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Are Greebles like faces? Using the neuropsychological exception to test the rule

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Abstract

Which image geometries count as face-like and which do not? Across multiple experiments [Vision Research 37 (12) (1997) 1673; Journal of Cognitive Neuroscience 11 (4) (1999) 349; Psychological Science 13 (3) (2002) 250], novel objects called Greebles have been used to argue that face-specific effects can be obtained with non-face stimuli under certain situations, in particular with expert observers. However, this claim depends on the argument that these non-face stimuli are not a priori treated by the face processing system. To address this question, CK, a neuropsychological patient well-known for exhibiting severe visual object agnosia and dyslexia but intact face processing, was tested with Greebles. CK performed poorly on Greebles, indicating that his intact face-specific abilities do not extend to include Greebles. These results suggest that insofar as CK is relying on face-specific visual processes, these processes do not a priori treat Greebles as faces.

Keywords: Greebles; Face-like; Face processing

1. Introduction

Neuropsychological studies of visual agnosia often examine the object domains affected in a given patient with the goal of understanding whether different object types are subserved by a common system or by separable subsystems. For example, objects, letters and faces are three domains in which deficits often arise, typically in combination but sometimes in isolation (Farah, 1990). Perhaps because of its social implications, the deficit in face recognition (prosopagnosia) that can occur in the absence of any obvious difficulties with general object recognition (Farah, Levinson, & Klein, 1995) is often studied with great interest. Explanations for this pattern of sparing and loss include the claim that faces are more similar to one another compared to other objects (Damasio, Damasio, & Van Hoesen, 1982) or that faces recruit visual processes that are more susceptible to brain damage (Bruce & Humphreys, 1994). However, such explanations have been ruled out because they cannot account for the reverse dissociation, namely impaired object recognition with relatively spared face recognition (McCarthy & Warrington, 1986; McMullen, Fisk, Phillis, & Maloney, 2000; Moscovitch & Moscovitch, 2000). A striking example of this latter, extremely rare deficit has been observed in CK, a man with visual object agnosia and dyslexia, but intact face processing abilities (Behrmann, Moscovitch, & Winocur, 1994; Behrmann, Winocur, & Moscovitch, 1992; Moscovitch & Moscovitch, 2000; Moscovitch, Winocur, & Behrmann, 1997). CK's face recognition abilities can be characterized as follows: his performance is comparable to normal control subjects when matching, recognizing or naming intact, upright faces, but he is impaired when faces are inverted or when the spatial configuration between facial features is altered. CK's preserved face recognition extends to two-tone "Mooney" faces, facial caricatures, cartoon characters and even composite faces made out of non-face objects. CK apparently has preserved the ability to recognize face-like objects but not other kinds of inputs. However, this begs the question of what constitutes a 'face-like' object: the study presented here is motivated by the fact that no clear answer exists for this question in the literature.

CK's performance with a range of different stimuli seems to depend on whether these objects are 'similar' to upright faces or not. A related claim is that the face-selective area in the fusiform gyrus (FFA) responds to the broad

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category of face stimuli, that is, anything that "looks like a face" (Kanwisher, Downing, Epstein, & Kourtzi, 2001). This logic led to the proposal that the increase of activity in the Fusiform Face Area (FFA) of subjects gaining expertise with artificial stimuli called "Greebles" may be explained by the fact that Greebles are face-like in several respects (Kanwisher, 2000). For instance they appear to be animate and have distinguishing features consisting of two lateral parts arranged symmetrically above two vertically arranged parts, i.e., a face configuration. However, this "similarity-to-faces" account of prior Greeble results seems to predict that CK should process these stimuli in the same manner he processes faces – a prediction tested here.

We take advantage of the rare dissociation found in CK to ask whether Greebles are effectively similar to faces. The answer has general implications because the interpretation of studies on face processing depends to a large extent on comparisons between faces and control stimuli (e.g., inverted or scrambled faces, familiar objects such as houses, or novel objects like Greebles). Claims that a control category is similar to faces can be made post hoc, that is, when they are empirically shown to be processed in a manner similar to faces, complicating the test of alternative accounts of category-selectivity. Such claims of face/control similarity have heretofore not been subjected to empirical investigation. The novel objects called Greebles are ideal for this test of the "similarity-to-faces" account because they have been used in studies directly addressing the domain-specificity of the system responsible for face processing. Before we present empirical findings from CK, we summarize findings from Greeble studies and explain why these studies alone are not sufficient to address the "similarity-to-faces" account.

The Greebles are designed with common parts in the same configuration: their identification thus poses a similar challenge to that of individuating faces. In a similar attempt to compare faces to control stimuli from a homogeneous category, one study matched the level of difficulty for faces and for eyeglass frames in control subjects to provide comparable tests for a prosopagnosic patient (Farah et al., 1995). However, it may not be meaningful to equate the difficulty of tasks using two different categories when subjects have expertise for one (faces) but not the other (eyeglass frames). An alternative is to manipulate the level of categorization for different categories, and compare how performance depends on this manipulation across categories rather than consider baseline differences between categories that may be difficult to interpret (Gauthier, Behrmann, & Tarr, 1999a). Thus, the Greeble set is hierarchically organized, so that the categorization level at which two Greebles are compared can be varied systematically.

The logic of studies using Greebles is to investigate whether faces are 'special' or whether similar behavioral or neural effects can be observed for non-face objects. Because all (or most) people are experts at face recognition, these studies have mainly examined whether the effects postulated to be specific to face processing can be obtained for Greebles in subjects trained to be Greeble experts. Even a few hours of training (5–10) over a few days leads to dramatic changes in Greeble object perception and neural processing. A hallmark of face recognition is holistic processing, which can be operationalized by a difficulty in selectively attending to part of a face while ignoring information in other task-irrelevant parts (Farah, Wilson, Drain, & Tanaka, 1998; Gauthier & Tarr, 2002; Young, Hellawell, & Hay, 1987).[1] Similarly, Greebles are processed more holistically by experts than novices (Gauthier & Tarr, 1997, 2002) and as with faces, this effect is obtained for upright but not inverted Greebles (in subjects trained with upright Greebles). These results suggest that, at least at a behavioral level, Greebles may be processed in the same manner as faces.

Neural signatures associated with faces are also observed in Greeble experts. For example, expertise with Greebles leads to increased activity in the Fusiform Face Area when viewing Greebles (Gauthier & Tarr, 2002; Gauthier et al., 1999a). In ERPs, Greeble experts looking at Greebles produce an inversion effect on the N170 potential that was previously found only for faces (Rossion et al., 2000, 2002). Finally, Greebles have also been used to assess the performance of two visually agnosic individuals suffering from prosopagnosia, SM and CR (Gauthier et al. 1999a). Although these patients were proficient at discriminating Greebles from non-Greeble objects, they were dramatically slower (and in some tasks made more errors) than non-neurological controls when discriminating between individuals instances of Greebles, even though they were often as fast and accurate when Greebles had to be discriminated from other dissimilar objects. This finding suggests that the patients' deficit lies in distinguishing between visually-similar objects such as Greebles or faces, rather than in face recognition per se.

Greeble studies provide converging evidence that putatively face-specific effects can be obtained with visually-similar non-face objects in expert observers. Although these results were originally interpreted as evidence for domain-generality in the mechanisms underlying face recognition, one alternative and perhaps simpler interpretation is that Greebles possess a face-like configuration sufficient to trigger face-selective visual processes (Kanwisher, 2000). Clearly, it is difficult to predict a priori whether a putative module for processing faces would be engaged by objects that have a face-like configuration across some of their parts, such as the front of some cars or houses, or in this case, Greebles (see Fig. 1). It could be argued that the fact that novices do not process Greebles holistically and do not show a large response in the FFA to these objects is already evidence against the "similarity-to-faces" account of the results with Greeble experts. However, because sep-

[1] Note that holistic processing has also been operationalized as a disadvantage for recognizing parts in isolation compared to parts in the context of a whole (Tanaka & Farah, 1993). For a discussion of the difference between the two definitions, see (Gauthier & Tarr, 2002).

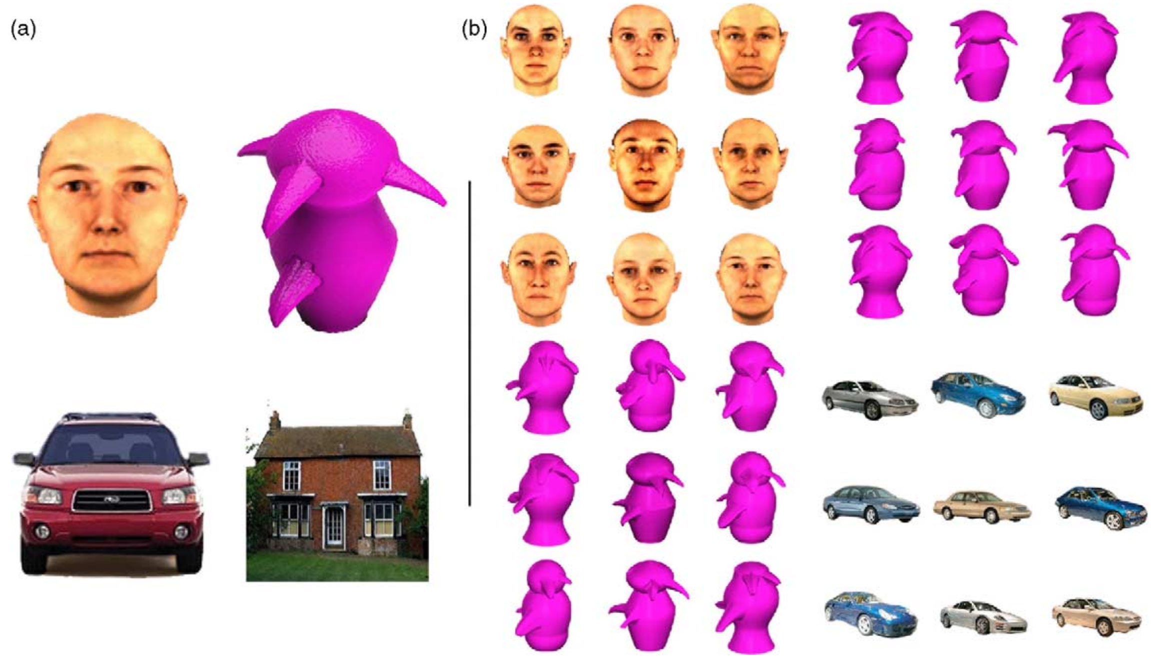

Fig. 1. Two different ways that object processing could be similar to that of faces. (a) On the one hand, objects can be similar to faces in their geometry, for example, to the extent that their parts are arranged in a face-like configuration. (b) On the other hand, most objects can be used in a task that is similar to face processing, despite limited similarity of each object to the face geometry, as long as all objects of a class share the same number of parts in the same configuration (Reed, Stone, Bozova, & Tanaka, 2003).

arate systems for processing faces and objects are often proposed (Farah, 1990; Moscovitch & Moscovitch, 2000), it is difficult to predict how these systems would interact in the uninjured brain: normal individuals could use both systems to recognize most stimuli, with different weighted contributions from each, and the systems could compete in a non-linear manner to produce behavior on any given task. This conjunctive contribution from the two systems would make it impossible to test the properties of either system independently of the other in normal individuals. For example, the "face system" in the intact brain might indeed treat Greebles as appropriate stimuli for further processing, but, without sufficient experience with Greebles, the "object system" may simply win the processing race.

CK's performance has been argued to reflect the workings of a putative face-specific module, uncontaminated by the effects of mechanisms responsible for object recognition (Moscovitch & Moscovitch, 2000). We therefore explored whether he would perceive and process Greebles as he does faces, or whether Greebles would be subject to the impairments he exhibits for non-face objects. Because CK did not possess pre-morbid expertise for Greebles, we predicted that he would be impaired with Greebles. This finding would lend support to the idea that Greeble are not classifiable a priori as face-like by the visual system, and that only with repeated experience do they begin to elicit face-like effects. In a sense, CK serves as an assay on the specificity of face expertise and sheds light on what the putative face module is willing to admit as a representation.

2. Methods

2.1. Subjects

CK has been described extensively in prior work (Behrmann et al., 1994; Moscovitch & Moscovitch, 2000). He was a right-handed man who was 38-years-old at the time of testing. He sustained a closed-head injury in 1988 and was diagnosed later with visual object agnosia and dyslexia. No focal damage was visible on MRI and CT scans although there was a hint of thinning of the occipital cortex bilaterally (it has not been possible to do a fMRI scan on him as he is claustrophobic). His visual acuity, language, memory and reasoning were normal as was his low-level visual processing of color, motion, orientation and so forth. CK's poor recognition of objects extended to two-dimensional black-and-white line drawings as well as colored photographs. CK was also impaired at recognizing three-dimensional real common objects (for example, a pipe for smoking, a padlock, a computer diskette) although he was not as badly affected as for the two-dimensional objects. The slightly better performance on real objects is likely attributable to the presence of information about surfaces and textures, image properties known to be exploited by visual object agnosics when possible (Chainay & Humphreys, 2001; Humphrey, Goodale, Jakobson, & Servos, 1994; Jankowiak, Kinsbourne, Shalev, & Bachman, 1992).

SM and CR were described extensively in (Gauthier et al., 1999a) as well as in (Behrmann & Kimchi, 2003;

Marotta, McKeeff, & Behrmann, 2002; Marotta, Genovese, & Behrmann, 2001) They were both young male adults at the time of testing (ages 23 and 17, respectively). SM became agnosic following a closed-head injury when he was 19-years-old. CT scans revealed a contusion in the right anterior and posterior temporal regions as well as deep shearing injury to the corpus callosum and basal ganglia. CR became agnosic following a right temporal brain abscess and a complicated medical history. MR scans revealed a right temporal lobe lesion consistent with acute micro-abscesses of the right temporal lobe. Control subjects were undergraduate and graduate students tested at Yale, Brown or Carnegie Mellon University. The number of control subjects in Experiments 1 through 4 was 13, 10, 9 and 9 respectively. All control data as well as data from SM and CR were presented in a prior report (Gauthier et al., 1999a) and are shown here only for comparison with CK.

2.2. Materials and procedures

2.2.1. Simultaneous matching of faces

Twenty faces (10 from each gender) were cropped to remove hair and paired in three randomly intermixed conditions (20 trials each). The two faces were either the *same* image, of different individuals of *different gender*, or different individuals of the *same gender*. 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.

2.2.2. Simultaneous matching of objects

Eighty greyscale pictures of common objects were used. Twenty target stimuli were paired with distractors in each trial of four randomly intermixed conditions. The two objects were either the *same* (40 trials, two repetitions), objects at different *basic* levels (20 trials), objects of different *subordinate* levels of the same basic level (20 trials) or different *exemplars* of the same subordinate level (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.

2.2.3. Simultaneous matching of Greebles

Sixty greyscale pictures of Greebles were paired in each trial within four randomly intermixed conditions with distractors differing in similarity (30 trials per condition). 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 distractor Greeble was either at a different *basic* level, a different *gender* (parts pointing up or down) but same family (as defined by the same of the large central shape), a different *family* but the same gender or a different *individual* of the same family and gender as the target.

2.2.4. Sequential matching tasks

Fifteen grayscale male faces without hair or any salient distinguishing feature were used, each in upright and inverted versions as well as 15 Greebles, all from the same gender (parts pointing in the same direction) and three from each family, each in upright and upside-down orientations. Stimuli of both categories were paired to create 15 "same" trials and 15 "different" trials for each orientation (all Greebles were paired within family). Sixty trials with faces (randomizing over orientation) were completed first, followed by 60 trials with Greebles (randomizing over orientation). Each trial began with a fixation point shown for 500 ms, followed by Stimulus 1 for 1500 ms, an interstimulus interval of 1500 ms and Stimulus 2 for 1500 ms.

Note that just as in Gauthier et al. (1999a), we did not intend to compare directly performance with different object categories, since it would be difficult to claim that they were equated in difficulty (for instance, the Greebles may be more visually-similar than our objects). In addition, it is difficult to deal with order effects when testing a single patient (in sequential matching, we presented faces before Greebles, which if anything should encourage CK to think of Greebles as faces – controls were tested with the same order as CK). Thus, our analyses focus on the comparison between CK and controls (as well as prosopagnosic patients SM and CR), and the main question is whether CK's performance with Greebles will resemble more his typically very good performance with faces or the deficits he shows with non-face objects.

3. Results

3.1. Simultaneous matching of faces and of objects

CK participated in experiments testing his ability to perform simple matching judgments of faces and objects. These two tasks were used in our prior studies to establish that two individuals with prosopagnosia, SM and CR, were more sensitive to the similarity of objects (faces and non-face objects) to be discriminated, as compared to control subjects (Gauthier et al., 1999a). The previously published data for SM and CR are displayed in all figures for comparison. Simultaneous matching is a relatively easy task, especially when the "same" trials consist of identical images, and CK's accuracy for both faces and objects was generally within the range of controls' performance (Fig. 2). CK's face judgments were numerically faster (and within less than 0.5 S.D.) than the average control performance in all conditions. In contrast, CK's object judgments were slower than those of the slowest control in all but the "different basic" condition. His RTs were 3.32, 2.08, 3.93 and 3.49 S.D. longer than the controls' in the same, different basic, different subordinate and different exemplar conditions, respectively. Consistent with this deficit on object matching, only

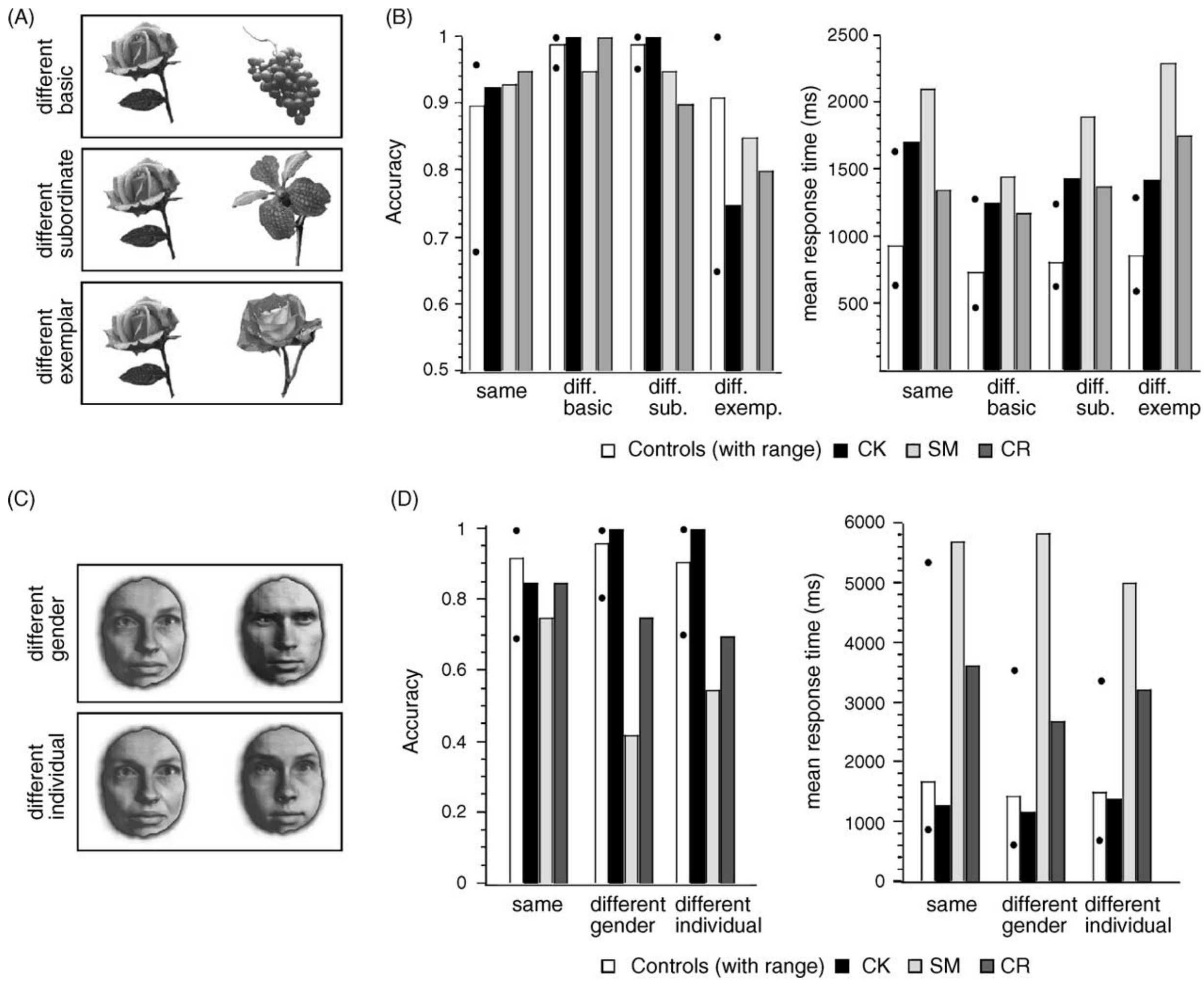

Fig. 2. Simultaneous matching of faces and common objects. (A) Examples of trials used in the object matching task. (B) Accuracy and mean response times for correct responses for CK, two prosopagnosic patients as well as control subjects. Error bars on the control data show two standard deviations. (C). Examples of trials used in the face matching task. (D) Accuracy and mean response times for correct responses for CK and the two prosopagnosic patients as well as control subjects from (Gauthier et al., 1999a). Error bars on the control data show two standard deviations. Note the different scales on Fig. 1b.

one control subject performed more poorly (65%) than CK at the exemplar level with objects. However, this subject's responses were very rapid (more than 1000 ms faster than CK), suggesting that he chose to adopt a response deadline that was detrimental in the most difficult condition. In contrast, in the exemplar condition, CK grouped with CR and SM as the three subjects who were both the least accurate and slowest of all participants. These results are consistent with the pattern of performance previously described for CK of normal performance with faces but impaired performance with objects (Behrmann et al., 1992, 1994). His deficit on this simple perceptual task with objects is not as pronounced as it is on a more challenging task such as naming (Behrmann et al., 1994). It is therefore particularly interesting to consider his performance in a similar perceptual task with Greebles as described in the next section, because we may expect this task to be relatively easy for CK.

3.2. *Simultaneous matching of Greebles*

CK was tested on simultaneous matching of Greebles, with which he was completely unfamiliar. For consistency with prior testing on patients SM and CR (Gauthier et al., 1999a), we used an ABX task in which, on each trial, one of two objects shown at the bottom of the screen had to be matched with a target object shown at the top of the screen.[2] SM and CR could perform this task accurately but

[2] This task used an ABX procedure rather than an AX procedure to make it easier for subjects to deal with a novel object class for which they had no prior knowledge of the range of interstimulus differences. Any concern regarding the difference between these two tasks needs to be viewed in the context of the fact that CK shows clear deficits with Greebles relative to controls in both ABX and sequential matching paradigms: thus, it is not crucial to our claim to compare the exact performance of CK with Greebles and objects, but only to note the converging evidence for his deficit with Greebles.

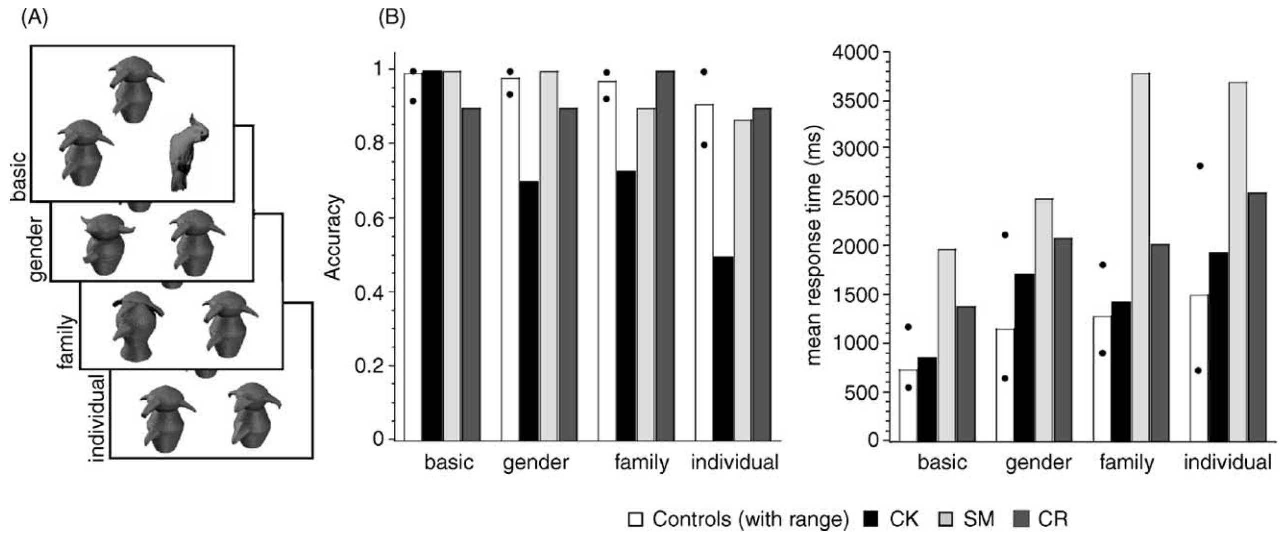

Fig. 3. Simultaneous matching of Greebles. (A) Example of trials in the Greeble matching task. (B) Accuracy and mean response times for correct responses for CK, two prosopagnosic patients as well as control subjects. Error bars on the control data shows two standard deviations.

their responses were found to be dramatically sensitive to the similarity of the target and distractor object (Gauthier et al., 1999a). CK's speed was within the normal range in most conditions (See Fig. 3) (and 2.15 S.D. slower than controls in the family condition). However, his accuracy was worse than that of the worst control and clearly deviant in all "different" conditions (8.6, 10 and 6.6 S.D. worse than controls in the gender, family and individual conditions, respectively).

Thus, CK's accuracy in Greeble matching is dramatically sensitive to level of categorization, as he only performs normally when comparing Greebles to other categories. Interestingly, prosopagnosic patients SM and CR exhibited a similar sensitivity to level of categorization with Greebles but only in response times (the same pattern was found in accuracy in sequential matching tests when presentation time was limited, Gauthier et al., 1999a). One possibility is that CK performed poorly but reasonably fast on Greebles because he saw Greebles as objects and at a metacognitive level he thinks of himself as impaired with all objects but faces. In contrast, SM and CR think of themselves as having mainly a deficit with faces (despite the impairments they showed with visually-similar objects). The first time the latter two patients saw Greebles, they suggested that these objects would be "easy" stimuli – accordingly, they appeared motivated to use the unlimited presentation time to compare Greebles one feature at a time (a strategy they later reported using). It is certainly difficult to compare deficits expressed across accuracy and response times, but CK appears to be at least as impaired as SM and CR at Greeble matching given the tight relationship between these two response measures. This conjecture can be tested further in the limited presentation time task we used next, where speed–accuracy tradeoffs can more easily be avoided.

3.3. *Sequential matching of faces and Greebles*

The selectivity of face processing in CK is evidenced by his ability to discriminate and recognize upright, but not inverted, faces (Moscovitch & Moscovitch, 2000). We used a sequential matching task with faces and Greebles in both upright and inverted orientations to determine whether CK's matching of Greeble images would similarly be sensitive to orientation. To the extent that Greebles are "face-like" it is because they share a similar configuration of parts to faces: if the configural relations between parts of Greebles is sufficient to trigger the holistic mechanisms associated with upright faces, CK should perform better with upright than inverted Greebles. Sequential matching is more difficult than simultaneous matching: for SM and CR, this task led to deficits in both accuracy and RTs relative to controls whereas simultaneous matching of Greebles produced only longer RTs (Gauthier et al., 1999a).

First, CK's performance with faces replicates the previous results obtained by Moscovitch et al. (1997): with upright faces, he showed normal accuracy (within 0.3 S.D. from controls) and speed (within 0.4 S.D. from controls) (See Fig. 4). In contrast, with inverted faces, his accuracy was 4.5 S.D. lower than controls (he performed below the worst control) and his responses were 2.1 S.D. longer than controls'. In contrast, his performance with Greebles did not reveal any sensitivity to orientation: his accuracy was very poor, 3.1 and 2.7 S.D. below controls in the upright and inverted conditions respectively (worse than the worst control in both orientations). He was also the slowest of all subjects tested, 2.6 and 2.1 S.D. slower than controls in the upright and inverted conditions (although RTs are relatively uninformative given that he was at chance). Not only is CK impaired with Greebles compared to normal controls, but this experiment confirms that his deficit is at least as bad

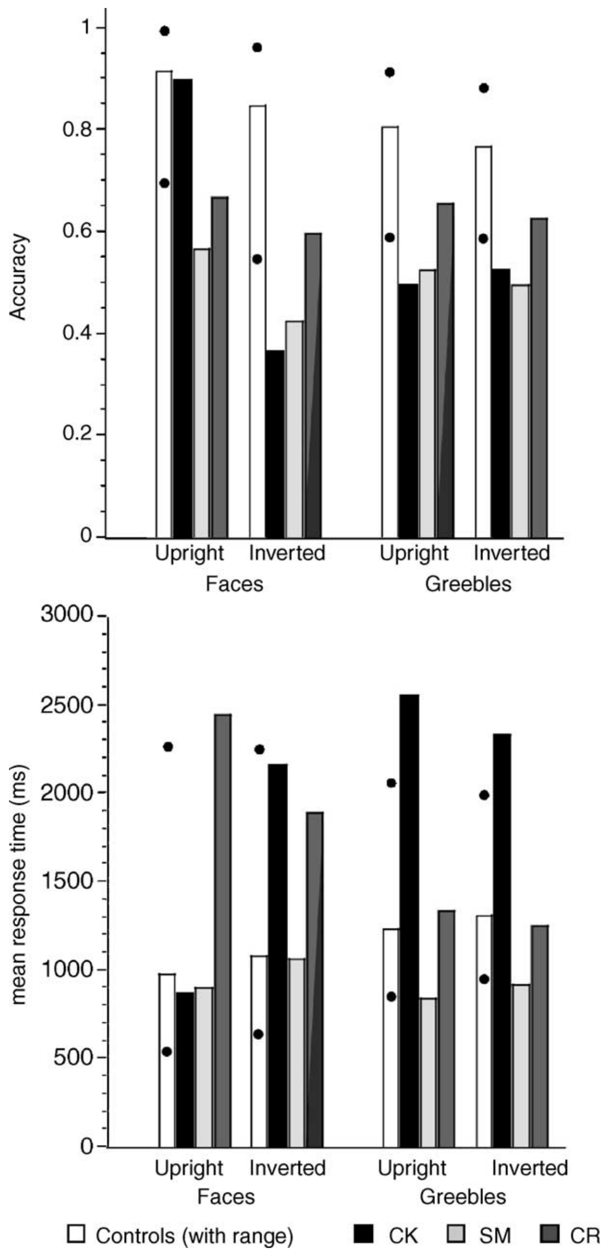

Fig. 4. Sequential matching of upright and inverted faces and Greebles. Accuracy and mean response times for correct responses is shown for CK, two prosopagnosic patients as well as control subjects. Error bars on the control data shows two standard deviations.

as that of SM and CR. While CK performs better than the two prosopagnosic individuals on upright faces, he is worse with inverted faces and with Greebles at both orientations (his accuracy is at chance and comparable to theirs but, in addition, he is much slower).

One question is whether we can conclude that CK shows no inversion effect with Greebles given that he is at floor at both orientations. On the one hand, we need to be careful interpreting this result: that is, CK is *clearly* impaired with Greebles at both orientations, but a possible orientation effect may be masked by the floor effect. If we missed a real inversion effect for Greebles with CK for this reason, one would expect that with a much easier task, his performance with upright Greebles should go up. On the other hand, it is interesting to note that his performance with Greebles at the individual level in the simultaneous task was also at floor, and this task was easier in two important ways: the Greebles were presented simultaneously and presentation time was not limited. Therefore, we tentatively conclude that CK's performance discriminating individual upright Greebles appears to be as bad as his performance when they are inverted, because it seems unlikely that we can get him to perform above floor with these stimuli at this categorization level, in either a sequential or simultaneous matching task.

4. Discussion

Many theoretical debates in cognitive neuroscience have centered on the issue of domain-specificity (Bates, 1994; Carmel & Bentin, 2002; Coltheart, 1999; Fodor, 1983; Rossion, Gauthier, Goffaux, Tarr, Crommelinck, 2002). However, this question is difficult to address unless we can define the domains a priori. For example, we have used Greebles as non-face objects in prior studies to test the hypothesis that face-specific effects can be obtained in subjects who have acquired Greeble expertise. Our assumption was that the particular geometry of the Greebles is not essential to this prediction: what makes Greeble recognition similar to face recognition is that Greebles, like faces, each have a number of similarly-shaped parts in the same global configuration across the class so that the presence of any single part does not serve as a diagnostic cue for discriminating an individual. However, given behavioral and neural face-like effects with Greebles for Greeble experts (Gauthier & Tarr, 1997, 2002; Gauthier et al., 1999b; Gauthier, Williams, Tarr, & Tanaka, 1998; Rossion et al., 2002), one proposed alternative was that this was because Greebles have many geometric properties in common with faces (Kanwisher, 2000).

Such a post-hoc "similarity-to-faces" argument renders the use of *any* control stimuli vulnerable to a sort of "Catch-22". If control objects fail to elicit key behaviors and neural effects, it is because they are outside of the domain. If face-specific effects are obtained with said objects, it is always possible to invoke the similarity of these objects to faces along some dimension. For example, other objects have a face-like configuration of parts (see Fig. 1): some houses (with one door and two symmetrically arranged windows) or the front view of many cars (two headlights, a hood ornament, and a radiator grille). Many other objects are animate, or symmetric along the vertical axis, or have individual proper names like faces. Thus, if we are to effectively test a given theory with regards to domain-specificity, it is critical that the crucial dimensions of the domain be defined up front when spelling out the properties of a putative neural module.

Fortunately, CK offers a unique opportunity to probe the boundaries of the face domain. Our results suggest that this domain does *not* extend to Greebles, stimuli for which CK exhibits extreme impairments in a simple matching task. He also shows little evidence for the dramatic sensitivity to inversion with Greebles that he demonstrates for faces (he is normal with upright faces and at chance with inverted faces but performs at chance with both upright and inverted Greebles). It is interesting to note that CK performs no better than prosopagnosic patients with Greebles. Thus, *whether or not one possesses a functioning "face module" is irrelevant with respect to Greeble recognition*. Accordingly, other evidence against modularity based on Greebles cannot be dismissed because Greebles are supposedly "face-like". CK's performance with Greebles helps break the circularity of the argument in which expertise effects with Greebles cannot support a domain-general hypothesis because they are face-like.

The "similarity-to-faces" hypothesis fails because it cannot account for *both* CK's pattern of results in tandem with that of prosopagnosic patients *and* the changes that occur in subjects as they acquire expertise with Greebles (Gauthier & Tarr, 1997, 2002; Gauthier et al., 1998, 1999b; Rossion et al., 2002).

While we would argue that an expertise account appears more consistent with these findings, it is important to note that no single explanation currently accounts for all the evidence. First, we need to explain CK's and prosopagnosics' impairment with Greebles relative to novice controls. That is, some visual areas, in particular the FFA and surrounding fusiform cortex, appear especially important in the subordinate-level processing of visually-similar objects even in novice subjects (Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997; Gauthier, Tarr, Moylan, Anderson, & Gore, 2000b). Accordingly, brain lesions in these areas may lead to a deficit in subordinate-level visual discriminations. In addition, we also need to explain CK's preserved face recognition in the context of his object agnosia. We suggest that this is related to the observed difference between novices and experts in subordinate-level tasks (Gauthier, Skudlarski, Gore, & Anderson, 2000a; Gauthier et al., 1999b): a process that leads to more focal specialization with expertise in the FFA and perhaps some other occipito-temporal areas (e.g., including the OFA).[3] A rare occurrence of focal damage falling exactly into a small area of specialization could produce an "island" of preserved perceptual ability such as in CK.

To the extent that our account explains CK's pattern of performance, one might expect that he should not only show preserved face recognition, but spared "expert" recognition for any homogeneous object categories learned pre-morbidly. There is indeed some evidence from category-specific agnosia that premorbid expertise with a category can protect against later deficits (Dixon, Schweizer, & Bub, 2002).

Unfortunately, this prediction is difficult to test with CK: on the one hand, CK was both an airplane and toy soldier "buff" before his brain injury, and in both instances he claims to have lost the ability to discriminate objects within these two categories (Moscovitch et al., 1997). Although he was never tested formally on these categories, he did not seem to be able to identify any airplanes when shown a Jane's military catalogue and asked to name various aircrafts. Unfortunately, we do not know the extent of his premorbid expertise for airplanes and whether he could have accurately performed this identification prior to his injury. It is also reasonable to question whether the expertise he had acquired in these other domains was comparable to that for faces. For example, one would want to know whether these skills rely on similar holistic processes that have been associated with face and Greeble expertise, and FFA activity (Gauthier & Tarr, 2002). Whether CK's Greeble processing would have been spared together with his face expertise if he had been trained with them prior to his injury, we will never know. CK's level of expertise with different homogeneous categories is most likely an important determinant for his condition. Specifically, no matter how much experience CK has had with airplanes and toy soldiers, his greater experience with faces may lead to their overrepresentation relative to other categories – including other domains of expertise. Thus, although face recognition will have a higher probability of impairment under focal injury, it may also have a higher probability of preservation following extensive damage (Cheng & Tarr, 2003).

Our account suggests that prior expertise with faces may have been crucial in producing isolated intact face processing as observed in CK. According to this view, novices with faces (e.g., as may be the case of people with autism or individuals with early visual deprivation, (Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002; Pierce, Muller, Ambrose, Allen, & Courshenes, 2001; Schultz et al., 2000) could never show the same pattern of preserved face recognition as CK's. We also conjecture that his extensive visual agnosia would prevent the acquisition of expertise in new object domains (unfortunately, CK is not available for Greeble training). That is, his impaired skills with objects may impede the early stages of learning that may be necessary as a scaffold for the perceptual strategies adopted by experts during training. A recent report suggested that a lesion to the occipito-temporal pathway very early in life – presumably before the onset of face expertise- can lead to prosopagnosia (Farah, Rabinowitz, Quinn, & Liu, 2000). Unfortunately, such a deficit cannot by itself distinguish between the modular and expertise hypotheses because the area damaged could be either face-specific or necessary for the acquisition of perceptual expertise with visually-similar objects. In contrast, the counterpart developmental deficit

[3] Interestingly, recent evidence indicates that some prosopagnosic patients may present with activity in the fusiform gyrus that is strikingly similar to the normal pattern of specialization for faces (Behrmann, Avidan, Hasson, Marotta, Harel, & Malach, 2003;Hasson, Avidan,Deouell, Bentin, Mallach, 2003). This finding is a reminder that no current account of specialization for faces can explain all existing data.

has never been described but could be more informative: a lesion early in life, occurring prior to the acquisition of face expertise and leading to visual object agnosia without prosopagnosia (as in CK). In other words, such a patient would be unable to acquire expertise for non-face objects such as Greebles but presumably could learn faces without a problem. This would provide strong evidence for a system dedicated to the acquisition of expertise for faces. To our knowledge no such case has ever been reported. In the past, emphasis placed on the theoretical importance for a yet-to-be observed syndrome (Farah, 1990) has led to its discovery (Humphreys & Rumiati, 1998; Rumiati & Humphreys, 1997), suggesting that many interesting deficits are ignored until their theoretical significance is established. Such efforts may prove to be a long (but necessary) search for further support for or against a modular theory of face processing.

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