Can face recognition really be dissociated from object recognition?

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We argue that the current literature on prosopagnosia fails to demonstrate unequivocal evidence for a disproportionate impairment for faces as compared to non-face objects. Two prosopagnosic subjects were tested for the discrimination of objects from several categories (face as well as non-face) at different levels of categorization (basic, subordinate and exemplar levels). Several dependent measures were obtained including accuracy, signal detection measures and response times. The results from Experiments 1 to 4 demonstrate that, in simultaneous-matching tasks, response times may reveal impairments with non-face objects in subjects whose error rates only indicate a face deficit. The results from Experiments 5 and 6 show that, given limited stimulus presentation times for face and non-face objects, the same subjects may demonstrate a deficit for both stimulus categories in sensitivity. In Experiments 7-9, a match-to-sample task, that places greater demands on memory, led to comparable recognition sensitivity with both face and non-face objects. Regardless of object category, the prosopagnosic subjects were more affected by manipulations of the level of categorization than normal controls. This result raises questions regarding neuropsychological evidence for the modularity of face recognition, as well as its theoretical and methodological foundations.

"I shouldn't know you again if we did meet," Humpty Dumpty replied in a discontented tone... "You're so exactly like other people." "The face is what one goes by, generally," Alice remarked in a thoughtful tone. "That's just what I complain of," said Humpty Dumpty. "Your face is the same as everybody has - the two eyes, so -" (marking their places in the air with his thumb) "nose in the middle, mouth under. It's always the same. Now if you had the two eyes on the same side of the nose, for instance - or the mouth at the top - that would be some help."
-Lewis Carroll (1946)

Introduction

The study of visual recognition deficits is central to the issue of whether there is a special module or area of the brain dedicated to face recognition or whether faces are processed by more general-purpose visual recognition mechanisms. According to the logic of the double dissociation method, if a brain-lesioned subject could be shown to suffer from a selective visual agnosia (recognition deficit) for faces while recognition of all other visual stimuli remained intact (and vice versa for another subject), this would serve as an existence proof of the dissociability of face recognition from non-face object recognition.[1]

We wish to thank Dr. P. Freeman and Dr. G. Ratcliff for referring these patients to us as well as CR, SM and their families for their cooperation and goodwill. We are grateful to Ian Neath for sharing scanned version of the snowflakes from Bentley & Humphreys (1962). This work was supported by NSF award to MJT (SBR 9615819) and by NIH award to MB (MH-47566-06). Reprint requests should be sent to: Isabel Gauthier, Department of Psychology, Yale University, P.O. Box 208205, New Haven, CT 06520, email: *isabel.gauthier@yale.edu*

Prosopagnosia: Evidence for a face-specific disorder

A strictly face-specific agnosia, known as prosopagnosia, is rare. Whereas one might expect evidence to accumulate over time in support of this specific deficit, the reality of neuropsychological history tells a different story. New cases of prosopagnosia are constantly reported but few candidates express a *pure* deficit. Moreover, there is a growing number of questions concerning the interpretation of such deficits and their significance in the debate on the modularity of face recognition.

Whiteley & Warrington (1977) presented the first evidence that a face-specific perceptual classification deficit was responsible for prosopagnosia. Three prosopagnosic subjects were found to have marked impairment on face matching with only mild impairments with letters and objects. However, De Renzi (1986) pointed out that the subjects' scores were not shown to be worse than those of non-prosopagnosic right brain-damaged subjects, suggesting a more general right

[1] According to Shallice (1988), a true double dissociation requires Subject A to do better than Subject B on Task 1 and vice versa for the other task, e.g., a crossover interaction.

hemisphere deficit. De Renzi (1986) himself argued for a face-specific agnosia in one of his subjects. While unable to recognize faces, this subject was able to recognize some of his own personal belongings, for example, a razor and wallet among 6 or 10 similar objects. However, Sergent and Signoret (1992a) argued that De Renzi did not demonstrate that his subject would have failed an equivalent recognition test with faces. The task in question, that of finding a target among a small number of distractors, might have been a very easy one compared to the rigors of everyday face recognition. Sergent and Signoret tested three prosopagnosic subjects in forced-choice recognition tests similar to those used by De Renzi, for both faces and familiar objects. Their subjects performed equally with faces and non-face objects. Nonetheless, one of these subjects had retained the ability to recognize makes of cars (McNeil and Warrington, 1993, also presented the case of a prosopagnosic subject who could recognize individual sheep). However, in addition to performing poorly in De Renzi's task with non-face objects, this subject showed a difficulty in recognizing objects from some homogeneous classes such as felines and flowers.

Although the previous paragraph is not an exhaustive review of cases of prosopagnosia (see Farah (1990), McNeil and Warrington (1991), Young (1992) for reviews), it is meant to illustrate two salient features of this literature. First, because of the absence of pure cases of prosopagnosia, authors who wish to address the possibility of a face-specific recognition deficit have to rely on a basis for comparison, i.e., the performance of normal control subjects or non-prosopagnosic patients in tasks with faces and non-face objects. Second, virtually all reports of evidence for a face-specific recognition deficit have been criticized for the validity of the comparison, critics suggesting that it cannot rule out more general perceptual deficits and/or the possibility that a face task is simply more difficult than an object recognition on some other dimension.

In this study of prosopagnosia, we take as a representative case a recent demonstration of a face-specific recognition deficit (Farah, Levinson, & Klein, 1995). In this study, the authors argue that they have ruled out the differential difficulty of face recognition or a general deficit with homogeneous exemplars from an object category as explanations for the prosopagnosia of their subject. In two experiments, Farah, Levinson and Klein (1995) compared LH, a prosopagnosic subject, to normal controls for recognition of different exemplars of non-face object categories. Although LH was not as good as normal subjects at recognizing non-face objects, he was even more impaired when it came to the recognition of faces. These findings were taken as support for a face-specific module. Farah et al.(1995) argued that LH's deficit with faces could not be simply a deficit in discriminating among highly similar exemplars of the same object category (called here subordinate-level judgments) because his performance was relatively better when discriminating between different eyeglass frames. However, the subordinate hypothesis may require further consideration for two major reasons. First, Farah et al. did not consider the possibility that LH might have shown differential speed and/or response biases between non-face objects and faces (in fact, LH was given more time than controls to study the stimuli). Second, their argument rests on the validity of equating the difficulty of a face and object task based on the accuracy of control subjects. As we address later on, the differential expertise of control subjects with faces and objects may invalidate this methodology, especially if the perceptual difficulties of prosopagnosic subjects limit their use of previously acquired expertise. Because we believe that it may be very difficult to make a case for equivalent task difficulty when comparing agnosic and control subjects, we decided to assess the importance of categorization level by manipulating this factor for each object category rather than trying to equate it across categories. We will discuss the roles of categorization level and expertise but before we do so, we will examine the main models of prosopagnosia.

Models of prosopagnosia

Moscovitch, Winocur and Behrmann (1997) review several models that attempt to account for prosopagnosia. Here we group them into multiple-systems or single-system accounts.

Multiple-systems accounts attempt to explain the apparent specialization of recognition behavior and the double dissociations of agnosia by postulating at least two underlying visual recognition systems (e.g., Diamond & Carey, 1986; Farah et al., 1995; Rhodes, Brake & Atkinson, 1993; Tanaka & Farah, 1993). These systems can be defined in at least two different ways: their preference for specific object categories and their ability to perform certain operations. One of the strongest views, the *face module hypothesis*, suggests that there is a specific processor in the brain whose restricted domain is defined by upright facial stimuli. To be complete, such an hypothesis should also specify the organization of the remainder of the visual recognition system. For instance, the visual system could be composed of several modules, each one dedicated to the processing of a particular object category. Indeed, such a model may be supported by recent neuroimaging results in which a putative "face area" was located in between two areas responsive to chairs and to houses (Ishai, Ungerleider, Martin, Maisog, & Haxby, 1997), and by patients with category-specific deficits for objects other than faces (Assal, Favre, & Anderes, 1984). Of course, because we cannot reasonably expect genetic predispositions for the visual appearance of chairs and houses, it is necessary to explain how the house or chair areas can arise in approximately the same position in the brain of different subjects (for instance, relative to their face area). This is where a conceptualization of modularity in terms of specialized operations is helpful: if an area of the visual cortex is better at processing objects into parts and another is better at processing objects as wholes (Farah, 1990. See also Carey & Diamond, 1994; Rhodes, Brennan & Carey, 1987; Rhodes, 1988), then objects which are more efficiently recognized as wholes will be preferentially processed by the latter area, and so on (this has been called the *holistic hypothesis*). An important issue then becomes: are there really objects which are best recognized according to a particular strategy? It can be argued that parts are most important when recognizing a face as a face and when reading a nonword but that the configuration of the parts becomes more important when discriminating between different faces or learning what ties all letters of a certain font together. That is, it seems as if almost any strategy can be usefully applied to any object depending on the recognition task. For this reason, multiple-systems accounts which define modules specialized for certain operations may be more powerful than those which carve the system in terms of conceptual categories.

In contrast, a single-system account suggests that the complexity lies not in the visual system, which it postulates as a single homogeneous entity, but rather in the constraints and requirements of the myriad of possible visual tasks. For instance the *individuation hypothesis* suggests that prosopagnosics are simply impaired at making fine discriminations among visually similar objects (Damasio, 1990). This particular approach appears to be refuted by the case of prosopagnosic patients who still can distinguish among different cars (Sergent & Signoret, 1992b) or sheep (McNeil & Warrington, 1993). Similar counter-arguments exist against most versions of the single-system account. For instance, faces cannot simply be more difficult to recognize because some patients do worse on objects than faces (Moscovitch et al., 1997). However, attempting to explain the entire spectrum of phenomena using a single factor such as object category or task difficulty may not be the most fruitful approach. For instance, it is not necessary to invoke the same cause (i.e., the existence of a face-specific module) for both prosopagnosia *and* object agnosia without prosopagnosia. Until alternatives to the face module hypothesis have been ruled out to explain *both* deficits, it may not be justified to use each deficit in turn to strengthen the modular interpretation of the other. The existence of agnosia without prosopagnosia does not indicate that prosopagnosia cannot be explained by the higher difficulty of face recognition but only that this factor cannot account for the entire range of recognition deficits. After all, the study of normal object recognition suggests several dimensions that are important in determining recognition behavior (level of categorization and expertise being particularly relevant to the recognition of faces) so there is no reason why a single dimension should account for the entire range of recognition deficits following brain lesions.

The problem of task equivalence

The difficulty associated with favoring a modular hypothesis of face recognition becomes more obvious when one considers the multidimensional space of all the factors that may be important to visual recognition behavior (Tanaka & Gauthier, 1997). For instance, stimulus-class membership (face vs. non-face), categorization level (placing objects in basic categories such as “chair,” “dog,” and “car” or in subordinate ones, such as “dalmatian,” “beagle,” and “bloodhound”) and level of expertise are all thought to be important to explain some of the differences between object and face tasks. In the simplified framework shown in Figure 1, a difference between novice basic-level object recognition and expert subordinate-level face recognition can be explained by one of three different factors and by several possible interactions. It is thus necessary to adequately control for a number of confounded factors before concluding that a pattern of results supports modular recognition systems and, in particular, face modularity. However, even this approach has weaknesses because we do not know how many relevant dimensions there are in “visual recognition space” (e.g., social importance, number of exemplars in a category, symmetry, complexity, etc. As the number grows larger, it becomes increasingly difficult to control for all factors). We are also bound to attribute differences to the dimensions that are experimentally manipulated in our experiments rather than to the dimensions that are controlled for. For instance, Farah et al. (1995) manipulated stimulus-class membership while attempting to control for task difficulty (by using a difficult subordinate-level task with both faces and objects): regardless of whether they were successful in equating task difficulty or not, their experimental design did not prepare them to find an effect of this factor. In contrast, because we were interested in assessing the importance of categorization level for prosopagnosia (and not that of object category, which has been examined in many prior studies) we explicitly manipulated this factor.

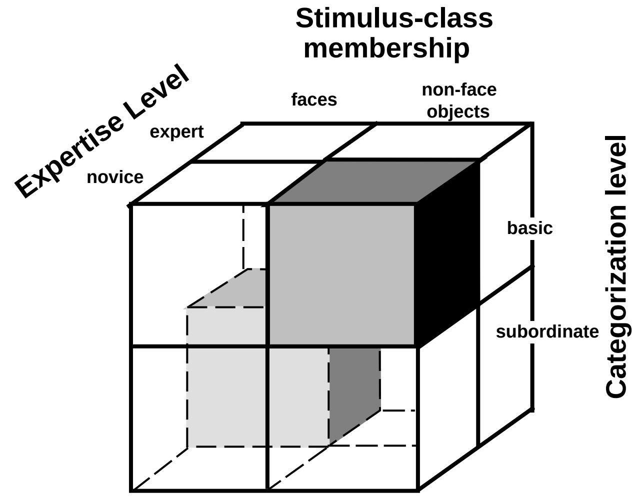

Figure 1. Simplified representation of the multidimensional space arising from all possible combinations of factors (here three, in reality an infinite number) constraining object recognition, such as stimulus-class membership, expertise, and categorization level.

Level of categorization.

Although most objects are recognized first and most efficiently at what has been called a “basic” level of abstraction (bird, chair, or dog) (Jolicoeur, Gluck, & Kosslyn, 1984; Rosch, 1978; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Tanaka & Taylor, 1991), all objects can be recognized at several different levels, including more “subordinate” levels (“hound dog,” “beagle,” and “Snoopy” are all subordinate relative to, or more specific than, the basic level “dog”). Objects in different basic levels can be distinguished by the presence of certain parts or configuration of parts (e.g., the presence of wings is highly diagnostic of the category 'bird' and the particular configuration of wheels under a seat is diagnostic of the category 'bicycle'). In contrast, objects within the same basic-level category share parts and their configuration (e.g., all cars have wheels, a bumper and a front seat in the same relative configuration). Thus, in order to discriminate objects at a subordinate level, including faces, one has to rely on other types of information which may include color, texture, surface details and metric variations of the basic configuration of features (Bruce & Humphreys, 1994; Diamond & Carey, 1986; Rhodes, 1988; Tanaka & Taylor, 1991).

It is interesting that although the role of categorization level in prosopagnosia is debated in several papers (Damasio, 1990; Farah et al., 1995; McNeil & Warrington, 1991, 1993; Sergent & Signoret, 1992b), a study manipulating this factor systematically has not been conducted with prosopagnosic subjects. Recent evidence indicates a strong relationship between subordinate-level categorization and the specialization in the fusiform gyrus for face processing. In particular, Gauthier, Anderson, Tarr, Skudlarski, and Gore (1997) found that subordinate-level matching for pictures of common objects (when compared to basic-level matching for identical stimuli) engaged the fusiform and inferior temporal gyri of normal subjects in a pattern that strikingly resembles the "face area" described in earlier functional imaging studies (Haxby et al., 1994; Kanwisher, McDermott, & Chun, 1996, 1997; McCarthy, Puce, Gore, & Allison, 1997; Puce, Allison, Gore, & McCarthy, 1995; Sergent & Signoret, 1992a). Thus, although there is a clear consensus from neuroimaging that there is an area in the fusiform gyrus which under most conditions is more activated for faces than other objects, the interpretation of such evidence is still debated.

In the following experiments, the manipulation of categorization level could also be viewed as a manipulation of visual similarity. However, it is a particular manipulation of visual similarity, along a dimension that depends on the shape of objects and is functionally relevant in most situations as well as being loosely related to our use of conceptual categories (Rosch et al., 1976). It is possible that a third factor not manipulated here mediates the relationship between level of categorization and subjects' sensitivity to this variable: for instance, configural information may be very important for subordinate-level discriminations (Diamond & Carey, 1986). We will not attempt to specify the underlying cause of impairments in subordinate-level recognition. In fact, as we discuss later on, it is likely that different types of perceptual impairments can lead to similar problems with subordinate-level discrimination.

Expertise.

Diamond and Carey (1986) demonstrated an important relationship between expertise and face recognition. They found that the equivalent of the face inversion effect (Yin, 1969), describing the fact that face recognition suffers more dramatically from inversion than the recognition of most other objects, could be obtained for the recognition of dogs but only for dog experts. Since then, several other putative face-specific effects have been replicated using non-face objects with expert subjects (Bruyer & Crispeels, 1992; Gauthier & Tarr, 1997; Gauthier, Williams, Tarr, & Tanaka, 1998; Rhodes & McLean, 1990). The mechanism most often suggested to mediate the acquisition of expertise is the use of configural processing: the specific relations between object parts are thought to be of particular importance in the heightened discriminability of objects for experts (Diamond & Carey, 1986; Gauthier & Tarr, 1997). A recent fMRI study (Gauthier, Tarr, Anderson, & Gore, 1997) also revealed a strong relationship between expertise and the neural substrate of face recognition: expertise recognizing novel objects can recruit the face area of individual subjects.

Here we do not propose that prosopagnosia is a specific deficit in expert processing, as others may have suggested (Blanc-Garin, 1986). However, because expertise with faces is expertise in subordinate-level processing, any perceptual impairment that is particularly disruptive for subordinate-level processing can be expected to also prevent prosopagnosic subjects from using (or acquiring, in the case of a developmental deficit) expert mechanisms when recognizing faces. This is perhaps most important when comparing the performance of prosopagnosic subjects to that of control subjects in tasks using faces and non-face objects.

Methodological considerations

Attempts to equate the difficulty of two tasks may be misleading because it all depends on each subject's strategy and available information. In other words, whether it is more difficult to eat soup or a bowl of noodles all depends on whether one uses a fork or a spoon. For instance, it may not be entirely fair to compare recognition of chairs or glasses to that of faces in normal subjects because their expertise with faces may have modified the way they perform face recognition (Diamond & Carey, 1986; Gauthier & Tarr, 1997; Rhodes & McLean, 1990). Nonetheless, the claim that subject LH is disproportionately impaired at face recognition (Farah et al., 1995) is based on the assumption that tasks with objects and faces can be equated based on normal controls' performance. However, if prosopagnosic subjects are impaired with subordinate-level processing of any object *and* if they cannot use their previously acquired expertise with faces, they would experience a double disadvantage when compared with control subjects on face recognition tasks (whereas they would only be disadvantaged for subordinate-level processing in tasks with objects for which the control subjects are not experts). There may be no obvious common ground for comparing prosopagnosic subjects to normal control subjects in their relative performance with objects and faces. For this reason, our study focuses on within-domain comparisons (varying categorization level for faces or for non-face objects) rather than between-category comparisons. This manipulation allows us to test whether prosopagnosic subjects are more affected than normal controls by the processing demands of subordinate-level tasks, regardless of object category.

Accuracy vs. sensitivity.

The dependent measure used most frequently when comparing prosopagnosic and control subjects has been overall accuracy (Farah et al., 1995; Farah, Wilson, Drain, & Tanaka, 1995; Sergent & Signoret, 1992b). This measure may provide a poor estimate of subjects' performance if they show differences in bias (criterion level) relative to control subjects. For instance, when making same/different matching decisions, a subject who responds "same" only 40% of the time cannot produce as many correct responses or as many hits (responding "same" on a "same" trial) compared with a subject who responds "same" 50% of the time, although the difference between the two may simply be in their willingness to give a "same" response. Measures of *sensitivity* rather than mere accuracy characterize a subject's ability to discriminate between same and different trials, independently of his/her response bias (Green & Swets, 1966). Therefore, two subjects whose hit and false-alarm rates are (.80,.40) and (.39,.07) respectively display the same sensitivity but differ in response biases and overall accuracy. Agnosic subjects can show very dramatic shifts of bias from one condition to another in the same experiment, which is why we opted to use sensitivity and bias as dependent measures. A nonparametric measure of sensitivity, A', was used in the following analyses. A' provides an approximation of the area under the isosensitivity curve (McNicoll, 1972). Chance performance yields a score of .5 and positive values indicate better than chance sensitivity. We used B"D as a measure of bias which has been shown to be independent of sensitivity (Donaldson, 1992). Positive values indicate a bias to say "different".

Response times.

Prosopagnosic subjects' responses tend to be slower overall and more variable than those of normal subjects and for this reason are often ignored. However, one important reason to pay attention to subjects' speed of response is the possibility of speed-accuracy tradeoffs across conditions. For instance, Kosslyn, Hamilton & Bernstein (1995) suggest that prosopagnosic subjects may feel pressured to respond faster to faces than to other objects. A possible reason for this was expressed by a congenital prosopagnosic on his internet homepage:

> "If you are face blind, in social settings, or even when watching TV, people will have come and gone long before you can identify them. So you never do. By the time eight seconds have passed, people in your presence who don't know of your face blindness will be offended at your failure to recognize them. And long before you even get your eight seconds, you know you will be criticized for "staring"..."

(Choisser, 1996). This may help explain why, even in the absence of time pressure to respond, someone with prosopagnosia may respond relatively fast, but fail at a recognition task using faces, and, in contrast, succeed at the same task with non-face objects but with response times (RTs) 3 or 4 times longer.

Because of the larger variance in many brain-lesioned subjects' RTs, the use of this dependent measure in comparing prosopagnosic and control subjects may require difficult decisions on how to deal with very long response times. Rather than an arbitrary criterion for outliers, our solution was to use the geometric rather than the arithmetic mean for our analyses (Stevens, 1966), thereby minimizing the effect of the tails of the RT distribution.

Results

Two prosopagnosic subjects, SM and CR, were tested in a series of experiments using faces, common non-face objects and novel objects (Greebles and snowflakes). Methodological details are provided in the Method section.

Experiments 1 and 2

Rationale and tasks.

In Experiments 1 and 2, SM and CR's performance in simultaneous-matching tasks with faces (Experiment 1) and common objects (Experiment 2) was evaluated and compared to that of normal control subjects. During "same" trials, pairs of stimuli were identical. In both experiments the similarity of distractors was varied so that in Experiment 1, a distractor face could differ from the target in: a) gender and identity (GI distractors); or b) only the identity of the face (I distractors). In Experiment 2, a distractor object could differ from the target at: a) the basic, subordinate and exemplar levels (BSE distractors, e.g., BIRD vs chair); b) only the subordinate and exemplar levels (SE distractors, e.g., DUCK vs pelican); or c) only the exemplar level (E distractors, e.g., DUCK1 vs duck2). The goal was to test the effect of manipulating categorization level on RTs for SM and CR as compared to control subjects. Our predictions were that the sensitivity measure would reflect a larger deficit for the face than non-face objects in SM and CR but that their RTs would reveal a greater effect of the categorization level manipulation than for control subjects.

Results and discussion.

Mean accuracy for control and prosopagnosic subjects for both experiments is given in Table 1. The only significant effect in Experiment 1 was that of Group: for sensitivity $F(1,12) = 29.8$, $p < .0002$ and for mean response time, $F(1,12) = 24.7$, $p < .0003$. Control subjects were not sensitive to the level manipulation with faces, perhaps because gender is particularly difficult to extract from our stimuli, given the absence of color, hair and face contour. Figure 2 presents the subjects' sensitivity and geometric mean RT for correct rejections for both face and non-face object matching as a function of distractor type.[2] One pattern is clear: considering either accuracy or sensitivity *alone*, the two prosopagnosic subjects are *disproportionately* impaired at face matching compared to non-face object matching relative to normal controls–a pattern of results not unlike that found by Farah et

[2] Note that correct responses on identical trials (hits) enter into the calculation of the sensitivity for all distractor levels.

Table 1
Accuracy for Experiments 1 and 2

	Controls	SM	CR
Expt 1- Faces			
identical	.93	.75	.85
GI	.95	.42	.75
I	.90	.55	.70
Expt 2- Non-face objects			
identical	.90	.93	.95
BSE	.99	.95	1
SE	.99	.95	.90
E	.91	.85	.80

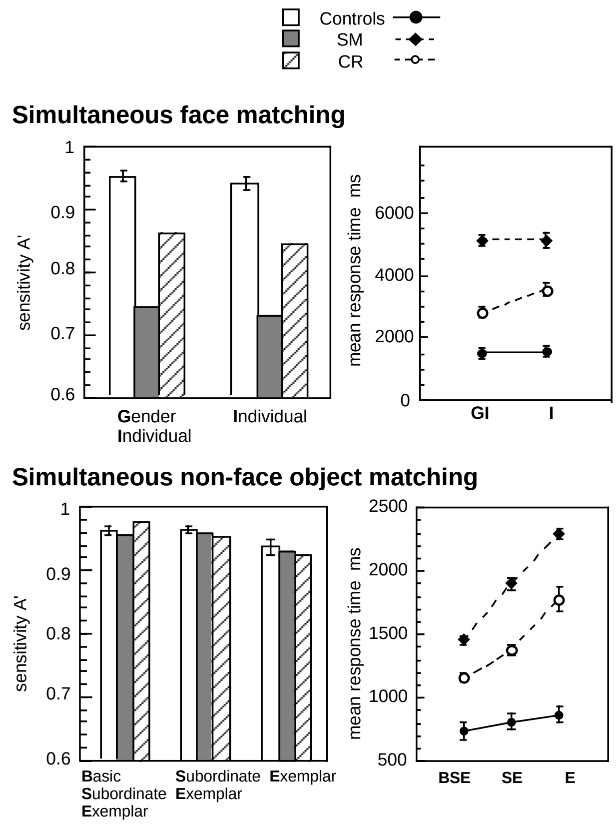

Figure 2. Sensitivity (A') and geometric mean of response time (ms) for correct rejections for SM, CR and control subjects in Experiments 1 and 2, as a function of the number of levels distinguishing the distractor from the target.

al., (1995). The crucial prediction here concerns RTs for object matching. While SM and CR's sensitivity appeared to be slightly influenced by the levels manipulation, their RTs show a marked sensitivity to this factor as compared to control subjects. An unequal-n ANOVA on RT revealed a reliable interaction of Level with Group $F(2,20) = 27.4$, $p \leq .0001$. Scheffé tests ($p < .05$) indicated that control subjects were faster at rejecting BSE than SE distractors with no other differences, while SM and CR showed an additional reliable difference between the SE and E distractor conditions.

It should be noted that controls' mean RTs for faces at the individual level are almost twice as long as those for the most subordinate level with non-face objects (1554 ms vs 868 ms), suggesting that even for normal (expert) subjects, face matching at the exemplar level is more difficult than the most subordinate level used here for objects. Importantly, RTs for SM and CR and normal controls show effects of task difficulty in a situation where control subjects are at ceiling on sensitivity.

Experiments 3 and 4

Rationale and tasks.

Experiment 2 indicated that prosopagnosic subjects whose deficit may appear highly selective for faces when accuracy is considered in isolation can nonetheless display a disproportionate sensitivity in their RTs in response to a manipulation of categorization level, within the domain of non-face objects. Experiments 3 and 4 were designed to replicate this result with novel non-face objects (Greebles- Figure 3). Here we used a slightly different task: rather than using an AX task, we used a ABX task in which one target and two choices appeared on each trial and subjects had to match one of the choices to the target. Although very similar to the task used in Experiments 1 and 2, this task may be a little easier to use with a novel set of objects for which subjects have no prior knowledge of the range of inter-stimuli differences. Moreover, this design allows us to consider response times for hits (rather than for correct rejections as in Experiments 1 and 2) because the level of categorization is manipulated within trials by the identity of the distractor (whereas in an AX design, it is impossible to know at which level subjects are performing identical judgments). Both experiments are identical except for the use of different sets of Greebles and for the fact that trials in Experiment 3 were blocked by level of categorization while those in Experiment 4 were entirely randomized.

Results and discussion.

Mean accuracy in both experiments for control and prosopagnosic subjects is shown in Table 2. Figure 4 presents the subjects' sensitivity and geometric mean RT for hits. SM and CR show a very high sensitivity, comparable in most regards to that of controls. Response times in each experiment were submitted to unequal-n ANOVAs with Level of categorization and Group as factors. Both experiments revealed significant interactions of Group with Level, Expt 3: $F(3,42) = 25.4$, $p \leq .0001$; Expt 4: $F(3,30) = 4.9$, $p < .01$. In Experiment 3, Scheffé tests ($p < .05$) revealed that both groups were slower at the individual and family levels than at the gender level, and slower at the gender than at the basic level (Greeble vs. Non-Greeble). The interaction lies in SM and CR being reliably slower than controls at all but the basic level, with the slope of the function relating RTs to categorization level being much steeper for SM and CR than controls.

In Experiment 4, Scheffé tests ($p < .05$) revealed that SM and CR were slower than controls at all levels. Controls were

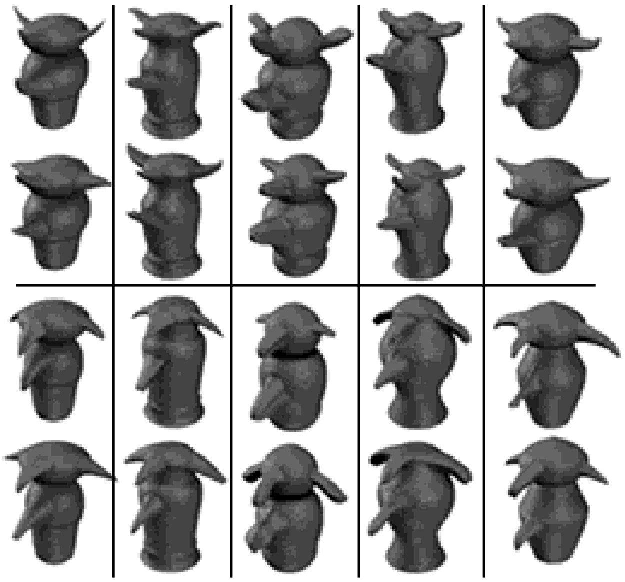

Figure 3. Greeble stimuli from the set used in Experiments 3, 4 and 7. Greebles are organized in 5 “families” (columns) according to their body shape and two “genders” defined by the orientation of their parts (up/down - top two rows vs. two lower rows).

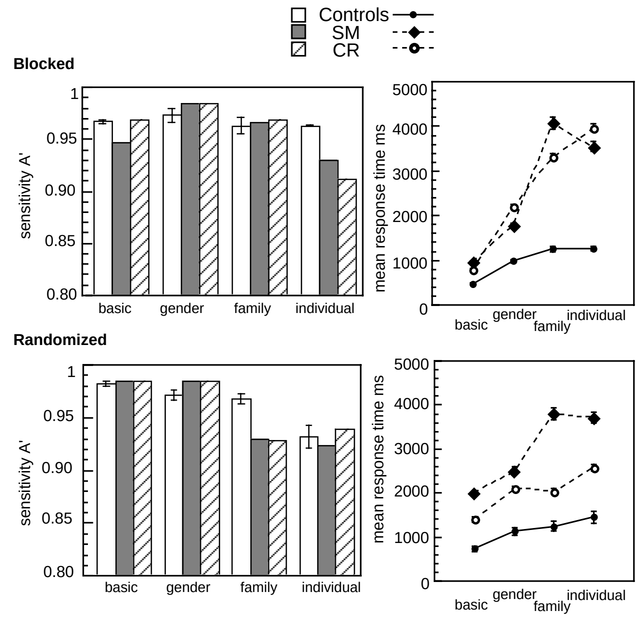

Figure 4. Sensitivity (A’) and mean response time (ms) for hits for SM, CR and control subjects in Experiments 3 and 4.

Table 2
Accuracy for Experiments 3 and 4

	Controls	SM	CR
Expt 3- Greebles blocked			
basic	.96	.93	.97
gender	.98	1	.87
family	.96	.97	1
individual	.96	.90	.87
Expt 4- Greebles randomized			
basic	.99	1	.90
gender	.98	1	.90
family	.90	.90	1
individual	.90	.87	.90

slower at the individual than gender level, as well as for all levels compared to the basic level. In comparison, SM and CR were reliably slower with the two most subordinate levels (family/individual) than with the other two levels (basic/gender).

Both simultaneous-matching experiments with Greebles replicated the pattern of results found in Experiment 2, showing that subjects whose sensitivity pattern may reflect a deficit for faces but not for non-face objects (as in Experiments 1 and 2) may be seen in a different light when RTs are examined: For both common objects (Experiment 2) and Greebles (Experiments 3 and 4), the prosopagnosic subjects’ RTs revealed a *disproportionate* sensitivity to categorization level. This illustrates why brain-lesioned subjects’ RTs should not be discarded. But here, at least in one condition (basic level, blocked design), the one for which controls were fastest, both SM and CR’s sensitivity and RTs were statistically indistinguishable from that of controls. Therefore, there exist cases where prosopagnosic subjects’ RTs may be informative regarding their deficits, rather than revealing only across-the-board slow responses. There was no difference between a randomized and a blocked design for controls’ general pattern of RTs, but there may have been some difference in the magnitude of the effect of categorization levels, especially for CR, who shows the largest improvement between Experiments 3 and 4: a difference of 725 ms/level in the slope of the function of RT regressed on categorization level (controls and SM showed slope reductions of 104 ms/level and 356 ms/level, respectively). This general reduction in slope could be due to strategic differences utilized in the two designs but it should be noted that all subjects who participated in both experiments experienced the blocked design first. At least, it suggests that CR may be better able than SM to benefit from practice. Recent evidence from a separate study with these two subjects also indicated that CR learned novel objects faster than SM (Williams & Behrmann, 1998).

Experiments 5 and 6

Rationale and tasks.

Experiments 2, 3, and 4 supported our hypothesis that RTs can reveal prosopagnosic subjects’ sensitivity to level of categorization with non-face objects when subjects are given no time constraint. Since the predicted and obtained interactions are not cross over interactions, a scaling factor could abolish them. However, it should be noted that analyses on log-transformed RTs, probably the most common transformation on response times, yield significant group x level interactions for Experiments 2 $F(2,20) = 4.27$, $p = .029$ and 3, $F(3,42) = 5.61$, $p = .003$. The log transformation abolishes the interaction in Experiment 4, $F(3,30) = .48$, n.s. As mentioned previously, the main difference between the two experiments with Greebles appears to be the improvement in performance for CR from Experiment 3 to Experiment 4.

A complementary hypothesis would be that the same subjects should show an effect on sensitivity when stimulus duration is limited. Experiments 5 and 6 test subjects' performance in a sequential-matching paradigm in which each of the two stimuli to be compared on each trial are shown for 1500 ms and separated by 1500 ms. In Experiments 1-4 subjects needed only to compare the particular stimuli shown on any given trial. A sequential-matching task should force subjects to encode the first stimulus without any knowledge of the comparison basis and without a chance to look back at it, therefore placing a heavier burden on memory processes.

As a secondary issue, Experiment 5 was conducted using upright and inverted male faces. Given their expertise with upright faces, we expected normal controls to do better with upright than inverted faces (Yin, 1969). Moreover, Farah and colleagues (1995) have reported a surprising finding with patient LH using a sequential-matching paradigm with drawings of faces: LH repeatedly performed better with inverted than upright faces. The authors suggested that this result provided strong evidence for a face-module which operates mandatorily upon presentation of upright faces. However, deGelder, Bachoud-Lévi and Degos (1998) recently reported the case of a patient who shows the same inversion superiority for faces and pictures of shoes. The mechanisms mediating the inversion superiority effect are still unknown, but the recent results with shoes indicates that it is not specific to faces. We were interested in looking for this effect with SM and CR. deGelder et al. suggested that the inversion superiority found with some prosopagnosic patients may be common to a variety of orientation-polarized objects, even in the absence of an inversion effect in normal subjects. If SM and CR demonstrate an inversion superiority with faces, testing them with Greebles would allow us to ask whether this effect depends on long term familiarity with a class of stimuli, which the patients do not have with Greebles. Experiment 6 thus used the same sequential-matching task with upright and inverted Greebles. However, our main hypothesis was that SM and CR would exhibit a deficit in sensitivity with the Greebles, paralleling the RT effect obtained in Experiments 3 and 4.

Results and discussion.

Mean accuracy in both experiments for control and prosopagnosic subjects is shown in Table 3. Figure 5 presents the subjects' sensitivity, bias and geometric mean RT for hits as a function of object category, orientation and testing block. Unequal-n ANOVAs were performed on these three independent measures in each experiment, with Orientation, Block and Group as factors.

For faces, the ANOVA on sensitivity revealed that SM and CR performed more poorly overall than normal controls $F(1,9) = 66.2$ $p \leq .0001$ and that subjects overall performed more poorly with inverted than upright faces $F(1,9) = 36.6$, $p = .0002$. This was qualified by an interaction of Orientation with Group $F(1,9) = 14.7$, $p < .005$. Although both groups

Table 3
Accuracy for Experiments 5 and 6

	Controls	SM	CR
Expt 5- Faces (block 1, block 2)			
upright	(.92, .94)	(.57, .53)	(.67, .70)
inverted	(.84, .84)	(.43, .53)	(.60, .47)
Expt 6- Greebles (block 1, block 2)			
upright	(.81, .83)	(.53, .53)	(.66, .63)
inverted	(.80, .78)	(.50, .60)	(.63, .67)

showed an inversion effect, the advantage of normal controls for upright over inverted faces was on average about 3.8%, while 17% for SM and CR. The analysis revealed no effect of bias, although it can be seen in Figure 5 that SM was extremely biased to say "same" while CR was more similar to normal controls. There was a reliable effect of Orientation on RTs $F(1,9) = 10.12$, $p < .05$ as well as an interaction of Orientation x Block $F(1,9) = 9.7$, $p < .05$. Scheffé tests ($p < .05$) indicated that all subjects were faster in Block 2 compared to Block 1 for upright but not inverted faces.

For Greebles, the ANOVA on sensitivity revealed that SM and CR performed more poorly overall than normal controls $F(1,9) = 13.8$ $p < .005$. As expected, there was no reliable effect of Orientation, $F(1,9) = .13$, ns. nor any interaction of Orientation with Group $F(1,9) = .9$, ns. The ANOVA on bias revealed no reliable difference between the groups $F(1,10) = 1.03$, ns. RTs revealed an interaction of Block x Group $F(1,9) = 5.7$ $p < .05$. Scheffé tests ($p < .05$) indicated that the SM and CR were faster than controls during the first block but not reliably different during the second block (an effect probably carried by CR).

As predicted, SM and CR were less sensitive with upright and inverted faces *and* Greebles relative to normal controls. There was no evidence for an inversion superiority effect.

Experiments 7, 8 and 9

Rationale and tasks.

Experiment 5 and 6 supported our prediction that with limited stimulus duration, prosopagnosic subjects would demonstrate an impairment in sensitivity with non-face objects, relative to controls. Experiments 7, 8 and 9 were designed to extend this finding to a different task which places a heavier burden on recognition processes than the sequential-matching task. In these experiments, a match-to-sample task was used in which a target was studied for 5 seconds and followed by a series of twelve stimuli which had to be classified as either the target or a distractor. A visual representation of the target has to be encoded without knowledge of the contrastive set and held in memory while the subject compares it to several similar exemplars. We also extend our testing to another class of non-face objects that is hierarchically structured. The stimuli (shown in Figures 3 and 6) were sets of 108 faces (Expt 7), 60 Greebles (Expt 8) or 90 snowflakes (Expt 9), each set orga-

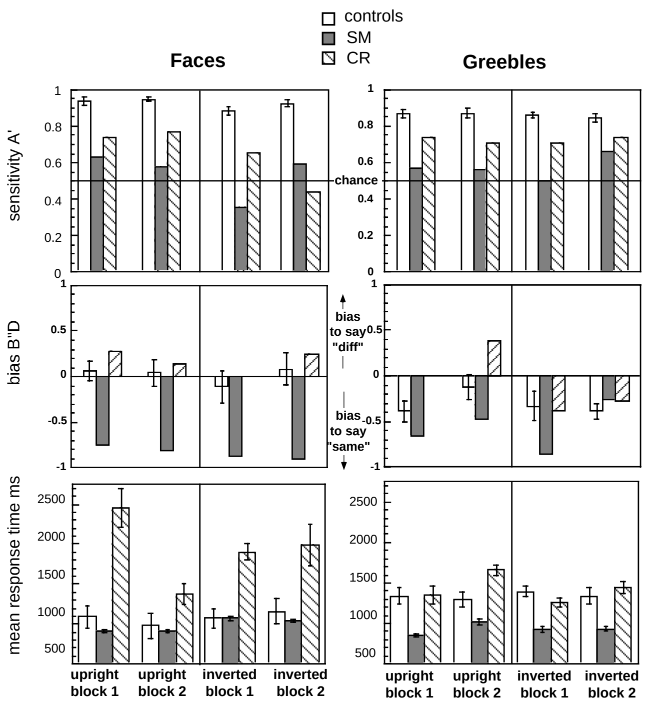

Figure 5. Sensitivity (A'), bias (B"D) and mean response time (ms) for hits for SM, CR and control subjects in Experiments 5 and 6.

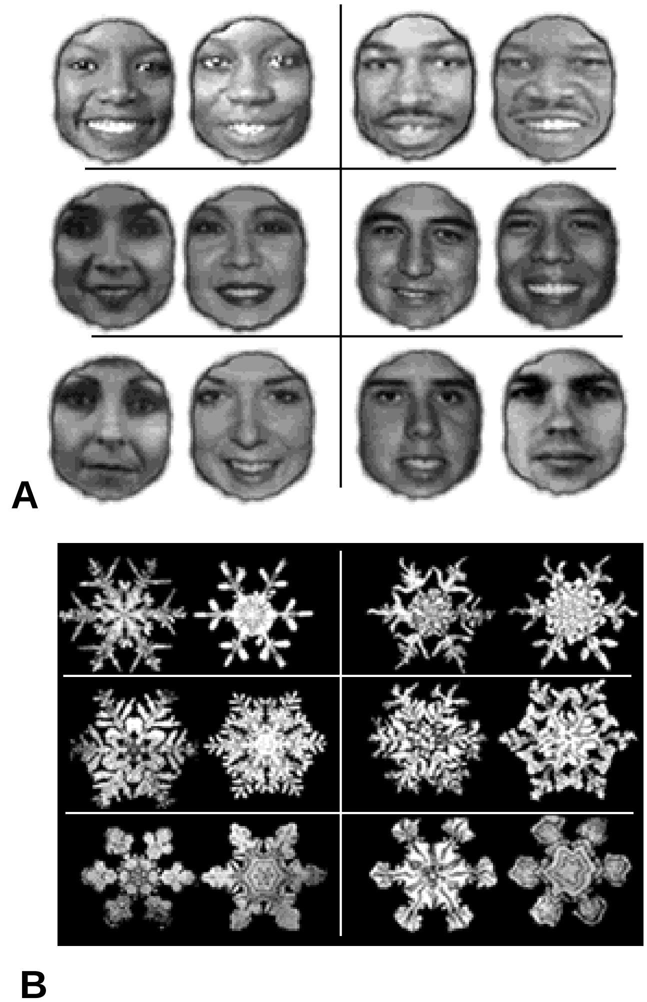

Figure 6. Stimuli from two sets of homogeneous objects used in Experiments 7 and 9. Faces were of three races (white, black, latino) and half were female faces. Snowflakes were organized in three "races" (round middle with thin rays, full-bodied, round middle with fat rays) and two "genders" (wavy/non-wavy).

nized along two orthogonal dimensions (e.g., for faces, family/race, and gender) with several exemplars within each cell (e.g., there were 18 faces for each combination of race and gender). On each trial, the target appeared on four occasions among eight distractors in a randomized order. The similarity of the distractors to each target was manipulated so that two distractors differed by 3 dimensions (for faces, a face of a different race, gender and identity), four distractors differed by 2 dimensions (for faces, race and identity or gender and identity) and two distractors were different exemplars within the same cell as the target (for faces, a different face of the same gender and race as the target). For simplicity, for all experiments we will use the term "individual" (I) for the exemplar dimension, the term "gender" (G) for the binary dimension (e.g., "wavy" vs "non-wavy" snowflakes) and the term "family/race" (R) for the other dimension, which had at least three levels (5 for Greebles). This design allowed us to explore the prosopagnosic subjects' sensitivity to manipulations of categorization level for faces and two classes of non-face objects. Assuming that subjects can perceive the different dimensions along which the stimulus sets are organized, a first prediction is that the more dimensions along which a distractor differs from a target, the easier it should be to reject. More importantly, we hypothesized that SM and CR may be more sensitive to this manipulation than normal control subjects.

Results and discussion.

Table 4 gives the accuracy for identical trials and the different levels of distractor trials for the 3 experiments. Figure 7 presents the sensitivity, bias and geometric mean RT for correct rejections for SM, CR, and normal controls in Experiments 7, 8, and 9. Unequal-n ANOVAs were performed on sensitivity and mean RT in each experiment, with Level and Group as factors. Because Level was manipulated within distractors in each experiment, the dependence of bias on Level mirrored that of sensitivity. Bias was therefore computed across all levels so as to investigate possible differences between Groups within each experiment. Two-sample *t*-tests were performed on bias in each experiment, none of them reaching significance.

To investigate within-category effects, ANOVAs were conducted on each experiment separately. For faces, the ANOVA on sensitivity produced reliable main effects of Level $F(3,45) = 37.2$, $p \leq .0001$ and of Group $F(1,15) = 154.2$, $p \leq .0001$ with a reliable interaction between these two factors $F(3,45) = 16.3$, $p \leq .0001$. Scheffé tests ($p < .05$) revealed that controls were less sensitive

Table 4
Accuracy for Experiments 7, 8 and 9

	Controls	SM	CR
Expt 7- Faces			
identical	.96	.48	.79
RGI	.99	.75	.79
GI	.99	.71	.54
RI	.98	.63	.63
I	.88	.68	.46
Expt 8- Greebles			
identical	.94	.77	.75
RGI	.99	.96	.79
GI	.97	1	.63
RI	.94	.63	.67
I	.74	.63	.46
Expt 9- Snowflakes			
identical	.89	.50	.70
RGI	.99	.96	.88
GI	.99	.88	.92
RI	.99	1	.88
I	.95	.92	.75

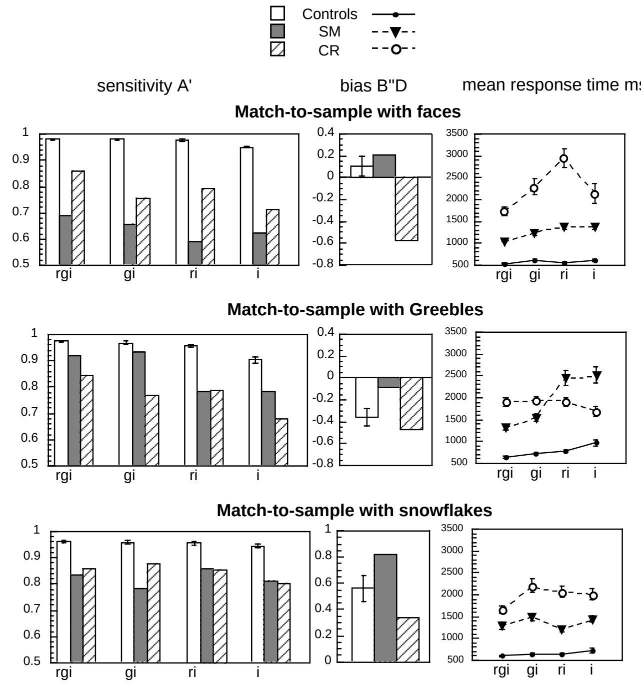

Figure 7. Sensitivity (A'), bias (B"D) and mean response time (ms) for correct rejections for SM, CR and control subjects in Experiments 7, 8 and 9.

with I distractors than with all other levels of distractors, while the prosopagnosic subject were less sensitive with I distractors than GI distractors, with RI distractors in between and not different from I and GI distractors. Finally, SM and CR were more sensitive with RGI distractors than with all other types. The ANOVA on RTs also revealed main effects of Level $F(3,45) = 28.0$, $p \leq .0001$ and Group $F(1,15) = 59.4$, $p \leq .0001$ with a reliable interaction between these two factors $F(3,45) = 24.8$, $p \leq .0001$. Scheffé tests ($p < .05$) indicated no difference among levels of distractors for control subjects, while the prosopagnosic subjects were fastest with RGI distractors, slowest with RI distractors, with I and GI distractors in between with not different from each other.

For Greebles, the ANOVA on sensitivity produced reliable main effects of Level $F(3,45) = 26.6$, $p \leq .0001$ and Group $F(1,15) = 53.9$, $p \leq .0001$ with a reliable interaction between these two factors $F(3,45) = 4.8$, $p < .01$. Scheffé tests ($p < .05$) indicated that controls were less sensitive with I distractors than with all other types of distractors, while prosopagnosic subjects were more sensitive with RGI and GI distractors than RI and I distractors, with no reliable difference between the GI and RI levels. The ANOVA on RTs also revealed main effects of Level $F(3,45) = 8.9$, $p \leq .0001$ and Group $F(1,15) = 116.3$, $p \leq .0001$. The interaction between these two factors was marginal $F(3,45) = 2.2$, $p < .108$. Scheffé tests ($p < .05$) indicated that controls were slower with I distractors than with all other types of distractors, while SM and CR were faster with RGI distractors than all other levels.

For snowflakes, the ANOVA on sensitivity produced reliable main effects of Level $F(3,30) = 8.1$, $p < .001$ and Group $F(1,10) = 66.9$, $p \leq .0001$ with a marginal interaction between these two factors $F(3,30) = 2.4$, $p < .09$. Scheffé tests ($p < .05$) indicated no difference among levels of distractors for control subjects, while the prosopagnosic subjects were less sensitive with I distractors than RGI and RI distractors, with GI in between and no different from all other levels. The ANOVA on RTs also revealed main effects of Level $F(3,30) = 13.2$, $p \leq .0001$ and Group $F(1,10) = 55.2$, $p \leq .0001$ with a reliable interaction between these two factors $F(3,30) = 6.8$, $p < .005$. Scheffé tests ($p < .05$) revealed that controls were slower with I than with RGI distractors, with GI and RI distractors falling in between and not reliably different from any other level, while prosopagnosic subjects were slower with GI than RGI and RI distractors, with I distractors falling in between and not reliably different from any other level.

The results from Experiments 7, 8 and 9 indicate that prosopagnosic subjects sometimes show dependencies on categorization level that are quite different from controls. Although SM and CR are more sensitive to categorization level overall, this could be due to a ceiling effect for sensitivity in controls or simply to a scaling factor since the interaction of Group and Level does not cross over. However, the prosopagnosic subjects' sensitivity to categorization level was also different in qualitative aspects. For instance, whereas all control subjects in Experiment 7 were less sensitive with I than with RI and GI distractors, SM performs no better with RI than I distractors, neither in terms of speed or sensitivity, suggesting that he makes little use of race information to recognize faces. Similarly, in Experiment 8, all but two of the 15 control subjects were less sensitive with I than RI distractors (one of the two outliers was equally sensitive at both levels and both were at least 100 ms faster with RI than I distractors), but SM did not appear to benefit from the family information to discriminate Greebles (note that Greebles' family is not implied to be in any way homologous to that of human family or race). Some differences between SM and CR were also present, for instance whereas SM was much better with GI than RI and I Greeble distractors, CR's performance was more similar between these two conditions but much worse with I Greeble distractors.

Critically, differences between the results for the 3 experiments should be interpreted with more caution than the similarities (for instance, the greater sensitivity of SM and CR to categorization-level manipulations in all cases). This is because we make no claim of having equated the level of difficulty across object categories. Moreover, the orthogonal dimensions manipulated to vary categorization-level in each experiment are not comparable (think of gender for faces, parts up/down for Greebles, and wavy/nonwavy for snowflakes). We should note however that the patients' sensitivity was most dramatic in those cases where the level manipulation is most effective for control subjects: this could simply reflect the fact that SM and CR cannot benefit from features that are not readily accessible to controls.

It is important to consider how much the SM and CR's deficit with objects would have been underestimated had they been tested only at a single level of categorization for all object categories and using only overall accuracy. In such a design, only differences in impairments for each prosopagnosic subject relative to controls would be available. Such an analysis would reveal an interaction of Group and Category, with prosopagnosic subjects being more impaired relative to control subjects with faces than non-face categories–a pattern that could be attributable to a ceiling effect for control subjects. However, Farah and colleagues (1995) successfully eliminated the ceiling effect by using a more difficult learning task and found the same interaction. Nevertheless, this does not necessarily indicate that LH, SM and CR are "disproportionately" impaired with faces, but may instead reflect the fact that control subjects are experts with faces but not Greebles, whereas SM and CR's perceptual impairments (as indicated by long matching RTs in Experiments 1 to 4) may prevent the use of previously acquired expert abilities (this argument would also hold for Experiments 5 and 6). Similarly, considering only sensitivity, one might argue that SM is more impaired with faces as compared to Greebles, relative to control subjects. This would however disregard the fact that SM is also much faster at the individual level with faces than Greebles, indicating a speed-accuracy tradeoff. The results do indicate that SM and CR are impaired with all three homogeneous categories and are more sensitive to categorization level than are control subjects. The interaction of Group and Level could in part be caused by a ceiling effect but the converging evidence from Experiments 2, 3 and 4 indicates that this effect can also be found in RTs. The strongest evidence against the possibility that the effect obtained in sensitivity is due to a ceiling effect comes from results of a group of 11 Alzheimer's disease patients in the match to sample task with Greebles (Naor, Tarr, Heindel, & Gauthier, 1998). The most significant difference between the two groups is that the prosopagnosic subjects, but not the Alzheimer's patients, seem unable to use the family information to recognize Greebles. Whereas control subjects and Alzheimer's disease patients show equivalent performance with RGI, RI and GI distractors (although overall Alzheimer's disease patients are less sensitive than controls), both prosopagnosic patients show a marked impairment with RI and I distractors compared to RGI and GI distractors. Importantly, the family information for the Greebles which SM and CR seem unable to use normally is much more configural than local and this pattern may reflect the prosopagnosic subjects specific difficulties with configural processing (Levine & Calvanio, 1989). The comparison with Alzheimer's disease patients also indicates that the pattern of deficit for the prosopagnosic subjects is unlikely to be due to a general problem with difficult tasks, since the Alzheimer's disease patients are not at ceiling: Alzheimer's patients actually perform more poorly as a group than either SM or CR on the easiest level (RGI) but do not show the same drop in performance when Gender information is no longer available.

Discussion

In summary, our results with two prosopagnosic subjects across 9 experiments suggest the following conclusions:

First, SM and CR displayed a pattern of strong sensitivity to categorization level with several object categories. An important question is whether this deficit can explain their face processing impairment. Recent neuroimaging results Gauthier et al. (1997), Gauthier, Tarr, Moylan, Anderson, and Gore (1998) revealed that subordinate-level categorization of non-face objects activates the putative "face area". Studies with monkeys have also suggested a role of inferotemporal neurons in subordinate-level recognition (Logothetis & Sheinberg, 1996). Thus, converging evidence points to this region of inferior temporal cortex as being important for both face and object subordinate-level recognition. Damage to such a region of the brain would be expected to produce the type of impairments found in both SM and CR.

Second, response times are very informative in the study of visual agnosia: although SM and CR were overall slower than normal controls, their responses were dramatically slower when the task was "subordinate", such as discriminating two Greebles of the same family and gender as compared to a much more categorical task of discriminating, say, a Greeble from a car. Group by Level interactions for sensitivity and/or RTs in several of the experiments revealed the significance of this effect in our subjects' object recognition deficit.

Third, differences in performance across object categories can stem from several indistinguishable sources (for instance, normal controls are experts with faces but not most other objects). However, SM and CR's sensitivity patterns in Experiments 5 and 6 illustrate a point. They were about as sensitive with faces as with Greebles although their relative deficit compared with controls appears larger with faces. (A pattern similar to that of LH in Farah et al., 1995). Although this could reflect the fact that the Greeble task is more difficult than the Face task, we believe this is not likely. For one thing, Greebles are rather simple stimuli compared to faces, with a small number of parts that should be easier to parse as most of them are visible in the object's bounding contour and they vary along fewer dimensions than face parts. Thus, an alternative is that the face task appears easier because normal subjects are experts with faces. Prosopagnosic subjects could have lost the ability to use such expertise, placing them at a disadvantage in comparison with face experts.

Fourth, SM and CR often exhibit extreme response biases (that is, a tendency for the proportion of their same and different responses to differ from the proportions used in the design of the experiment). Whereas normal controls tended to be less biased with faces than with other categories of objects, SM and CR often showed an equal response bias to respond "same" with faces and objects (sometimes with a larger bias for faces). This aspect of their performance was not explored in detail but it is yet another relative difference between control and prosopagnosic subjects that may attributed to control subjects processing faces differently as compared to other stimuli, because of their particular expertise with this category. [3] In any case, this indicates the importance of using a 'bias free' measure of performance when comparing prosopagnosic patients to normal controls.

Finally, although untested, other patients who are diagnosed as having more serious difficulties with faces than with objects would be expected to yield similar patterns as observed for SM and CR. For instance, LH (Farah et al., 1995) was also tested by Levine and Calvanio (1989). These authors reported that LH can only identify objects that have a unique distinguishable feature and otherwise reverts to a slow sequential visuospatial analysis of the object. They found that LH had serious difficulties in tests of visual closure with non-face objects. LH was found to be slow and somewhat impaired at recognizing objects, identifying the picture of an anvil as a briefcase, that of a panda as an owl, and identifying many four-legged creatures as "animals." This characterization of LH illustrates many commonalities with SM and CR and suggests that LH would also display a general deficit in subordinate-level recognition.

Neuropsychological evidence for a face-module

Evidence of a specialized neural substrate for face comes from neurophysiological studies in both monkeys (Gross, Roche-Miranda, & Bender, 1972; Yamane, Kaji, & Kawano, 1988; Perrett et al., 1991) and humans (Allison et al., 1994; Puce, Allison, Spencer, Spencer, & McCarthy, 1997). For example, several neuroimaging studies have reported face-sensitive regions in the ventral temporal cortex (e.g., Haxby et al., 1994; Sergent, Ohta, & MacDonald, 1992; Puce, Allison, Asgari, Gore, & McCarthy, 1996) and recent experiments (McCarthy et al., 1997; Kanwisher et al., 1997) seem to suggest that the response of the "face area" may be highly selective (but see Gauthier et al., 1997, 1998). In a recent case study of prosopagnosic patient LH, Farah et al. (1995) found that LH performed better with inverted than upright faces (the reverse of the pattern of performance seen in uninjured subjects) and argued that this demonstrated a deficit in a face-exclusive module specifically selective for upright faces. This conclusion is undermined by the recent finding of another prosopagnosic patient who shows the same advantage for inverted stimuli with shoes (Gelder et al., 1998). Finally, perhaps the strongest evidence supporting modularity of face recognition may be found in the apparent double dissociation of face- and object-recognition processes in different cases of brain-lesioned subjects (Moscovitch et al., 1997). The evidence for both sides of the dissociation is briefly reviewed next.

Prosopagnosia without object agnosia.

Farah (1990) notes the lack of evidence for prosopagnosia without any perceptual impairment. This is relevant to the question of specificity of prosopagnosia insofar as some authors (Davidoff, Matthews, & Newcombe, 1986; De Renzi, 1986) have argued that prosopagnosia attributable to perceptual impairments is unlikely to produce a face-specific recognition disorder. Farah's (1990) extensive review of 99 cases of associative visual agnosia (visual agnosia with relatively good perception) reveals no documented evidence that any of these subjects had normal performance, in terms of both speed and accuracy, on the Benton and Van Allen test, a test which requires matching of unfamiliar faces over viewpoint and illumination changes. However, some authors believe that their subjects' perceptual impairments cannot explain their face recognition deficit. For instance, one subject scored poorly on tests of figure-ground discrimination and on the Benton and Van Allen test, but De Renzi (1986) pronounced the subject better on such tests than brain-damaged subjects who are equally impaired at perceptual tests but are not prosopagnosic. This comparison cannot produce conclusive evidence because a slightly more difficult perceptual task (or a different measure, such as speed) might have revealed a stronger perceptual impairment in the prosopagnosic subject. Bruyer et al. (1983) also concluded that their subject's perceptual impairments could not account for his prosopagnosia. Although this subject had some difficulty matching face pictures, when playing cards he could not discriminate between suits of the same color or between jacks and kings and could not visually discriminate coins. Although he recognized his own cows, he did so by using simple diagnostic features such as marks on the skin, making it difficult to conclude that his ability to perform non-face subordinate-level discriminations was intact. As in most other cases (Farah et al., 1995; McNeil & Warrington, 1991), there is no definitive evidence for a dissociation of face recognition from object recognition processes. This is consistent with the results of the experiments conducted here with SM and CR.

[3] Admittedly, normal subjects could behave differently with faces than with non-face objects because of a preserved "face module" – however, this is an empirical question. For instance, one can test whether subjects can acquire similar behaviors with non-face objects following expertise training (Gauthier & Tarr, 1997; Gauthier et al., 1998).

Object agnosia without prosopagnosia.

The evidence for specific preservation of face recognition abilities is both sparser and more impressive than that supporting a face-specific deficit. Very rarely, a subject will loose the ability to visually recognize objects but preserve that of recognizing faces. The recently reported case of CK (Moscovitch et al., 1997) is an example of this. CK is very impaired at recognizing common objects and shows severe perceptual impairments. For instance, Behrmann et al., (1994) found that he could recognize only 50% of line drawings presented to him, but none when they were overlapping. He also displayed stronger viewpoint dependence and made more false alarms than control subjects when identifying simple volumetric shapes (Suzuki, Peterson, Moscovitch, & Behrmann, 1997). Nonetheless, CK's abilities to recognize faces in photographs, line drawings or even from caricatures and cartoons, is strikingly good as long as the faces are upright and the features in the appropriate configuration. In contrast, when tested with Greebles for sequential matching (as in Experiments 5 and 6), he performed at chance level with both upright and inverted versions (Behrmann, Gauthier, and Tarr, in preparation).

What does the existence of such a case imply for the modularity of face recognition? Clearly, any model of object recognition needs to account for this surprising deficit. Contrasting such a deficit with that found in prosopagnosic subjects, one may be tempted to adopt a two-systems model, with a general object-recognition system in addition to a domain-specific face module, or a less-modular two-systems approach such as that proposed early on by Farah (1990). She suggested that a part-based system was necessary for recognition of words and useful for object recognition and that a holistic recognition system was necessary for face recognition and useful for object recognition (as in the case of subordinate-level recognition). However, evidence that recognition of non-face categories such as cows, sheep or cars can be selectively preserved or impaired, with or without face agnosia, renders such dichotomous models insufficient (Assal et al., 1984; Bornstein, Sroka, & Munitz, 1969; McNeil & Warrington, 1993; Sergent & Signoret, 1992b).

Double dissociations.

As used in neuropsychology, the double dissociation method may be characterized as a crossover interaction between the type of lesion and task performance. Such an interaction is thought to reveal the presence of at least two functionally independent and spatially distinct systems. This logic depends on several assumptions which have been discussed elsewhere (Dunn & Kirsner, 1988; Farah, 1994; Shallice, 1988; Weiskrantz, 1969). Of particular importance here, it can be shown that several types of non-modular functional architectures are capable of producing double dissociations when damaged (Shallice, 1988). For instance, Plaut (1995) showed that double dissociations can be produced by "lesioning" a connectionist network that has no separable components. This indicates an important limitation of the logic which takes double-dissociations as transparent evidence of modular organization in the brain. Even more surprising, two instances of *equivalent* lesions to the network (lesions are made by removing a randomly selected set of connections) may produce drastically different deficits, actually giving rise to double dissociations. The difficulty of capturing the architecture of a network by looking at dissociations between specific lesions is demonstrated by these simulations. It raises the possibility that rare cases like CK and some prosopagnosic subjects may be "outliers" which we define as "pure cases", but who may not be representative of the distribution of the effects of lesions to particular systems. Of course, this argument does not prove that the system is not modular: rather it suggests that a modular system is by no means the only structure which could give rise to double dissociations.

The relevance of level of categorization and expertise to prosopagnosia

A non-modularist approach should attempt to capture the full distribution of impairments that arise from brain damage, associations as well as dissociations (Ellis, 1987; Plaut, 1995). Before the studies with LH which led to an interpretation of prosopagnosia as evidence for the modularity of face recognition, Farah (1990) noted the absence of a dissociation between associative agnosia and perceptual impairments. She argued that until such evidence is found, models which propose that associative agnosia (defined as agnosia without major perceptual deficits!) is caused by damage to stored visual memory representations (Damasio, 1985; Mesulam, 1985) receive little support. In the case of associative prosopagnosia, these perceptual deficits are varied, including trouble encoding curvature (Kosslyn et al., 1995), difficulties with global perception (Rentschler, Treutwein, & Landis, 1994), shape integration (Arguin, Bub, & Dudek, 1996; Davidoff et al., 1986) or visual closure (Levine & Calvanio, 1989). The heterogeneity of perceptual impairments may in part be due to the heterogeneity of testing methods. The importance of such perceptual impairments to the issue of whether prosopagnosia is a domain-specific deficit is often discarded because, for any given impairment, there appear to be some cases of prosopagnosia in which it is not found. Therefore, the logic goes, perceptual impairments could be associated with prosopagnosia because of spurious reasons but may in fact be caused by damage to independent systems (Farah et al., 1995; McNeil & Warrington, 1991).

However, Levine and Calvanio (1989) suggested that prosopagnosia represent a loss of configural processing and predicted that all prosopagnosic subjects should show deficits on visual closure tasks (as they found with patient LH). The current evidence offers no definitive proof against this conjecture, as long as one accepts the authors' argument that neither good face matching performance (Benton & Allen, 1972; McNeil & Warrington, 1991; Tzavaras, Hécaen, & Bras, 1970) nor covert recognition (McNeil & Warrington, 1991; Tranel & Damasio, 1985) can be taken as proofs of normal face perception. Levine and Calvanio argue that face matching can be performed using sequential visuospatial strategies (as suggested in SM and CR by the difference in sensitivity between simultaneous and sequential matching) and that autonomic responses indicative of covert recognition may be provoked by recognition of isolated features or of configural information to a degree that is not sufficient to support overt recognition. These authors also pointed out that not all subjects impaired on test of visual closure should be prosopagnosic, one reason being that tests of visual closure may place greater demand on configural processing than the processing of normal objects or faces. Deficits in configural processing could be at the basis of SM and CR's difficulties with subordinate-level judgments.

Thus, one possibility is that some perceptual impairment (e.g., deficit in configural processing) cannot actually be dissociated from prosopagnosia and could cause at once difficulties with faces and subordinate-level judgments for non-face objects. Another possibility is that, even if every perceptual impairment is dissociable from prosopagnosia (that is, at least one prosopagnosic subject may not show this particular perceptual problem), *one* of these impairments may cause every instance of prosopagnosia. In other words as suggested by Davidoff and colleagues (1986) , prosopagnosia may not be a unitary syndrome and similar recognition impairments with faces may stem from different sources in different subjects. Indeed, the two dimensions that we consider crucial to the understanding of prosopagnosia, the level of categorization and the degree of expertise, come together under such an account. Several dimensions have been found to be more important to the processing of subordinate-level tasks (including faces) as compared to basic-level tasks, e.g., such as shading, texture, color, surface detail, pigmentation and spatial arrangement of features (see Bruce and Humphreys, 1994, for review). Subordinate-level recognition of misoriented objects is also particularly dependent on normalization processes (leading to viewpoint-dependent effects) (Hamm & McMullen, 1998; Newell, 1998). For this reason, a wide range of perceptual impairments affect subordinate-level more than basic-level recognition. In addition, when subjects become experts with a given class of objects, they have been found to rely on hyper-specific representations: that is, expertise is disrupted by changes in orientation, configuration of the features or brightness reversal (Diamond & Carey, 1986; Gauthier & Tarr, 1997; Gauthier et al., 1998; Phillips, 1972; Tanaka & Farah, 1993; Yin, 1969; Young, Hellawell, & Hay, 1987). Experts may perform at novice levels when looking at images transformed in any of several ways for a common reason: the input does not match their specialized image-based representations of the category exemplars. It is possible to invoke the same argument for the disruption of expertise through brain-injury: because of any of several impairments in perception, inputs may be too distorted to effectively access expert representations. In addition, perceptual deficits may in some cases limit the acquisition of new expert abilities (more studies of perceptual expertise are needed before a model of the necessary aspects of perceptual inputs for expertise acquisition can be articulated).

The main conclusion from this study (that the account of prosopagnosia as a face-specific recognition deficit may need to be reconsidered) is based on methodological arguments as well as on empirical evidence. We argue that the differential expertise of control subjects with faces and non-face objects must be taken into account in order to achieve stimulus equivalence. This may be necessary in order to argue that a prosopagnosic subject is disproportionately impaired at face recognition (Farah et al., 1995). Thus, given that no pure case of prosopagnosia has been reported, a non face-specific account of prosopagnosia cannot be ruled out. Whereas it is often argued that only dissociations can inform us about issues of modularity, we believe that the study of deficits *associated with* prosopagnosia remains central to the issue of its putative specificity. The literature suggests that all prosopagnosic subjects may suffer from non-trivial perceptual impairments. These impairments may lead to general deficits in subordinate-level recognition, such as those which we found in the case of SM and CR when categorization-level was manipulated for several object categories. The same perceptual impairments may also reduce access to the hyper-specific representations that support expert recognition. Indeed, both categorization level and expertise have been found to account for a large part of what makes faces “special” for normal subjects and each dimension on its own has been suggested to be important in some prior models of prosopagnosia (Blanc-Garin, 1986; Damasio, 1990). Thus, a complete account of face recognition deficits, integrated with models of normal object and face recognition, may necessitate the consideration of both factors.

Method

Subjects

The two subjects, SM and CR, are both young adult males who sustained cerebral damage fairly recently. This section includes the medical history and background for both subjects as well as a description of their performance across a host of standardized perceptual and object processing tasks (see Table 5). Both patients are alert, cooperative and interactive.

SM is a 23-year-old male who was enrolled in college when he sustained a closed head injury and loss of consciousness in a motor vehicle accident just over four years ago. Repeated CT scans indicated a contusion in the right anterior and posterior temporal regions accompanied by deep shearing injury in the corpus callosum and left basal ganglia. At the time of this testing, SM was independent in all functions, was employed in his father's store and had started taking courses at a nearby Community College. Neuroopthalmological examination in late 1995 revealed acuity of 20/20 bilaterally and the eyes were unremarkable for pathology of any form. SM complains of a profound difficulty in recognizing faces, including those of his own family. His own face is also unfamiliar to him when he looks at a photograph or in a mirror. To determine a person's identity, SM is reliant on cues such as voice, or other obvious contextually-based visual cues such as a moustache, hat or earrings. SM acknowledges that he might have some minor difficulties in object recognition but that these are minimal relative to the difficulty he has with faces.

CR is an 17-year-old male who presented in May 1996 with a right temporal brain abscess with a complicated medical course including a history of Group A toxic shock syndrome, pneumonia, cardiac arrest, candida bacteremia and metabolic encephalopathy. The MR scan done at that time was positive for a right temporal lobe lesion consistent with acute micro- abscesses of the right temporal lobe and medial occipital lobe. At that time CR displayed some memory problems and difficulties in problem solving but these appear to have resolved. CR received extensive rehabilitation and has recovered full physical mobility. The testing reported here was carried out between July and October 1996. CR has returned to school on a part-time basis and has received additional tuition at home. He planned to return to school full-time from the fall of 1997.

Both SM and CR perform within the normal range on all tests of low-level visual processing, as seen from the data in Table 5. Neither patient shows any evidence of hemispatial neglect on a standard bedside battery (Black, Vu, Martin, & Szalai, 1990) and performance is within normal limits (although sometimes in the lower range) on tests of size, length, orientation, as well as on tasks of shape matching and form discrimination. SM and CR also perform well on tests that require matching of objects presented from different viewpoints as well as from a foreshortened axis (tests 7 and 8 from the BORB, see Table 5).

SM is impaired at identifying overlapping stimuli (letters, geometric shapes and line drawings where each type is blocked) with relatively better identification of the same items when presented in non-overlapping format, suggestive of an integrative form of agnosia. He is at chance at object decision (71/128; chi-square .45, n.s.) and performs well below two standard deviations from the mean.

Object recognition is impaired in both subjects, as evidenced on their naming of black-and-white pictures in the Boston Naming Test and on the Snodgrass and Vanderwart set. SM's pattern of performance is stable as seen over two tests on the Boston Naming Test, a year apart. His errors are predominantly visual, calling an ACORN - > coconut and a HARMONICA - > a register. When he fails to recognize an item, he does not appear to possess any semantic or action information about the item. He can provide good definitions to the auditory label for those items he missed when presented visually and his tactile object recognition is good. CR's object recognition, while still impaired, is likely better than that of SM. His errors too, however, are visual in nature, calling a NAIL - > screw and an ELEPHANT - > bear.

Both patients perform very poorly on tests of face recognition. SM's performance on the Benton Facial recognition test is in the impaired range with a score of 36 and, when presented with a set of pictures of famous people including Bill Clinton, Sylvester Stallone, and Steve Martin, he was unable to recognize any. CR also performed poorly on the Benton Facial recognition test with scores of 36 (July 1996) and 37 (April 1997), both of which are indicative of severe impairment. CR is unable to recognize any pictures in the set of famous people.

SM's reading performance is accurate although extremely slow and he shows the typical letter-by-letter pattern with a monotonic increase in word length as a function (466 ms per additional letter). CR's reading is also accurate but slow.

Normal control subjects were undergraduates and graduate students participating either for pay or course credit. Normal subjects typically participated in a few experiments only (for instance the same subject might participate in all sequential-matching tasks, while a different subject might participate in all simultaneous-matching tasks). The number of normal controls in Experiments 1 through 10 respectively was as follow: 10; 12; 14; 10; 10; 10; 15; 15; 11; 11 (1 subject was dropped from the analyses in each of Experiments 5, 6 and 10, for failure to follow instructions).

Procedure

SM was tested at Carnegie Mellon University and CR was tested at his home. Control subjects were tested at either Yale, Brown or Carnegie Mellon Universities. All experiments were performed on Macintosh computers equipped with color monitors (standard resolution 17" screen) except for CR who was tested on a Powerbook 540c). The experiments were conducted using RSVP software (http://psych.umb.edu/rsvp/).

Stimulus Materials

Five sets of stimuli were created for use in the different experiments. Face set A consisted of 60 greyscale faces (half male, hale female) scanned using a 3D laser and obtained from Heinrich Bülthoff and Niko Troje (Max Planck Institute, Tübingen, GERMANY). All faces were cropped using the same 2.25 x 3 inches oval window to remove cues from the hairline and face contour. Face set B consisted of 36 faces from each of 3 races (white, black and latino) with 18 males for each race. Most faces were obtained from Michael Zarate (University of Texas at El Paso). Additional faces were obtained from the University of Essex face collection. All faces were cropped using the same 1.75 x 2 inches oval window. There was more variation in face set B than A, with variation in facial expression and some moustaches. We made a special effort to select stimuli so that these cues would not be diagnostic to the identification of any individual. A set of 140 greyscale pictures of common objects was used. Most objects were created by rendering 3D object models using Silicon Graphics Inventor software. The object models were obtained from several sources, including models created in our lab using Alias Sketch software, models provided to our lab by Viewpoint Corporation (Orem, UT), models provided free with 3D software packages, and models available as part of several commercial 3D model CDROMs. A few additional pictures were obtained from the Photodisc stock photography collection and from public domain internet servers. Sixty-eight novel objects (Greebles (Gauthier & Tarr, 1997) were rendered in different orientations from 3D models created by Scott Yu with Alias Sketch! software (Alias Research Inc., Toronto). All Greebles have four protruding parts organized in approximately the same spatial configuration on

Table 5
Performance of patients SM and CR on standardized visual processing tasks

	SM	CR
A. Low-level visual processing		
Visual Object and Space Perception Battery	normal range	normal range
(Warrington & James, 1991)	on all subtests	on all subtests
Benton Visual form discrimination	low average	normal
Benton line orientation	low average	borderline
Efron shape matching task	24/25	not available
Birmingham Object Recognition Battery:		
(BORB; Riddoch & Humphreys, 1993)		
line length (test 2)	normal	normal
orientation (test 4)	normal	normal
size (test 3)	normal	normal
gap position (test 5)	normal	normal
minimal feature match (test 7)	normal	normal
foreshortened views (test 8)	normal	normal
overlapping shapes (test 6)	impaired	mild impaired
object decision (test 10)	impaired	impaired
B. Object recognition		
Boston Naming test	32/60 (July 1996)	46/60
(Goodglass, Kaplan, & Weintraub, 1983)	35/60 (June 1997)	
Snodgrass and Vanderwart (1980) pictures	172/259 (66%)	149/185 (80%)
i. living	122/165 (74%)	43/67 (64%)
ii. nonliving	50/94 (53%)	106/118 (89%)
C. Face processing		
Benton Face recognition test	36/54	36/54 (July 1996)
(Benton et al., 1983)		37/54 (April 1997)
D. Reading	slow but accurate	slow but accurate
	466 ms per letter	not available

a vertically-oriented central part. The set is organized orthogonally along two categorical dimensions, such that each Greeble is a member of one of two "genders" and one of five "families". There are five central part shapes each defining one of the five families. The gender difference is defined by the orientation of the parts relative to the central part, either all pointing upward or downward. Although some of the parts are very similar to each other, every individual part is unique within the set. Finally, a set of 90 greyscale pictures of snowflakes was selected from a larger pool of images (Bentley & Humphrey, 1962) so as to fall into three distinguishable "races" (round middle with thin rays, full-bodied, round middle with fat rays). Half of the snowflakes from each race were transformed using the "ripple" filter in Adobe Photoshop (Adobe Systems, San Jose, CA) to produce two genders of "wavy" or "non- wavy" snowflakes.

Experiments 1-4

Stimuli for Experiment 1 were 10 faces of each sex from face set A. Faces were paired in three conditions: 1. identical (20 trials), 2. different-gender (GI) (20 trials) and 3. same-gender (I) (20 trials). Stimuli for Experiment 2 were 80 target pictures of common objects. Twenty target stimuli were paired in the following way: 1. identical (40 trials -two repetitions), 2. different basic, subordinate and exemplar levels (BSE, 20 trials), 3. different subordinate and exemplar (SE, 20 trials) and 3. same subordinate level but different exemplar (E, 20 trials). On each trial, the two stimuli were shown side by side on a computer screen and remained present until the subject pressed a SAME or a DIFFERENT key. Trials were randomly intermixed for each subject.

Stimuli for Experiments 3 and 4 were greyscale pictures of 60 Greebles. There were four conditions, pairing each Greeble with distractors differing in their similarity (30 trials per condition): 1. Basic (distractor was a familiar object, ex: a car or bird; 60 common objects were used, not shown in Experiments 1 and 2), 2. Gender (distractor was another Greeble of same family but different gender), 3. Family (distractor is another Greeble of same gender but different family), 4. Individual (distractor is another Greeble of same gender and same family). Trials were randomly intermixed within each block for each subject. On each trial, a sample stimulus was presented simultaneously above two choices. The stimuli remained on the screen until subjects pressed a LEFT or a RIGHT key to indicate which of the two choices was identical to the sample. The procedure was identical for both experiments except that in Experiment 3, trials were blocked by level of categorization (from most basic to most subordinate) while in Experiment 4, trials were entirely randomized.

Experiments 5 and 6

Stimuli for Experiment 5 consisted of 15 different male faces from face set A (not used in previous experiments), each in upright and upside-down orientations. Stimuli for Experiment 6 consisted of 15 Greebles, all from the same gender and 3 from each family, each in upright and upside-down orientations. Stimuli in each Experiment were paired to create 15 "same" trials and 15 "different" trials for each orientation (All Greebles were paired within races). Sixty trials per Experiment resulted from this design. Normals and patients were tested in two identical blocks (trials randomized within each block) of these 60 trials. Each trial began with a fixation point shown for 500 ms, followed by stimulus 1 for 1500 ms, an interstimulus interval (ISI) of 1500 ms and stimulus 2 for 1500 ms.

Experiments 7-9

Stimuli for Experiment 7 consisted of 108 faces from face set A, 18 from each cell of a 2 (gender) by 3 (race: white, black, latino) matrix. Two faces from each cell were used only as targets. The experiment consisted of 12 trials. At the beginning of each trial, a target face appeared for study for 5000 ms, than subjects pressed the space bar to see a series of 12 stimuli presented sequentially. Subjects had to decide whether each of these stimuli was identical to the target or was a distractor. Four of the faces were identical to the target, two were from the same race and gender as the target, two were the same gender but different race, two were same race but different gender and two were from a different race and gender as the target. Stimuli remained on the screen until the subject made a response. Trials were randomized for each subject.

Stimuli for Experiment 8 consisted of 60 Greebles, 6 from each cell of a 2 (gender) by 5 (family - see Figure 3) matrix. Two Greebles from each cell were used only as targets. Stimuli for Experiment 9 consisted of 90 snowflakes (Bentley & Humphrey, 1962), 15 from each cell of a 2 (gender) by 3 (race - see Figure 6) matrix. Two snowflakes from each cell were used only as targets. The design and procedure were otherwise identical to that of Experiment 7.

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