks from the BORB (*minimal feature view task*, *foreshortened match task*), in which objects presented in different viewpoints were also used in order to be matched, these tasks were particularly demanding because all objects were highly similar structurally, and no surface cues could be used to discriminate between them. Moreover, because all were non-existent objects, normal subjects could not use any knowledge-based strategy to perform the task and thus did not have any advantage over NS.

In a first task (set A), 10 objects, each with a different vertically-oriented central volume, and four smaller horizontally-oriented volumes attached to it ("parts"), were used (Fig. 7). In the other two tasks (sets B and C), 12 objects, each with the exact same vertically-oriented central volume, but with different parts were used. In all three tasks, five versions of each object, which correspond to five different viewpoints (0, 30, 45, 60, and 90°), were used. Two objects were presented simultaneously and the task was to decide whether the objects were identical or different. Forty pairs were presented in the first task (set A), and 60 pairs in the other two tasks (sets B and C). In each task, half of the trials presented the same object. In the first and third task (sets A and C), the objects in a pair were presented under different viewpoints, whereas in the second task (set B), they were presented under the same viewpoint.

For the 'identical' trials, there was no significant difference between the performance and the speed of NS and the nine age-matched controls to perform the three conditions (Table 3, all $P > 0.05$). However, NS was disproportionately impaired in all conditions for the different trials. This was observed when he had to distinguish two novel objects presented under different viewpoints, whether they had a different central part (set C; $Z = 5.04$, $P < 0.001$) or not (set A; $Z = 2.48$, $P < 0.01$). He performed also below the normal range for the set of objects presented under the same viewpoint (set B; $Z = 4.93$, $P < 0.001$), and was slowed down in the three conditions compared to controls (set A: $Z = 5.62$, $P < 0.001$; set B: $Z = 1.85$, $P < 0.05$; set C: $Z = 3.136$, $P < 0.001$).

3.5.1. Conclusion

NS is clearly impaired relative to controls at matching tasks that require exclusively the integrity of high-level visual processes, without any involvement of previous knowledge about objects. His response times also reflect his difficulty at performing these tasks. There does not seem to be a dramatic effect of viewpoint change on NS'

[6] Objects from the Brown University Object Data Bank (Tarrlab): http://www.cog.brown.edu/~tarr/.

Table 3
Accuracy and correct response latencies of NS and control subjects at the structural encoding of novel objects task (experiment 5)

		NS		Controls ($n = 9$)	
		Correct (%)	RTs (ms)	Correct (%)	RTs (ms)
Set A (identical central part) different viewpoint	Same	75	4323	71 (S.D. 12.4)	3414 (S.D. 1496)
	Different	85	4828	98.1 (S.D. 2.6)	1771 (S.D. 544)
Set B (different central part) same viewpoint	Same	96.7	2560	99.2 (S.D. 1.57)	2028 (S.D. 728)
	Different	75.1	2294	96.9 (S.D. 4.42)	1416 (S.D. 280)
Set C (different central part) different viewpoint	Same	69	7018	75 (S.D. 12.4)	5339 (S.D. 1970)
	Different	69	7431	88.3 (S.D. 7.76)	4763 (S.D. 1439)

Fig. 8. Example of cars used in the matching structurally similar objects task (experiment 6).

performance and RTs since the patient presents large difficulties even when the viewpoint is kept constant (set B).

3.6. *Experiment 6: matching structurally similar objects task*

The previous experiments have suggested that NS presents deficits at extracting an integrated or perceptually coherent representation of a whole object. Given this, he should also be impaired at recognizing structurally similar real objects. In this experiment, we tested NS with a simultaneous matching of cars presented under different viewpoints (one full front, one 3/4 profile). Seventy-two pairs of gray-level pictures of cars (Fig. 8) were used and displayed in the center of the screen. NS' performance he was below normal controls, and slowed down relative to controls (Table 4; accuracy: $Z = 2.34$, $P < 0.01$, RTs: $Z = 2.14$, $P < 0.05$).

3.6.1. *Conclusion*

This experiment confirms that NS presents some deficits at the perceptual level for structurally similar objects, which extend to real, known objects.

Table 4
Accuracy and correct response latencies of NS and control subjects at the matching structurally similar objects task (experiment 6)

	NS		Controls ($n = 8$)	
	Correct (%)	RTs (ms)	Correct (%)	RTs (ms)
Identical trials	97	3802	97 (S.D. 3.2)	2595 (S.D. 1025)
Different trials	78	3478	92.3 (S.D. 4.95)	1229 (S.D. 371)

3.7. *Experiment 7: perceptual processing of upright and inverted faces*

Just how good is NS with perceptual aspects of face processing? In a previous report, he had been reported as normal at all tasks requiring a visual analysis of unfamiliar faces and thus classified as an associative prosopagnosic (Pesenti et al., 2000). However, he was tested with unlimited presentation time, and external cues (haircut, rings, etc.) were present in the stimuli (see Bruyer & Schweich, 1991). He also achieved a reasonable score at the Benton face matching test, but several authors have criticized this test as a correct measure of prosopagnosic abilities at face perceptual tasks, at least when the response time is not considered (e.g. Davidoff & Landis, 1990; Duchaine & Weidenfeld, 2003; Sergent & Signoret, 1992).

The previous experiments on novel objects have suggested that NS presents difficulties at the perception of an object as an integrated structure, and thus it is particularly difficult for him to discriminate these objects when they have similar features and organization. Compared to other categories of objects, faces form, arguably, the most 'visually homogeneous' category (Damasio, Damasio, & Van Hoesen, 1982): all members of the face category share the same types of features, and the same basic organization of these features (a central elongated nose below two eyes and above mouth). Furthermore, behavioral studies in normal subjects have shown that faces are perceived holistically, i.e. with little or no decomposition in parts (Farah, Wilson, Drain, & Tanaka, 1998). This holistic hypothesis is mainly based on the whole/part advantage effect—the fact that face parts are better recognized when presented in the whole face than isolated (Tanaka & Farah, 1993). Interestingly, when faces are presented upside-down, this effect is not observed, suggesting that the holistic perception of faces is disrupted by inversion (Maurer, Le Grand, & Mondloch, 2002; Tanaka & Farah, 1993). Thus, given his perceptual deficits at integrating object features and his massive prosopagnosia, we hypothesize that NS, despite his normal performance at face matching tasks as measured by the Bruyer and Schweich battery (1991) and the Benton face matching test (lower range), should present also large deficits at the extraction of coherent individual face representations. In addition, since

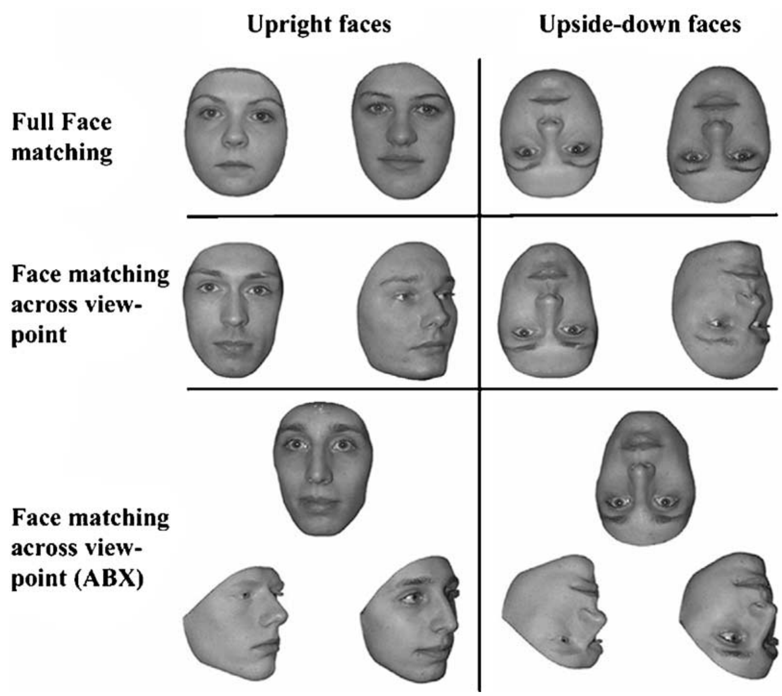

Fig. 9. The three conditions used in the perceptual processing of upright and inverted faces task (experiment 7).

NS cannot rely on any configural (holistic or metric, see Maurer et al., 2002) information to process faces, he should not present an advantage for upright faces, and thus a reduced difference between upright and inverted faces or no difference at all, as it has been shown for other prosopagnosics (Boutsen & Humphreys, 2002; Gauthier et al., 1999; Marotta, McKeeff, & Behrmann, 2002; Maurer et al., 2002). Sixty pairs of faces (Fig. 9) were presented in three different tasks. In the first task, the two faces of a pair were presented full front. In the second task, one face was presented full front and the other as a 3/4-profile view. In the last task (ABX), one target full front face was presented on top of a pair of 3/4 profile faces, the same person as the target and a distractor. In all three tasks, 2 conditions were compared, namely upright and upside-down faces.

The results at these tests are presented in Table 5. When both faces of the pair were presented simultaneously, NS's performance was inferior to controls for both upright ($Z = 15.59$, $P < 0.0001$, RTs: $Z = 2.54$, $P < 0.01$) and inverted (accuracy: $Z = 3.93$, $P < 0.001$) faces. Moreover, there was no difference between upright and inverted faces for NS (t-test on items; accuracy rates: $t_{114} = 0.442$, $P = 0.659$; RTS: $t_{90} = 1.316$, $P = 0.191$) while there was a significant difference for the control subjects (accuracy rates: $t_4 = 2.127$, $P < 0.066$; RTs: $t_4 = 3.144$, $P < 0.05$). Two other tests confirmed the absence of inversion effect for NS either when the 2 faces were presented under different viewpoints (accuracy rates $t_{99} = 0.890$, $P = 0.376$: RTS: $t_{102} = 1.07$, $P = 0.285$) or when one of two faces had to be matched to a simultaneously presented target (accuracy rates: $t_{59} =$

Table 5
Accuracy and correct response latencies of NS and control subjects at the perceptual processing of upright and inverted faces task (experiment 7)

	NS		Controls ($n = 5$)	
	Correct (%)	RTs (ms)	Correct (%)	RTs (ms)
Full face matching				
Upright faces	78	2769	96.7 (S.D. 1.18)	1808 (S.D. 379)
Inverted faces	75	2441	92.7 (S.D. 4.50)	2411 (S.D. 200)
Face matching across viewpoint				
Upright faces	56	5720	79.4 (S.D. 6.22)	3120 (S.D. 422)
Inverted faces	64	6046	76.2 (S.D. 7.22)	3397 (S.D. 615)
Face matching across viewpoint (ABX)				
Upright faces	65	6124	87.4 (S.D. 6.00)	2718 (S.D. 828)
Inverted faces	54	5839	77.1 (S.D. 3.78)	4149 (S.D. 1007)

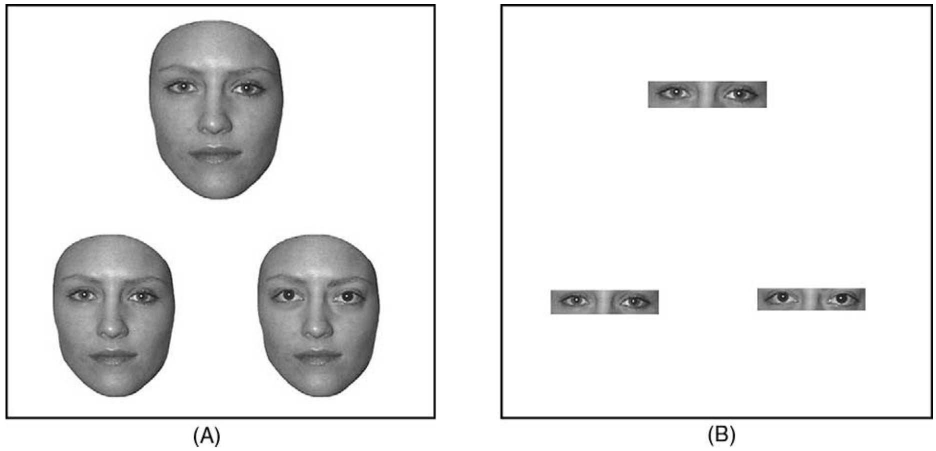

Fig. 10. Example of stimuli used in the perceptual processing of whole (A) and parts (B) faces matching task (experiment 8).

0.890, $P = 0.376$: RTS: $t_{102} = 1.07$, $P = 0.285$). In both cases, his performance for upright faces was largely below the normal range (pairs: accuracy rates: $Z = 1.74$, $P < 0.05$, RTs: $Z = 6.16$, $P < 0.001$; triplets: accuracy rates: $Z = 3.66$, $P < 0.001$, RTs: $Z = 1.68$, $P < 0.05$).

3.7.1. Conclusion

The results of these simultaneous face matching tasks are crystal clear: NS presents large difficulties at perceptual aspects of face processing, and his former classification as an associative prosopagnosic on the basis of his performances at the Bruyer and Schweich battery (Bruyer & Schweich, 1991; Pesenti et al., 2000; Schweich & Bruyer, 1993) was incorrect. Moreover, neither NS' performance rate nor his average response time suffered at all from the upside-down inversion of the face, whereas normal controls showed the classical face inversion effect. This confirms the hypothesis that, contrary to controls, NS is not using relational features at all when matching upright faces.

3.8. Experiment 8: perceptual processing of whole and parts faces matching task

The last experiment tests more directly the hypothesis that NS presents a deficit at extracting a holistic perception of a face. NS and normal controls were presented with simultaneous triplets of either whole faces differing by a single part (the eyes), or the parts presented in isolation (eyes), with the task of matching the upper stimulus to one of the lower stimuli (90% of size of the stimulus presented above) (Fig. 10). In the two conditions, the physical difference between the two stimuli was thus identical. Forty trials were used in each condition and displayed one by one in the center of the screen. Accuracy rates and RTs for correct trials for NS and seven age-matched controls are presented in Table 6 and Fig. 11. Controls did not show any advantage, performing slightly better with whole faces compared to isolated features ($t_6 = 1.313$, $P = 0.237$), but also slower ($t_6 = 2.201$, $P = 0.07$), both effects being non-significant.

Table 6
Accuracy and correct response latencies of NS and control subjects at the perceptual processing of whole and parts faces matching task (experiment 8)

	NS		Controls ($n = 7$)	
	Correct (%)	RTs (ms)	Correct (%)	RTs (ms)
Whole face	50	4257	90.42 (S.D. 10.5)	2126 (S.D. 566)
Parts	75	4216	85.91 (S.D. 02.8)	1842 (S.D. 351)

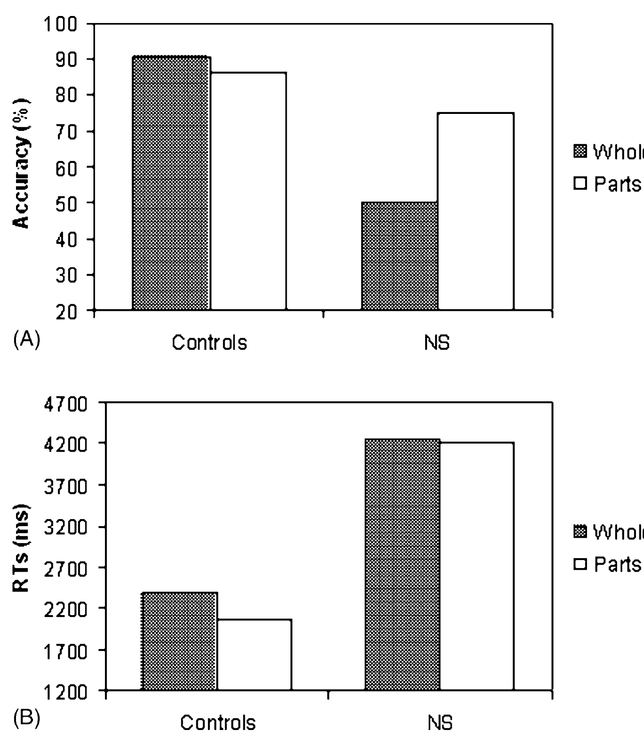

Fig. 11. Accuracy (A) and correct response latencies of NS and control subjects at the perceptual processing of whole and parts faces matching task (experiment 8).

Overall, NS was lower in that task compared to controls in accuracy ($Z = 4.176$, $P < 0.001$) and correct response latencies ($Z = 5.132$, $P < 0.001$), but more importantly, he was much better than at chance for isolated parts ($P = 0.02$) but not for whole faces. When compared directly, the first condition was also performed better than the second one ($t_{78} = 2.36$, $P < 0.05$), but there was no difference for the correct response latencies ($t_{48} = 0.934$, $P = 0.355$).

3.8.1. Conclusion

NS performs better with matching face parts than whole faces differing by single parts. This can be interpreted in two ways. On the basis of a similar result in HJA, Boutsen and Humphreys (2002) suggested that there was an interference of contextual information (the whole face) on the processing of face parts, in the line of Farah and colleagues (Farah, Wilson, Drain, & Tanaka, 1995; see also Marotta et al., 2002). On the other hand, it may well be that face parts in isolation are easier to match simply because the patient does not have to scan the whole face to detect differences or check for identity when presented with face parts. In other words, there may not be any interference mechanisms at work here, but simply a loss of holistic face processing abilities in NS and a reliance on an analytical strategy that is more efficient when the parts to look at have been selected for the patient. The fact that isolated face parts are also easier to match than whole faces also when all stimuli are presented upside-down (Boutsen & Humphreys, experiment 2), supports this latter (and simpler) explanation.

4. General discussion

We reported the detailed case study of a visual agnosic, measuring his performance and response times on a number of object and face perceptual tasks. In a nutshell, this investigation in a patient who performs normally at classical tests of high-level visual processing, led us to conclude nevertheless that his deficits lay at the perceptual level. More precisely, NS appears to have troubles integrating features as a whole percept, for both faces and objects. These observations have both theoretical and methodological implications for studies of associative visual (prosop)agnosia.

4.1. Evidence for perceptual deficits in visual associative agnosics

According to the classification criteria of agnosias generally used to distinguish apperceptive from associative agnosia (Humphreys & Riddoch, 1987; Lissauer, 1890), there is no doubts that NS should be categorized as an associative agnosic. Indeed, while presenting large difficulties at recognizing a variety of visually presented objects, he does not present any low-level visual deficits and performs normally at tasks such as visual matching (e.g. tasks from the BORB) and copying of drawings.

However, we observed that when tested with matching tasks for structurally similar objects and possible/impossible decision tasks (experiments 4–6), NS was disproportionately impaired and slowed down compared to controls. Furthermore, although he performed at ceiling and reacted as fast as controls for a simple line detection task, he was disproportionately slowed down when two lines had to be combined to detect distractors (experiment 3). This result and the outcome of the other experiments show the importance of measuring RTs during object perception tasks in visual agnosics to reveal deficits at object perception, which would have been most likely hidden if only accuracy scores had been measured (see Gauthier et al., 1999).

Overall, these observations strongly reinforce Farah's view (Farah, 1990) that a perceptual impairment necessarily subtends the deficits at object recognition presented by associative visual agnosic patients. A number of other cases have been described as associative visual agnosics in the literature, thus supposedly with preserved perception (e.g. Butter & Trobe, 1994; Humphreys & Rumiati, 1998; Turnbull & Laws, 2000). However, while being in the normal range, they actually perform below the patient reported here at the object matching tasks (for instance, the minimal feature views and foreshortened views) of the BORB, and their drawings are arguably not as good as those realized (quickly) by NS. Moreover, no information regarding the time taken by the patients for matching tasks are given. NS' case can also be related to the extensively studied patient LH (e.g. Levine & Calvanio, 1989; Farah et al., 1995) and HJA (Boutsen & Humphreys, 2002; Humphreys & Riddoch, 1987). However, NS' perceptual deficit appears even less severe and is thus harder to characterize. HJA has visual agnosia, prosopagnosia and alexia without agraphia, but also achromatopsia and topographical impairments (see Riddoch & Humphreys, 1987). His drawings of objects from copies are relatively good although slow and servile, he is also able to match objects presented under different viewpoints and he recognizes real objects better than line drawings (Riddoch & Humphreys, 1987). However, unlike NS, he presents large deficits at recognizing overlapped letters and objects (test 6 of BORB, and experiment 1, this paper), and shows an advantage at recognizing objects depicted as silhouettes (experiment 2). Accordingly, HJA has been classified as an apperceptive agnosic presenting problems at feature integration (Riddoch & Humphreys, 1987). LH (Farah et al., 1995; Levine & Calvanio, 1989; Levine, Calvanio, & Wolfe, 1980) has a massive prosopagnosia and object agnosia, being especially impaired at recognizing living things (Levine & Calvanio, 1989; Levine et al., 1980). He is severely impaired at tasks in which he has to complete fragmented objects or words to identify them (Levine et al., 1980), which suggested a deficit at holistic perception of objects, including faces (Levine & Calvanio, 1989). He presents however additional deficits at the lower level (color vision, low acuity, left superior quadranopsia), which certainly play a role in his performances at object and face processing. Arguably, these patients do not provide any serious challenge to the claim that a case corresponding to the classical definition of visual associative agnosia, namely "a normal perception stripped of its meaning", does not exist, unless the patient presents deficits at the semantic level which thus concern the recognition of items through other modalities (see Farah, 1997). NS, the patient described here, presents similar patterns of performances with both HJA and LH (or other cases of integrative agnosia, e.g. Butter & Trobe, 1994), but the excellent preservation of his low-level visual abilities and neuropsychological functions allowed him not only to match and copy common objects accurately and quickly, but also to perform at a normal level at some tasks tapping visual integration processes, and thus made him a very good case to test whether 'associative' agnosic patients necessarily present perceptual deficits causing their deficits at object recognition. In sum, the present study supports this view, advocated by Farah (1990), although it still might be possible to describe a visual agnosic without any perceptual deficits in the future.

4.2. Is prosopagnosia also due necessarily to perceptual problems?

The conclusion that associative agnosics necessarily present perceptual problems should be extended to prosopagnosia (Farah, 1990): impairments in face recognition are most likely to be due to an inability to construct a correct individual representation of a face. Similarly to the debate concerning object agnosias, it has been argued that the preservation of the ability to match faces in some prosopagnosics excludes a perceptual defect as the explanation of prosopagnosia (De Renzi et al., 1991). However, the early cases upon which this proposal has been made (e.g. Assal, 1969; Benton & Van Allen, 1972) have been reported as achieving face matching tasks particularly slowly and with sequential strategies, strongly suggesting that their perception of faces was abnormal (see Levine & Calvanio, 1989). Over the last decade, a number of new cases of acquired prosopagnosia have been described (e.g. Barton, Press, Keenan, & O'Connor, 2002; Henke et al., 1998; Sergent & Signoret, 1992). The face perceptual abilities of these patients are usually assessed through the Benton and van Allen facial matching test or a variant. Although this test may not be the best indicator of the sparing of perceptual aspects of face processing (e.g. Davidoff & Landis, 1990; Farah, 1990; Sergent & Signoret, 1992), especially when no time constraint is imposed to the patients, it is striking that almost all reported cases of prosopagnosia have presented scores below the normal range at this perceptual face matching test (and below our patient NS). To our knowledge, over more than 30 cases reported in the last decade, the only exceptions described are the cases from the following studies (De Renzi & di Pellegrino, 1998; De Renzi et al., 1991; Henke et al., 1998; McNeil & Warrington, 1991; Nunn, Postma, & Pearson, 2001). However, in the three first studies, we have no indication of the time taken by the patients to perform the task or any description of the strategies used, whereas in the last two studies, the patients realized high scores, but were described as particularly slow and using a feature-by-feature strategy. In addition, a number of prosopagnosic patients (6/9) have also been described as performing in the normal range at face matching tasks tapping the structural encoding stage by Schweich and Bruyer (1993), and have thus been interpreted as associative prosopagnosics, supporting the distinction from apperceptive prosopagnosia (Schweich & Bruyer, 1993). Yet, this conclusion was based on the outcome of tests of the six patients at which our patient also succeeded flawlessly, despite his important deficit at perceptual aspects of face processing. How can two similar types of tests that are supposed to assess the same functions give completely different outcomes? The reason most probably lies in both the fact that the face stimuli used in the clinical battery were presented under completely natural conditions, with all external cues (glasses, earrings, etc.) and facial hair not removed or masked from the stimuli (see also Sergent & Signoret, 1992). Furthermore, we presented our face matching tasks to NS for a limited time (10 s maximum) and recorded his RTs, which were much longer than normals. Even when external cues are removed or masked, it is well known that most prosopagnosics have developed feature-by-feature analytic strategies that allows them to discriminate face stimuli, and achieve a reasonable level of performance, for instance, at the Benton face matching test. In any case, it is clear that NS presents large deficits at perceptual aspects of face processing when careful investigations are conducted. This observation casts serious doubts on the report of normal face perception in some (rare) prosopagnosic patients based on results at these batteries (e.g. De Renzi et al., 1991; McNeil & Warrington, 1991; Schweich & Bruyer, 1993) and thus on the very existence of associative prosopagnosia, as a deficit concerning the stored representations of faces with normal perception (e.g. De Renzi et al., 1991).

The absence of inversion effect (Yin, 1969) in NS is also consistent with a deficit at the visual level since behavioral, neuroimaging and electrophysiological studies all suggest that the origin of this 'face inversion effect' lies at the perceptual encoding level of faces, rather than at the storage of face representations in memory (see Rossion & Gauthier, 2002 for a review). The processing of inverted faces has been investigated previously in cases of prosopagnosia (e.g. Boutsen & Humphreys, 2002; Farah et al., 1995; Gauthier et al., 1999; Marotta et al., 2002). Some patients present a "normal" face inversion effect, although being largely impaired with matching upright faces (Gauthier et al., 1999), others show an absence of face inversion effect, consistent with NS' data (e.g. Boutsen & Humphreys, 2002; Marotta et al., 2002), and the prosopagnosic patient LH has been reported to perform even better with inverted faces than upright faces, although his performance with inverted faces remains below normal controls (Farah et al., 1995). There is thus no general pattern of performance for prosopagnosic subjects at tasks of matching individual upright and inverted faces, although a majority of such patients present a reduced or an absence of difference between upright and inverted faces (Boutsen & Humphreys, 2002; Marotta et al., 2002; the present study). Furthermore, all these patients are similar in that they are all clearly impaired at perceptual aspects of face processing, and they also present object recognition problems (Gauthier et al., 1999; Levine & Calvanio, 1989). Their different pattern of performance with upright and inverted faces may be thus due to different tests and stimuli, but more likely to different degrees of low and high-level visual impairments.

In sum, the present case study and the previous literature supports the idea that 'associative' prosopagnosia refers actually to a deficit at the perceptual level, that is at high-level visual processes necessary to extract a correct individual representation of a face.

4.3. A deficit in the holistic perception of objects and faces

At which functional stage(s) of perceptual processing of object is NS impaired? From his pattern of results at the various experiments, it must be clear that he presents some deficits at extracting a structural representation of objects and faces, i.e. a complete visual representation of the object or face parts and of the relationships between these parts. According to Farah (1990, 1991), the construction of such a representation can be divided in two main capacities or processing systems, one—localized mainly in the left hemisphere—being the ability to decompose objects into multiple parts, and the other—right lateralized—to represent the parts themselves or the whole object if it cannot be decomposed into parts. Depending on which of these two abilities is impaired and to what degree, the associative agnosic will be in difficulty recognizing either objects that undergo little or no part decomposition (such as faces), or objects that needs to be divided into multiple parts for their recognition (such as words). According to this framework, these two types of stimuli represent two extremes of a continuum, on which other types of objects would be represented, depending on their relative reliance on part decomposition or holistic processes. Depending on the type of ability impaired and the degree of visual impairment, the patient will thus either suffer from one of five syndromes: pure alexia, alexia + object agnosia, pure prosopagnosia, prosopagnosia + object agnosia, or the three deficits if the two processing abilities are damaged (Farah, 1991).

NS can be relatively easily interpreted within this framework since he presents a massive prosopagnosia and an object agnosia, but no alexia, following bilateral posterior lesions with a right predominance. These observations are fully consistent with the nature of his problems at the object perception experiments that we administrated to him. The possible/impossible object decision task can be performed by a part-by-part analysis, but becomes then excessively slow, and could certainly not be performed within the 10 s allowed for most trials. By contrast, for normal controls, the inadequacy of impossible objects is striking and can be apprehended rapidly, not by a part-by-part analysis but by referring to the global structure of the object (see Fig. 7). Similarly, NS' disproportionate impairment and slowing down at discriminating structurally similar novel objects (experiment 5) is consistent with the inability to perceive objects as a whole structure in a glance. Finally, his poor performances at perceptual face processing, the absence of a decrease of performance for upside-down faces and his advantage at processing isolated face parts all point out to the idea that his deficit concerns the inability to process objects that are perceived holistically (Farah, 1991).

Acknowledgements

The research reported in this article was conducted by Jean-François Delvenne in partial fulfillment of the requirements for a Master degree at the University of Louvain (UCL) under the supervision of Xavier Seron and Bruno Rossion. J.F.D. and B.R. are currently supported by the Belgian National Fund For Scientific Research (FNRS). We are deeply indebted to NS for his time, willingness and efforts to do the experiments, and his insights about the nature of his difficulties at recognizing objects and people. We also thank Michael J. Tarr for making available the novel objects used in the experiment 5, Thomas James and an anonymous reviewer for their comments on previous version of this manuscript.

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