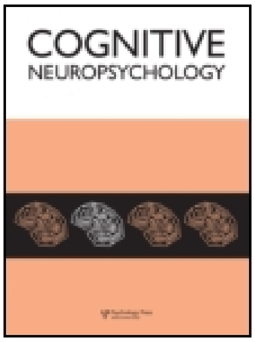


Routledge
Taylor & Francis Group

Cognitive Neuropsychology

ISSN: 0264-3294 (Print) 1464-0627 (Online) Journal homepage: http://www.tandfonline.com/loi/pcgn20

Impairments in part–whole representations of objects in two cases of integrative visual agnosia

Marlene Behrmann & Pepper Williams

To cite this article: Marlene Behrmann & Pepper Williams (2007) Impairments in part–whole representations of objects in two cases of integrative visual agnosia, Cognitive Neuropsychology, 24:7, 701-730, DOI: 10.1080/02643290701672764

To link to this article: http://dx.doi.org/10.1080/02643290701672764

COGNITIVE NEUROPSYCHOLOGY, 2007, 24 (7) 701–730

Psychology Press
Taylor & Francis Group

Impairments in part–whole representations of objects in two cases of integrative visual agnosia

Marlene Behrmann
Carnegie Mellon University, Pittsburgh, PA, USA

Pepper Williams
University of Massachussetts at Boston, Boston, MA, USA

How complex multipart visual objects are represented perceptually remains a subject of ongoing investigation. One source of evidence that has been used to shed light on this issue comes from the study of individuals who fail to integrate disparate parts of visual objects. This study reports a series of experiments that examine the ability of two such patients with this form of agnosia (integrative agnosia; IA), S.M. and C.R., to discriminate and categorize exemplars of a rich set of novel objects, "Fribbles", whose visual similarity (number of shared parts) and category membership (shared overall shape) can be manipulated. Both patients performed increasingly poorly as the number of parts required for differentiating one Fribble from another increased. Both patients were also impaired at determining when two Fribbles belonged in the same category, a process that relies on abstracting spatial relations between parts. C.R., the less impaired of the two, but not S.M., eventually learned to categorize the Fribbles but required substantially more training than normal perceivers. S.M.'s failure is not attributable to a problem in learning to use a label for identification nor is it obviously attributable to a visual memory deficit. Rather, the findings indicate that, although the patients may be able to represent a small number of parts independently, in order to represent multipart images, the parts need to be integrated or chunked into a coherent whole. It is this integrative process that is impaired in IA and appears to play a critical role in the normal object recognition of complex images.

Keywords: Integrative agnosia; Object recognition; Part–whole representations; Visual agnosia; Visual categorization.

Correspondence should be addressed to Marlene Behrmann, Department of Psychology, Carnegie Mellon University, Pittsburgh, PA 15213–3890, USA (E-mail: behrmann@cmu.edu).

This work was supported by a grant from the National Institutes of Mental Health (MH54246) and to the Perceptual Expertise Network (James S. McDonnell Foundation) to M.B. The authors thank S.M. and C.R. and their families for their enthusiasm and continued participation in this research. Thanks also to James Nelson and Matt Shugrue for their help in testing the patients and control participants, respectively. We thank Stacy Cho for help with manuscript preparation.

http://www.psypress.com/cogneuropsychology
DOI:10.1080/02643290701672764

Introduction

How multipart complex visual objects are represented during perception remains a subject of ongoing investigation. One source of evidence that is used to elucidate this issue comes from studies of patients with visual agnosia. By definition, patients with visual object agnosia have difficulty recognizing common objects that they were perfectly capable of recognizing before their brain damage, despite intact sensory input and preserved semantic knowledge, as well as preserved object recognition under conditions in which objects are presented in a modality other than vision (Farah, 2004). Understanding the object-processing failures in such individuals provides important evidence for the nature of the computations underlying normal shape perception. Indeed, in recent years, much of the emphasis of these neuropsychological investigations has been on understanding the nature of the perceptual deficit (G. W. Humphreys & Riddoch, 2006) rather than on simply defining agnosic patients as having either apperceptive or associative agnosia (Lissauer, 1890). Importantly, the outcome of these studies will expand our understanding of the normal visual perceptual system and will constrain evolving theories of object perception (see for recent example, Ullman, 2007).

Integrative agnosia

One fruitful product of these recent investigations of agnosia has been the examination of the performance of a subgroup of agnosic individuals who appear to have available to them the features or elements present in the input, but who are nevertheless unable to bind the elements into unified shapes (Behrmann & Kimchi, 2003b; Behrmann, Peterson, Moscovitch, & Suzuki, 2006; G. W. Humphreys, 1999; G. W. Humphreys & Riddoch, 2006; Riddoch & Humphreys, 1987, 2003). These individuals, referred to as integrative (or intermediate) agnosic (IA) patients (the term coined by Riddoch & Humphreys, 1987), fail to synthesize the components of the visual input into a coherent whole and tend to oversegment visual images. Patient H.J.A., perhaps the best known IA patient (Giersch, Humphreys, Barthaud, & Landmann, 2006), for example, produced the following response to a picture of a pepperpot: “a stand containing three separate pans; the top has a design on its lid, the second has a slightly smaller diameter than the top pan; the bottom pan has a wider diameter than the second pan and is longer in length” (G. W. Humphreys & Riddoch, 1984, p. 399). Another IA individual also identified parts as separate items: Shown a cup and asked to identify it, he stated that it was “a large oval item together with a smaller oval item (pointing to the handle)” (Butter & Trobe, 1994). This oversegmentation can also apply to letters; for example, patient F.G.P. selected subparts of letters, reporting R as D and Q as O (Kartsounis & Warrington, 1991), and these failures suggest a breakdown in the process of visual part–whole synthesis.

The difficulty in part–whole synthesis becomes even more apparent when the stimulus includes multiple internal segmentation cues (Riddoch & Humphreys, 1987); for example, IA patients are typically unable to derive a coherent object in a display in which the objects overlap (either transparently or via occlusion) but do better when the same objects are presented in a nonoverlapping format. Moreover, some patients show improved performance when required to identify silhouettes in which local cues have been removed compared with line drawings (Butter & Trobe, 1994; Giersch, Humphreys, Boucart, & Kovacs, 2000; G. W. Humphreys et al., 1994; Lawson & Humphreys, 1999; Riddoch & Humphreys, 1987), in direct contrast with the pattern of normal observers. The failure to segment and integrate elements of a complex display is also evident on tasks that require figure–ground segregation, although some patients do exhibit residual sensitivity to configural cues, such as convexity and symmetry, which can still be exploited to determine figure–ground assignment (Peterson, de Gelder, Rapcsak, Gerhardstein, & Bachoud-Lévi, 2000).

In contrast with these examples of fragmented perception, when the task does not require contour integration, the performance is generally well preserved. For example, the patients typically show intact performance on the Efron shape-matching task (Efron, 1968) in which squares or rectangles of variable flux are to be matched, and they have well preserved low-level visual processes including discrimination of line length, spatial localization of dots, and colour and motion processing. They can also make line orientation and size judgements at normal levels (Davidoff & Warrington, 1993; Ricci, Vaishnavi, & Chatterjee, 1999) and can extrapolate local contours, as reflected in their ability to integrate collinear edges of Gabor elements into a contour (Behrmann & Kimchi, 2003b; Behrmann et al., 2006; Giersch et al., 2000). These IA patients also typically benefit from the addition of surface details to images: colour, motion or other surface cues such as luminance and texture aid the integration of form elements into a coherent perceptual whole (Bartolomeo et al., 1998). In addition, depth information, conveyed both by binocular disparity cues as well as by head movement, provides additional cues for object recognition (Chainay & Humphreys, 2001; Jankowiak, Kinsbourne, Shalev, & Bachman, 1992).

The perceptual deficit exhibited by these IA patients extends beyond object recognition. Most, although not all, of these patients experience difficulties recognizing faces (Behrmann, Marotta, Gauthier, Tarr, & McKeeff, 2005; Gauthier, Behrmann, & Tarr, 1999; Moscovitch, Winocur, & Behrmann, 1997; Riddoch & Humphreys, 1987), which are often thought to be the paradigmatic stimulus requiring configural or holistic processing, and other living objects that also engage configural processing (Thomas & Forde, 2006). Also, these individuals process letters in strings serially so reaction time scales linearly with the number of letters (Osswald, Humphreys, & Olson, 2002).

In sum, the deficit in these IA patients becomes most apparent when there are multiple elements to be encoded and integrated and when exposure duration or stimulus quality is affected such that serial encoding is not possible. When sufficient time is available, and encoding can be done sequentially, or when cues to segmentation are present (for example, colour or other surface properties), performance is somewhat better. Despite the increasing refinement in the characterization of IA, several fundamental questions remain. For example, it is unclear how much information the patients have about the relations between the various elements and about the three-dimensional arrangements (spatiotemporal information) of objects in the display. It is also unclear whether the patients may have some access to this type of information at an implicit level, as has been suggested recently (see below). Understanding these issues provides insights into the processes by which normal object perception might proceed and can help flesh out theoretical accounts of how parts and their relations are bound in the service of object representations (Palmeri & Gauthier, 2004).

Parts and their relations in integrative agnosia

One recent study suggests that a patient with IA is able to represent the individual or disparate parts of objects but not the relations between the parts, supporting the notion that, in normal object perception, there are two independent processes, one for representing parts and one for representing their relations. In this study, integrative agnosic patient S.M. (who also participates in the present study) and matched control participants learned to identify four different objects, each made of two simple 3-D volumetric forms ("geons"; Behrmann et al., 2006). The two geons of each object were unique to a single object. To evaluate the nature of the representations derived during learning, at test, the original four objects were presented along with distractors: Half of the distractors (part-changed distractors) could be discriminated on the basis of a mismatching part (one of the two original geons was replaced by a different geon), and the remaining half differed from the target by a spatial rearrangement of the original two geons (relational change distractors). The first important finding was that S.M. was able to learn to identify the targets although he clearly required longer to do so than the normal subjects, and his reaction times at the end of learning were still elevated relative to the control subjects. But perhaps of greater interest is

S.M.'s error pattern at test: While he never mistook a part-changed distractor as one of the original targets, suggesting that he had the local elements of the image available, he made 100% false alarms to the relation-changed distractors. These findings are striking in showing that S.M. had access to the local elements, but was unable to integrate them in a way that defined a unique target—when objects shared the same two parts, even in a different spatial relationship, he nevertheless considered them identical.

The conclusion from this study was that there is independence between the representations of parts and their relations, an outcome that strongly supports object recognition theories that propose separation between parts and their relations (Biederman, 1987; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996). While this is theoretically provocative, it remains uncertain whether this independence for parts and their relations holds for all objects. One possibility and the one we explore here is that for objects that have multiple parts, representing the parts individually is not possible, and it is only in the context of being able to integrate them into a bound whole that all the parts can be fully represented. This notion is akin to the idea that chunking or unitizing an object allows more information to be represented, both in short-term as well as in long-term memory (Chase & Simon, 1973; Miller, 1956). If this claim holds, one might predict that IA patients are able to represent a small number of parts well and independent of their spatial relations, as already demonstrated, but that the representation of parts would fail for more complex objects because of the increased reliance on the integration of the elements as the number of parts scales. In this study, we address this issue by exploring the performance of two IA patients (one of whom participated in this previous study) on objects that differ on one to four parts.

Suggestive data to support the idea that there is an interaction between parts and their relations when the number of parts is more than two come from related work by Arguin and Saumier (Arguin & Saumier, 2004; Saumier, Arguin, Lefebvre, & Lassonde, 2002). In these studies, control participants and an agnosic patient searched for a target consisting of three volumetric geons arranged in a particular spatial relationship. The target was embedded amongst distractors that were composed of either the same or different parts and had either the same or a different spatial organization of the parts as the target. The control participants and the patient showed a performance cost both when the target and distractors shared parts (i.e., they could not differentiate the target from the distractors when parts were shared) and also when they shared spatial organization but were composed of different parts. There was also a marginally significant interaction with poorest performance when both part and spatial organization were shared, suggesting that at least with items made of three elements, there is an interaction between the representation of the parts and their spatial relations.

A further issue to be addressed concerns whether the ability to integrate parts (independent of their number) can proceed without conscious awareness. In one recent study (Aviezer et al., 2007), patient S.E., who had severe difficulties in globally integrating local elements, was nevertheless able to categorize words semantically with the assistance of a visual prime that, on its own, could not be identified. Additionally, S.E. showed priming of objects from related but not unrelated word primes. These findings have been taken as evidence that S.E. was able to integrate the elements at a covert level but was unable to use this integrated representation explicitly for object perception. We examine whether the IA patients in the present study are able to bind the elements covertly. Rather than using object–word priming, we examine whether these patients can incidentally derive the prototype from a series of exemplars. No explicit knowledge is required to derive the visual prototype, and many classical studies reveal how prototypes can be implicitly derived from exposure to a series of exemplars (Posner & Keele, 1968, 1970).

In sum, we address two primary questions: the first concerns the extent to which IA patients are able to represent multiple local elements of objects, and the second question is whether these patients are able to integrate local elements at a covert level. To do so, in this paper, we report five experiments, which examine the representations extracted by two IA individuals in tasks requiring stimulus discrimination and categorization. Specifically, we parametrically manipulate the number of local elements in an image and the extent to which the parts are shared between different exemplars (from one to four shared parts) to determine whether the patients still have the constituent parts of an object available as the number of relevant parts increases. We also manipulate the species or category membership of the exemplars and evaluate the extent to which the patients are able to make category membership judgements based on these "family resemblances". In this context, we explore whether the IA individuals are able to derive category prototypes implicitly based on exposure to related exemplars.

In these experiments, we use photorealistically 3-D rendered images of novel objects ("Fribbles"), which have several component parts, all of which need to be integrated for the purpose of identification. These objects allow for systematic experimental manipulation and are ideal for shedding light on how part representation might occur in normal and disordered object recognition. As shown in Figure 1 (top three rows), there are 12 "species" of Fribbles, each of which has a unique structural configuration including a large, central main body and four appendage part shapes. Each "socket" for an appendage part can take any of three different 3-D volumes, so there are a large number of potential exemplars in each species. This Fribble stimulus set has several advantages for our purposes. The arrangement of the components allows us to explore the ability of the patients to match exemplars that differ by one, two, three, or four parts and, hence, to document the extent and nature of the process by which parts are available for the patients. The logic of the studies is as follows: Participants are shown a target Fribble and then a choice display (for example, for same/different matching). If the participant is able to represent all the parts, performance will be good in all conditions, even when the target and choice differ minimally, say just in one part. If only a small number of parts are represented, then when the target and choice differ on many parts (say three or four), there are many more opportunities for the participants to decide whether the same two objects are the same or not. If, however, only a small number of parts are represented, and the target and choice differ only in one or two parts, there is an increased probability that the relevant part information has not been represented for this distinction, and errors will be made.

In addition to the object discrimination tasks, because individual Fribbles are members of one of several categories (see Figure 1 bottom row, all stimuli are DUVAs), where exemplars all share the same spatial relations between parts, even if the parts themselves differ, we can also document the participants' ability to derive information about the spatial relations of the parts and to learn to categorize Fribbles into classes. Finally, given the large number of exemplars in a class, we can evaluate the patients' ability to generalize their learning to Fribbles, which were not included in the original training set, based on common spatial arrangements of the local components, and to extract the modal representation (prototype) of the category. Taken together, the findings on part judgements, category distinctions, and ability to learn to represent prototypes from Fribble exemplars will uncover the impairments mediating IA and will allow us to elucidate some of the mechanisms of normal object perception.

EXPERIMENTAL STUDIES OF OBJECT PERCEPTION

Case reports

Two IA patients, S.M. and C.R., participated in all the following experiments.

Patient S.M.

S.M.'s case history has been described in detail in a number of other publications (Behrmann et al.,

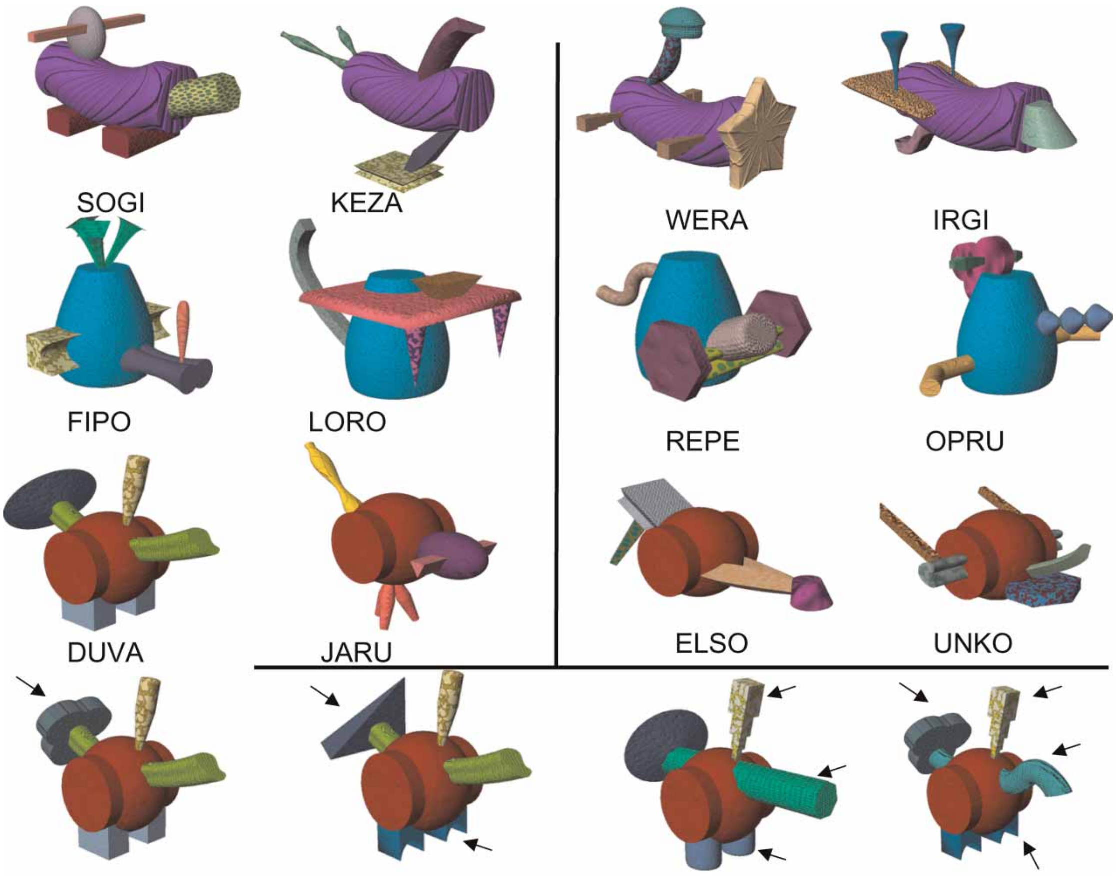


Figure 1. *The first three rows show prototypical exemplars from the 12 Fribble species. The six species to the left of the vertical line were used in Experiments 1, 2, 3, and 4, while the six species to the right of the vertical line were used in Experiment 5 only. Labels given to the species in Experiments 1 and 2 are shown above each prototype. The bottom row shows four additional exemplars of the DUVA species, with changes from the prototype highlighted by arrows. The leftmost exemplar in this row differs from the prototype by one appendage part shape, the second exemplar differs from the prototype by two shapes (note that the "foot" shape is repeated twice in every exemplar), and the third and fourth exemplars differ by three and four shapes from the prototype. Images used in the experiments were brightly coloured and revealed more texture detail than shown here. [To view the figure in colour, visit the Journal's website (http://www.psypress.com/cogneuropsychology) and navigate to the online version of the paper.]*

2005; Behrmann et al., 2006; Gauthier et al., 1999; K. Humphreys, Avidan, & Behrmann, 2007). Briefly, at the time of this testing (done over 2 months in 1999), S.M. was a 23-year-old male who, at age 18, sustained a closed head injury and loss of consciousness, as well as injuries to both legs and his right arm, in a motor vehicle accident. Although initially right-handed, because of the damage to his right hand, he sometimes prefers to use his left hand for responding. Repeated computed tomography (CT) scans taken prior to this testing indicated a contusion in the right anterior and posterior temporal regions accompanied by shearing injury in the corpus callosum and left basal ganglia (see Figure 2 for a recent MRI scan taken in 2005,[1]

---

[1] Note that this scan was acquired six years after the present study but still indicates, at a minimum even after any possible recovery of these six years, the involvement of the right ventral visual cortex.

and note volume reduction in right inferotemporal cortex). Neuro-ophthalmological examination continues to reveal acuity of 20/20 bilaterally, and S.M.'s eyes are unremarkable for pathology of any form. An intensive rehabilitation programme immediately after the accident resulted in recovery of most functions, and, at the time of this testing, S.M. was independent in all functions and was employed in his father's photographic store. S.M. participated in a rehabilitation study in 2000, and the findings from that study were reported in 2005 (Behrmann et al., 2005). Note, however, that the data reported in the present paper were acquired in 1999 prior to the intervention study, and thus the intervention data have no direct empirical bearing on the present findings. In Table 1, we tabulate S.M.'s performance on a variety of standardized measures of perception and object processing, collected at the same time as the current study was conducted.

S.M. performs well on almost all measures of low-level visual processing, falling within the normal range on all subtests of the Visual Object and Space Perception Battery (Warrington & James, 1991). S.M.'s performance on the Benton visual form discrimination and Benton line orientation tasks were in the low-average range (Benton, Sivan, Hamsher, Varney, & Spreen, 1983), and he scored 24/25 on the Efron shape-matching task. His judgements of line length, orientation, size, and gap size from the Birmingham Object Recognition Battery (BORB; Riddoch & Humphreys, 1993) were all within normal limits. He was also able to match objects from minimal features and along a foreshortened axis within the normal range (BORB Subtests 7 and 8). He was, however, at chance at identifying overlapping stimuli (letters, geometric shapes, and line drawings where each type is blocked; Subtest 6) with relatively better identification of the same items when presented in nonoverlapping format, consistent with a diagnosis of the integrative form of agnosia. He also performed in the impaired range in the object decision task of the BORB, discriminating real-world from nonsense objects (Subtest 10; 71/128 correct).

S.M. shows normal colour vision, as assessed on the brief Farnsworth colour vision arrangement test (http://www.univie.ac.at/Vergl-Physiologie/colortest/colortestF-en.html), a screening profile of colour deficiency. His performance is within the normal limits on this measure, confirming his own intuition that he is able to use colour as a cue in his perceptual judgements.

S.M.'s ability to identify real-world objects was also poor (see Table 1): He identified only 58% of the pictures from the Boston Naming Test and 66% from the Snodgrass set. His errors were predominantly visual; for example, he called an ACORN a "coconut" and a HARMONICA a "register". When he failed to recognize an item, he did not appear to possess any semantic or action information about the item. He was, however, able to provide good definitions in response to the auditory labels of the items he missed visually, and his tactile object recognition was good.

S.M.'s face processing was also markedly impaired; his score of 36 on the Benton facial recognition test was in the impaired range, and he was unable to recognize any pictures out of 57 famous faces including photographs of Bill Clinton, Sylvester Stallone, and Steve Martin. He shows no evidence of hemispatial neglect on a standard bedside battery (Black et al., 1994). His reading performance is accurate but extremely slow, and he shows a typical letter-by-letter pattern with a monotonic increase in reading time as a function of word length (466 ms per additional letter).

Patient C.R.

C.R. was a 16-year-old male high school student in 1996 when he presented with a right temporal brain abscess, part of a complicated medical course including a history of Group A toxic shock syndrome, pneumonia, cardiac arrest, Candida bacteremia, and metabolic encephalopathy. The magnetic resonance imaging (MRI) scan done at that time was positive for a right temporal lobe lesion consistent with acute microabscesses of the right temporal and medial occipital lobe (see Figure 2 for structural MRI). At the time of the testing reported in this paper (1999),

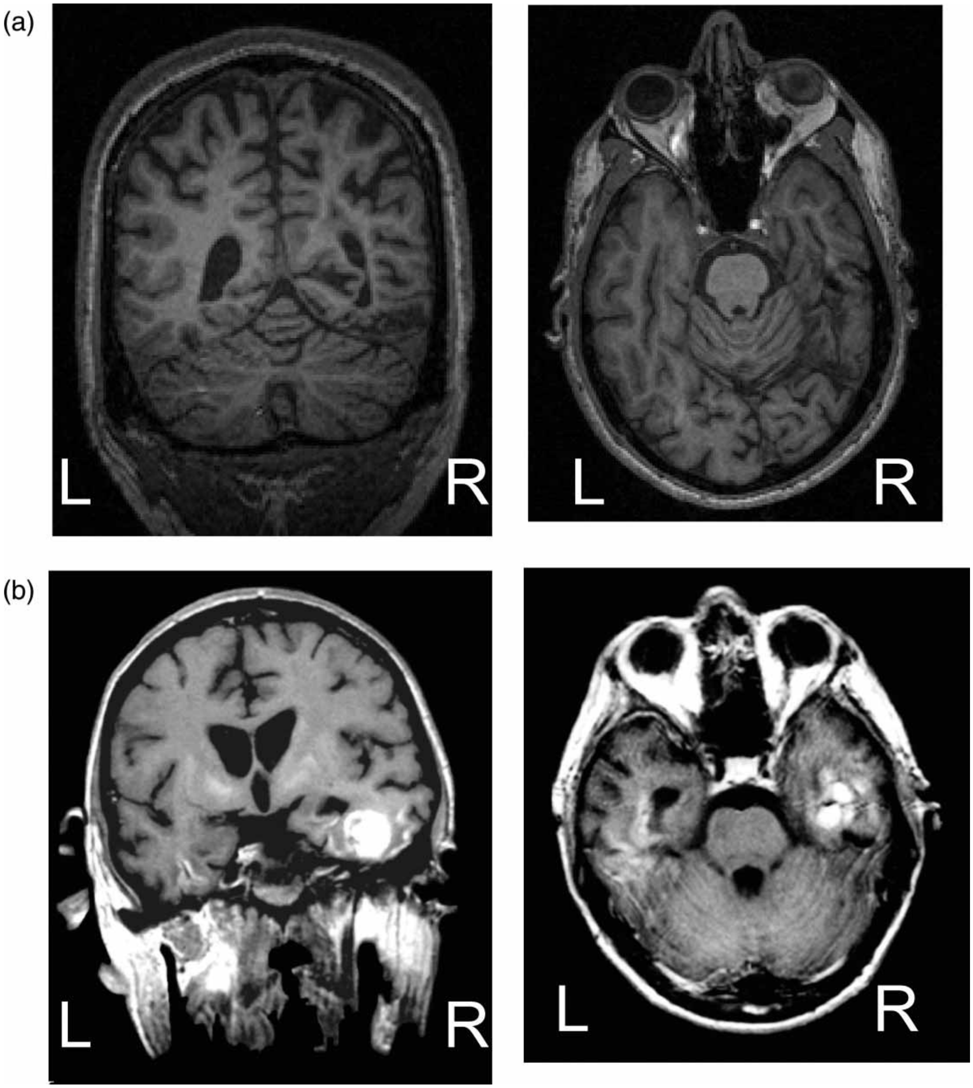


Figure 2. *Coronal and axial view of magnetic resonance imaging (MRI) scans for (a) S.M. and (b) C.R. showing right inferotemporal lesion. For ease of examination, the right hemisphere is on the right of the page and the left hemisphere on the left.*

C.R. was 19 years old. At the initial hospitalization, C.R. displayed some memory problems and difficulties in problem solving but these appear to have resolved at this testing. After extensive rehabilitation and recovering full physical mobility, C.R. completed high school. At the time of this testing, he was enrolled in a community college (during which time, he received additional remedial assistance).

Like S.M., C.R. performed within the normal range on low-level tests of visual processing on all the subtests of the Visual Object and Space Perception Battery (Warrington & James, 1991). His performance on the Benton visual form discrimination was normal but his Benton line orientation tasks were borderline. His judgements of line length, orientation, size, and gap size from the BORB (Riddoch & Humphreys, 1993) were

Table 1. *Performance of patients S.M. and C.R. on standardized visual processing tasks*

		S.M.	*C.R.*
A. Low-level visual processing	Visual Object and Space Perception Battery (Warrington & James, 1991)	Normal range on all subtests	Normal range on all subtests
	Benton visual form discrimination	Low average	Normal
	Benton line orientation	Low average	Borderline
	Efron shape-matching task	24/25	23/25
	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 (Goodglass, Kaplan, & Weintraub, 1983)	35/60 (58%)	46/60 (77%)
	(Snodgrass & Vanderwart (1980) pictures	172/249 (66%)	149/185 (80%)
	i. Living	122/165 (74%)	43/67 (64%)
	ii. Nonliving	50/94 (53%)	106/118 (89%)
C. Face processing	Benton facial recognition test (Benton, Sivan, Hamsher, Varney, & Spreen, 1983)	36/54	37/54
D. Reading		Slow but accurate (466 ms per letter)	Slow but accurate (104 ms per letter)

all within normal limits, and he performed well on the Efron shape discimination task (23/25). C.R. was also able to match objects presented from different viewpoints, from minimal features, and along a foreshortened axis within the normal range (BORB Subtests 7 and 8). C.R. was mildly impaired at identifying overlapping triplets of stimuli (letters and line drawings where each type is blocked) with relatively better identification of the same items when presented in nonoverlapping format, suggestive of a mild form of IA. C.R. was significantly above chance on the easy object decision task (51/64 correct), although on the hard version of this task he was impaired and scored more than two standard deviations below the normal mean (22/32).

C.R. identified 77% of the pictures from the Boston Naming Test and 80% from the Snodgrass and Vanderwart set. Like S.M., his errors are visual in nature, calling a NAIL "a screw" and an ELEPHANT "a bear". Also like S.M., C.R. is profoundly prosopagnosic, producing a score of 37 on the Benton facial recognition test. C.R. was also unable to recognize any pictures in a set of 57 famous people designed for college-age students. He showed no evidence of hemispatial neglect on a standard bedside battery (Black et al., 1994). Finally, again like S.M., C.R.'s reading is accurate but slow with an increase of roughly 100 ms for each additional letter.

We note that a quick comparison of S.M. and C.R.'s findings on these neuropsychological tasks suggests that S.M. is somewhat the more impaired of the two, and, as will be seen, this severity differential is also manifest in the experimental paradigms.

EXPERIMENT 1: DISCRIMINATING BETWEEN NOVEL OBJECTS

In this first experiment, we compared the ability of S.M. and C.R. with that of matched control participants on perceptual matching (change detection) on a pair of sequentially presented Fribbles. Because we use Fribbles that are either identical or vary from each other by 1–4 local parts, we examine performance as a function of part difference. Data from this experiment will not only characterize the extent of the object recognition deficit but will also shed light on the nature of the patients' deficit as the number of shared parts differs parametrically between exemplars.

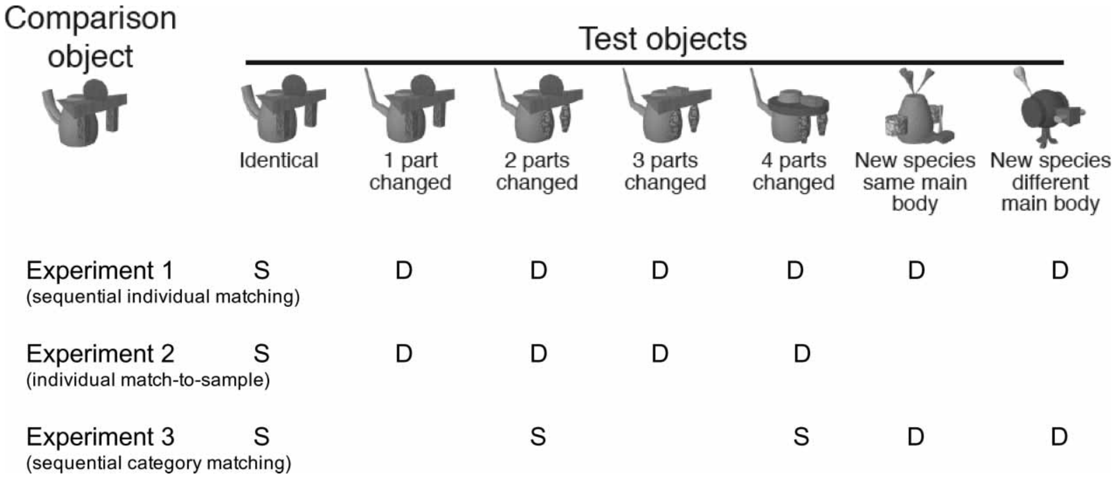
Method

S.M., C.R., and 10 undergraduates (in the same age range as the patients, ranging between 18 to 30 years) at the University of Massachusetts at Boston participated in exchange for course credit. All individuals had normal or corrected-to-normal vision, and all consented to participate.

Materials and procedure

Stimuli. The Fribble set (see Figure 1) consisted of 12 categories/species of objects, designed and rendered with Strata StudioPro software (Strata, Inc., St. George, Utah) on a Macintosh computer. Each species was primarily defined by a set of part relations; more specifically, each species was composed of a main body and four appendage-part shapes in a distinctive configuration that was constant across all exemplars of a species. The main body of a species remained constant for all exemplars, but since there were only three main body shapes for the 12 species (each main body shape was shared by 4 species), main body was not perfectly diagnostic of species identity. The main source of variation between exemplars of a single species was in the shape of appendage parts: There were three potential shapes for each appendage part of each species. For example, the first three objects in the bottom row of Figure 1 show the three possible "tail" shapes for the DUVA species (a cloverleaf shape, a thin triangle, and a discus shape). All parts of all Fribbles were brightly coloured and richly textured. Colours and textures of the appendage part shapes were similar (but not identical) across exemplars of a species, and the colour changes were evenly distributed across exemplars (importantly, colour is not a diagnostic feature per se). More details about the initial construction of the Fribble set are available in Williams (1997), and a set of Fribbles can be downloaded from http://alpha.cog.brown.edu:8200/stimuli/novel-objects/. Six Fribble species (shown in the first two columns of Figure 1 to the left of the dividing line) were used in this experiment. All stimuli were scaled to fit in a rectangle 400 pixels wide by 300 pixels high, which translated to a visual angle on the order of 12 by 9 degrees (participants were not restricted in how far away from the monitor they kept their heads).

Procedure. In this and all subsequent experiment, both patients were run on the same Macintosh G3 Powerbook computer, and control participants were run on a desktop Macintosh. This experiment employed a sequential matching task in which participants saw pairs of images, separated by a 1.5-s blank interval, and decided whether or not the two images represented exactly the same object. Objects from six Fribble species were employed as stimuli. Each of the 240 trials began with a 1,000-ms blank screen and a 500-ms fixation cross, followed by one Fribble image that stayed on the screen for 1,500 ms, a 1,500-ms blank screen, and a second Fribble image that stayed on the screen until the participant responded. On 96 trials, the two Fribble images were identical; participants were to press the V key on these SAME trials. On the remaining 144 trials, the two images were of different Fribbles. Participants were to press the M key on these DIFFERENT trials. More specifically, there were 24 trials each in which the two Fribbles were from the same species but differed by 1, 2, 3, or 4 appendage parts (e.g., see different exemplars of DUVA in Figure 1 with the arrows denoting the 1–4 differences relative to the exemplar in row 3, column 1), 24 trials in which the two Fribbles were from different species with the same main bodies (e.g., DUVA and JARU, see Figure 1),



Comparison object	Identical	1 part changed	2 parts changed	3 parts changed	4 parts changed	New species same main body	New species different main body
Experiment 1 (sequential individual matching)	S	D	D	D	D	D	D
Experiment 2 (individual match-to-sample)	S	D	D	D	D		
Experiment 3 (sequential category matching)	S		S		S	D	D

Figure 3. *Test conditions employed in Experiments 1–3. In trials of all three experiments, participants evaluated the match between a comparison object and various test objects. An "S" in this table indicates that the correct response for the given experiment was "SAME" while a "D" indicates that the correct response was "DIFFERENT".*

and 24 trials in which the two Fribbles were from different species with different main bodies (e.g., DUVA and FIPO, see Figure 1). The conditions used in this and subsequent experiments are also shown in Figure 3. Trials were evenly distributed among the six species and were randomly ordered for each participant. Participants were given breaks and were told that the two objects would differ on 60% and be identical on the other 40% of the trials. The expectation is that, if the patients have all the parts available to them, performance will not differ for the patients and controls. If this is not the case, the more different the Fribbles (e.g., greater number of part change), the easier it will be for the patients to detect the difference, and the more normal their performance. If the IA individuals do have all the parts available to them, they would also perform as well as the control participants even when there is only a small difference between exemplars, as in the 1- and 2-part change conditions.

Results

Results for S.M., C.R., and control participants are shown in Table 2 with an indication where

Table 2. *Accuracy rates for patients C.R. and S.M. and mean for 10 control participants in Experiment 1*

	Same species					*Different species*		
Participants	*Identical*	*1 part change*	*2 part change*	*3 part change*	*4 part change*	*Same main body*	*Diff main body*	*Overall*
C.R.	.87	.13*	.63	.63*	.79*	.96	.83	.74*
S.M.	.71	.42	.63	.75*	.88*	.96	.92	.74*
Controls[a]	.82 (.06)	.52 (.01)	.70 (.01)	.88 (.02)	.93 (.02)	.97 (.02)	.98 (.02)	.77 (.06)

Note: Accuracy rates are shown as proportion correct. There were 96 trials per participant in the identical condition and 24 trials per participant in all other conditions.

*Indicates that the patient data fall more than 2 standard deviations from the mean of the control group. [a]Means; standard errors in parentheses.

the patient's accuracy rate (proportion correct) fell more than 2 standard deviations from that of the mean of the controls.[2] Averaged over all trial types, the mean control participant accuracy rate was 78%. Both patients' accuracy rates were 74% (177/240 correct for S.M. and 178/240 for C.R.), with performance just over 1 standard deviation from the mean of the control group for both patients. Perceptual matching (detecting change) was relatively easy for all participants when the exemplars were drawn from different species, and this was true even if the two species shared the same main body (although note that C.R. shows a trend towards a decrement when the main body differs; $z = 1.88$). The patients also performed relatively well when the identical displays were shown. The more interesting differences come from the trials when the species were the same but the exemplars differed. As expected, control participants exhibit higher accuracy in detecting the differences as more parts changed across the two Fribbles in a trial; clearly, the more different the exemplars, the easier to distinguish between them. A one-way analysis of variance (ANOVA) on the control accuracy data from 1-, 2-, 3-, and 4-part changes reveals a significant effect of part, $F(3, 27) = 7.5$, $p < .001$, with a significant linear trend ($p < .01$) across the 4-part change conditions. We note that S.M. and C.R. also show this gradient in accuracy as a function of shared parts. Both, however, show significantly lower accuracy than controls for the 3- and 4-part changed displays. The lack of clear differences for the 1- and 2-part displays between the patients and the controls (aside from C.R. in the 1-part change display) might arise from the fact that the control subjects are performing rather poorly in these apparently difficult 1- and 2-part trials too (.52 and .70, respectively).

The data from this first experiment suggest that the two IA individuals perform relatively more poorly than their controls in this experiment but only under conditions in which 3 or 4 appendage parts change across the exemplars within a trial. When the change detection is more subtle, as in cases when just 1 or 2 appendages change, the difference between patients and controls is less obvious, perhaps because the performance of the control subjects is not very good. Presumably the fact that the control participants are not at ceiling in accuracy is attributable to the fact that they do not have enough time (just 1.5 s) to encode the object in sufficient detail in order to reliably detect whether or not a small change has occurred when the second Fribble is seen. When there are fewer opportunities for false alarms, as is the case with increasing number of part changes or when the species is different, performance is better than when only one (accuracy .52) or two (accuracy .70) parts change between the sequential stimuli. It is possible that, as is true with the patients, normal participants were attempting to process as many parts of the Fribbles as possible in the short time available and were unable to derive an integrated representation of the stimulus. Given that the patients perform more poorly than controls when there are greater changes but equivalently when there are fewer changes across exemplars, we conducted a follow-up experiment to explore the performance of the patients in a situation in which normal participants are more easily able to derive an intact representation of the object. The expectation is that the divergence between the controls and patients might be greater under these conditions and might reveal important properties of the patients' deficit. In Experiment 2, we asked participants to make similar change detection decisions to those required in Experiment 1, but we employed a simpler *individual match-to-sample* task.

EXPERIMENT 2: MATCH-TO-SAMPLE OF NOVEL OBJECTS

This match-to-sample task also required participants to detect changes among sequential stimuli

---

[2] This is a somewhat conservative criterion but is useful in clearly denoting the patients in relation to the distribution of the controls. It is also used often in interpreting neuropsychological data and thus has precedence.

but it differed in two ways from Experiment 1. The first difference is that participants were exposed to one "sample" or target Fribble for 8 seconds to allow for greater encoding accuracy. The second difference was that, following this lengthy exposure duration, in a single trial, participants performed change detection on a series of six Fribbles, two identical to the sample and the other four differing by 1, 2, 3, and 4 parts from the sample, where all are members of the same species. This procedure should allow normal perceivers enough time to form a reasonably complete and rich representation of the sample Fribble, and the prolonged exposure duration should benefit the control participants. The outstanding question is whether the patients are able to form a complete representation of the stimulus under these more optimal conditions and, if not, what the nature of the failure might be.

Method

A total of 10 University of Massachusetts at Boston undergraduates (roughly in the same age range as the two patients, aged between 18 and 30 years) who did not participate in Experiment 1 participated in addition to S.M. and C.R. All individuals had normal or corrected-to-normal vision, and all consented to participate.

Materials and procedure

Stimuli. Exemplars of the six Fribble species from Experiment 1 were again used here.

Procedure. The experiment was run in a series of 24 blocks of trials. Each block began with an 8-s presentation of a sample Fribble. The sample was then erased, and after a 250-ms blank screen, the first target object was shown. This target stayed on the screen until the participant pressed V if it was exactly the same as the sample object, or M if one or more parts of the target object were different from the sample. This response was followed by another 250-ms blank screen and another target, and this sequence was repeated a total of six times per block. Each block included two targets that were identical to the sample and one target each that differed by 1, 2, 3, and 4 parts from the sample (participants were informed prior to the experiment of this distribution of trials). All targets were from the same species as the sample, and the six targets were randomly ordered. Each block included objects from the six Fribble species. The conditions used in this experiment are shown in Figure 3 for clarity.

Results and discussion

Normal perceivers found the match-to-sample task to be easier than the sequential matching task used in Experiment 1, as shown in Table 3, averaging 93.7% accuracy, compared to 82% for the comparable conditions (identical and 1–4-part change trials) in Experiment 1. An ANOVA on the data from the two experiments with experiment as a between-subjects factor reveals a significant difference in performance across the two experiments, $F(1, 18) = 185$,

Table 3. *Accuracy rates for patients C.R. and S.M. and mean for 10 control participants in Experiment 2*

	Same species					
Participants	*Identical*	*1 part change*	*2 part change*	*3 part change*	*4 part change*	*Overall*
C.R.	.77*	.42*	.83*	.83*	1.0	.77
S.M.	.67*	.38*	.83*	.75*	.83*	.69
Controls[a]	.94 (.04)	.78 (.14)	.98 (.03)	.99 (.03)	.99 (.03)	.94

Note: Accuracy rates are shown as proportion correct.

*Indicates that the patient data fall more than 2 standard deviations from the mean of the control group. [a]Means; standard deviations in parentheses.

$p < .0001$. There was also a significant interaction of Experiment × Part Change, $F(3, 54) = 14.4$, $p < .0001$, with no difference in the 4-part change across the experiments but lower accuracy in 1- and 2-part changes in Experiment 1 than Experiment 2 and a marginally significant trend in that direction for 3-part change trials too. These control data suggest that this experiment might provide a better window on the nature of the alteration in the IA patients' object perception.

In contrast with the improved control performance from Experiment 1 to Experiment 2, S.M.'s accuracy rates in the two experiments for the comparable conditions were almost identical, 68.8% and 69%, $\chi^2(1) = ns$, and he shows a significant decrement in accuracy (more than 2 standard deviations from the control mean) in overall accuracy ($z = 12.3$, $p < .00001$) and in each of the individual part-change conditions. Like the control participants, C.R. showed significant improvement from Experiment 1 to Experiment 2 although this was more modest, from 70.3% to 77.1% for the comparable conditions, $\chi^2(1) = 4.9$, $p < .05$. He is still impaired relative to the controls in overall performance, $z = 8.21$, $p < .0001$, and this is also the case for the 1-, 2-, and 3-part change trials in which his accuracy is more than 2 standard deviations from the control mean. He does not differ from the control group when the target differs from the choices by 4 parts.

Whereas the control subjects were able to derive a rich representation of the sample Fribble, this was not the case for the two patients. S.M. derived no additional benefit from the prolonged exposure over the brief exposure, suggesting that he is unable to process more than a small portion of an image at a time and that the additional exposure duration was of no additional value. Whereas with longer exposure duration, the normal perceivers were now able to form a relatively complete representation of the sample object, and their accuracy was high, S.M. was still limited to representing a small portion of the Fribble. C.R. did show some, albeit slim, benefit from the prolonged exposure although performance was still substantially poorer than that of the control participants. He too shows a decrement for 3-part changed exemplars although not as dramatic as that for S.M., and his performance is somewhat better than that of S.M. across the board. These findings clearly indicate that both IA patients perform substantially more poorly than the control participants with S.M. being the poorer of the two, as predicted by the neuropsychological profiles. The findings from the first two experiments clearly indicate that the patients do not have all the elements of the display available to them. Consistent with the findings of Behrmann et al. (2006), S.M. performs relatively well under conditions in which only a small number of parts are encoded but performance clearly worsens as more parts need to be encoded. The same is true for C.R. albeit to a slightly lesser degree.

EXPERIMENT 3: SEQUENTIAL CATEGORY MATCHING

Having demonstrated that the visual performance of the two patients deviates significantly from that of the controls and that their accuracy is affected by the number of parts to be represented on individual Fribble matching, the question is whether the patients would be able to perceive species category differences and extract information that is relevant to differentiating classes or species of Fribbles. In order to categorize the stimuli, a more abstract representation of whole shape (based on the integration of all the elements) must be derived. No absolute part is sufficient for the categorization. Differentiating between categories requires the observer to represent the spatial relations between the components (see Figure 1)—even though two categories may share the same main body, the way in which the appendages are attached differs between categories.

There is a hint from Experiment 1 that the patients show some sensitivity to the species differences as detecting changes in different species that share the same main body seems to be better than when the two exemplars come from the same species (see Table 2). At issue then is whether this is indeed the case and, if so, what information is being represented that supports the sensitivity to species differences. Information about the species categories would suggest that the patients do have relational information available to them, and our prediction is that this is not the case. In this experiment, as above, the participants make sequential match judgements but here, same/different is determined by category rather than by exemplar.

Method

In addition to S.M. and C.R., 7 undergraduates (spanning the age range of the two patients, between 18 and 27 years old) at the University of Massachusetts at Boston participated in exchange for course credit.

Materials and procedure

Stimuli. The conditions used in this experiment are shown in Figure 3 for clarity. Objects from the six Fribble species used previously were employed here. In this experiment, an initial object was displayed for 1,500 ms, followed by a 1,500-ms blank screen, followed by a second object, which stayed on the screen until participants responded by pressing the V key if the two objects were members of the same category or the M key if the two objects were from different categories. There were 120 trials, 24 each in which the two objects were (a) identical; (b) from the same species but differed by two appendage parts; (c) from the same species but differed on all four appendage parts; (d) from different species but shared the same main body; and (e) from different species with different main bodies. Trials from (a) to (c) all required the "same" response, and trials from (d) and (e) required "different" responses. A 1,000-ms blank screen and a 500-ms fixation cross preceded every trial. Prior to the start of the experimental trials, participants saw displays containing triplets of objects (two from the same species and one from a different species with the same main body) explaining what was meant by a category difference. They then received a series of practice trials that were identical to test trials except that, after they made their response, they saw the two objects side-by-side with the correct answer ("same category" or "different category") beneath the figures.

Results and discussion

Results for control and patient participants are presented in Table 4. In evaluating performance on the sequential category-matching task, first note that all participants were highly accurate in recognizing that two identical objects were members of the same species. Likewise, all participants were good at recognizing that objects with different main bodies were from different species. S.M. was perfect on these trials, C.R. scored 92% accuracy (see his slight sensitivity to different main body in Experiment 1, as well), and mean

Table 4. *Accuracy rates for patients C.R. and S.M. and mean for control participants in Experiment 3*

	Same species			*Different species*		
Participants	*Identical*	*2 parts changed*	*4 parts changed*	*Same main body*	*Different main body*	*Overall*
C.R.	1.00	.71*	.79*	.88	.92	.86*
S.M.	1.00	.92	.92	.58*	1.00	.83*
Controls[a]	.98 (.03)	.95 (.06)	.95 (.05)	.95 (.05)	.98 (.05)	.96 (.04)

Note: Accuracy rates are shown as proportion correct.

[*] Indicates that the patient data fall more than 2 standard deviations from the mean of the control group. [a] Means; standard errors in parentheses.

control accuracy was 97.8%. Clearly, both identical and very different exemplars are accurately matched by the patients.

It is the case, however, that both patients scored significantly lower overall than the control participants (excluding the high-accuracy conditions, S.M. scores 79.3% and C.R. 80.6% compared with controls 95%). Consider the two most difficult conditions: trials in which all four parts changed but the two objects were from the same species (for example, Figure 1, third row, left exemplar and bottom row, rightmost exemplar) and trials in which the two objects were from different species but shared the same main body (for example, Figure 1, third row, two leftmost exemplars). Control participants were almost as accurate on these trial types as on the "easy" trials, averaging 94.6%. S.M. and C.R., however, had much more difficulty on these types of trials, with S.M. getting 36/48 (75%) correct and C.R. 40/48 (83%) correct (note that S.M. is more sensitive to the 4-part change and C.R. to the shared main body).

One possible explanation for S.M.'s reasonably good pattern of performance on the 2- and 4-part changed trials is that he may have tried to perform the task by comparing the dominant colours of the two Fribbles (recall that his colour perception falls within the normal range). His performance on the same main body/different species trials supports this possible conclusion: The only species pair he consistently responded to as coming from different categories were FIPO/LORO combinations (see Figure 1): LORO exemplar images are dominated by the flat horizontal part, which is pinkish-red and thus easy to contrast with the greenish-blue main body of the FIPO species, which dominates its exemplars' images. S.M. scored 8/8 of the FIPO/LORO trials correct but only responded correctly on 4/8 of the DUVA/JARU trials and 2/8 of the SOGI/KEZA trials. Overall, then, S.M.'s performance is consistent with the hypothesis that he is unable to process and/or encode more than a relatively small portion of a Fribble image. He appears then to have chosen an alternative strategy of relying on the objects' dominant colours to distinguish categories in this task, a strategy that worked well for all different exemplar/same main body trials in this task and thus gave rise to reasonably high accuracy. When the same body is shared across species, however, he assumes that the exemplars are from the same species and is obviously incorrect (accuracy 58%).

C.R.'s data also suggest that he can process only a limited portion of an image, and he was significantly impaired relative to control participants when exemplars differed by 2 or 4 parts.

Taken together, aside from S.M.'s apparent strategic use of colour, which may have served him under some conditions, neither patient performs normally on the sequential category match. These findings indicate that both agnosic patients are unable to represent the full complement of parts and their relations on the Fribbles. While knowing the exact physical detail of each part is necessary for exemplar matching and the patients fail on this when more than a very small subset of the input needs to be encoded to detect exemplar differences, knowing the relations between the components is necessary for categorization, and the patients perform poorly on this too.

EXPERIMENT 4: LEARNING CATEGORY MATCHING

The findings thus far indicate that the patients are impaired at precise part and relations representation. Although they process a subset of the input, this does not suffice for the difficult exemplar match (in which all parts needs to be processed) nor for the category match in which knowledge of part relations is required. A final question concerns the plasticity of the system—specifically, the issue is whether the patients are at all able to learn to categorize stimuli. Some recent data suggest that even severely impaired agnosic patients can benefit from visual training (Rosenthal & Behrmann, 2006). In the course of this experiment, we not only train the patients to categorize Fribble exemplars but also examine whether, if any learning occurs, there is generalization to untrained Fribbles and what underlying representations are derived over the course of the experiment. At issue too is whether the patients are able to derive an implicit representation of the input even though they appear unable to categorize or match them overtly.

Method

Stimuli

The same stimuli as those used in the previous experiments are used here.

Procedure

The experimental session included three phases: training, old/new recognition test, and generalization and retention.

Training phase. Participants were trained to press a key corresponding to the first letter of the species name for eight exemplars each from six species (the first six species in Figure 1). In the first block of trials, participants saw 24 Fribbles (4 from each species) along with their species names for 5 s and simply tried to learn the associations (in this and all subsequent blocks, objects were always shown individually on the screen). In the second and third blocks, participants saw the initial 24 objects and the remaining 24 objects, again presented along with their species names, and learned to press the correct keyboard key (participants were allowed to view the Fribbles and names as long as they wished). Trials in the fourth block presented the initial 24 objects without species names; participants attempted to press the correct key and, if incorrect, heard a beep and saw the correct name. In the fifth and sixth blocks, participants saw all 48 objects without names, attempted to press the correct key, and heard a beep only if they were incorrect (correct names were not shown). Control participants concluded training at this point, while the two patients performed an additional three blocks, 7–9, which were repetitions of blocks 4–6. Each trial in Blocks 4–9 was preceded by a 1,000-ms blank screen and a 500-ms fixation cross, and participants viewed the objects for as long as they wished before responding.

Old/new recognition test. This followed immediately after training, and the patients and control participants saw the 48 training Fribbles and 90 untrained exemplars drawn from the same six species. On each trial, participants first decided whether or not the object was seen during training and then rated their confidence (on a 1–3 scale) in their decision. These two responses were combined to form a confidence score that ranged from 1 (sure the object was new—that is, it was not seen during training) to 6 (sure the object was old—it was definitely seen during training). Each trial was preceded by a 1,500-ms blank screen and a 500-ms fixation cross, and participants viewed objects for as long as they wished. Training exemplars were selected such that each object shared two appendage parts with a species “prototype”, with the other two parts differing from the prototypical parts. Typically, consistent with previous studies on abstracting a prototype during implicit visual learning (Edelman, 1999; Posner & Keele, 1970), normal perceivers performing this task tend to call the species “prototypes” “old”—these are exemplars that were not studied but have the most common appendage part shapes in each socket—that is, share part relations. Untrained exemplars on the old/new recognition test included the species prototypes and novel exemplars differing by one, two, three, or four parts from the prototypes. Of particular relevance here is whether the IA individuals show any sensitivity to the prototype—if so, this would indicate some implicit knowledge about the common invariance across the exemplars and might support the claim of covert object representations in IA (Aviezer et al., 2007).

Retention and generalization. Immediately following the old/new recognition phase, the two patients (but not control participants) performed a final naming test on a subset of the novel exemplars from the old/new recognition test. This final test served to measure the retention of learning across the interim delay and to see whether the patients could generalize their knowledge of species identities by labelling exemplars on which they had not been explicitly trained. As in Blocks 4–9 of training, Fribbles were shown individually, and participants attempted to press the keyboard key corresponding to the first letter of the object's species name. No feedback was given in this final naming task. Each trial was preceded by a 1,500-ms blank screen and a 500-ms fixation cross, and participants viewed objects for as long as they wished.

Results

Training

Figure 4 shows the categorization accuracy rates and response times (RTs) in training for all participants. As is evident, the normal perceivers have little difficulty in learning to label the Fribble species: In the sixth block of their training protocol, they correctly classified Fribbles with an average accuracy rate of 96%. Even the poorest of the control participants achieved a 92% accuracy rate on this block. In stark contrast, neither patient exceeded 55% accuracy on Block 6 of the training protocol. The patients also took more than 2 standard deviations longer than the controls in RT to make their classification responses: The mean response time for control participants in Block 3 was 1,148 ms (*SD* 620 ms), while C.R. took an average of 3,379 ms and S.M. an average of 4,270 ms on trials in this block (note that at the scale used to plot RT for the patients, the standard error bars are not visible for the control group).

While the two patients performed similarly on Blocks 4–6 of training, with S.M. showing slightly higher accuracy but also longer RTs than C.R., their performance on Blocks 7–9 diverged sharply, especially in accuracy. C.R. became much more accurate, reaching a level of performance on his final training block (92% accuracy) that was as good as the worst of the control participants. He also became considerably faster, although his mean RT of 2,110 ms on the final block was still almost two standard deviations slower than controls' RT on the sixth training block. S.M.'s performance, on the other hand, remained mostly unchanged with an accuracy rate of 33% and a mean RT of 4,412 ms on the final training block.

Table 5 shows controls' and patients' error rates, across all training blocks, for individual Fribble species. Controls' error rates were uniformly low, all between 2.1% and 8.3%. C.R. was quite accurate at classifying SOGIs (error rate 8.3%) and about equally poor on the other species (error rates between 45.8% and 63%). S.M.'s error rates were more widely distributed; he was best on LOROs (17% error rate), better than 50% accurate on JARUs and SOGIs, and extremely poor on KEZAs, DUVAs, and FIPOs (greater than 60% error rates on each). Table 5 also gives the proportion of trials on which participants gave the label as the alternative species that shares the same main body as the response. These data indicate that normal perceivers hone in on the objects' large central components when learning Fribble names, since 51% (23/45) of the control participants' training errors came from giving the name of the alternate species with the same main body (e.g., calling a DUVA a JARU or vice versa). By chance alone, such errors should be made on only one of every five trials (20%); control participants' main body confusion rate was significantly greater than this chance rate, $\chi^2(1) = 7.4$, $p < .01$. C.R.'s and S.M.'s errors did not show this main-body replacement pattern: Their main body confusion rates were 19% (12/63) and 23% (18/78), respectively, both not statistically different from chance: C.R., $\chi^2(1) = 0.06$, $p > .5$; S.M., $\chi^2(1) = 0.03$, $p > .5$. In fact, both patients' errors seem to be fairly randomly distributed with no obvious attention to particular aspects of the display.

Old/new recognition test

Participants were tested for their old/new recognition and confidence on trained items, species

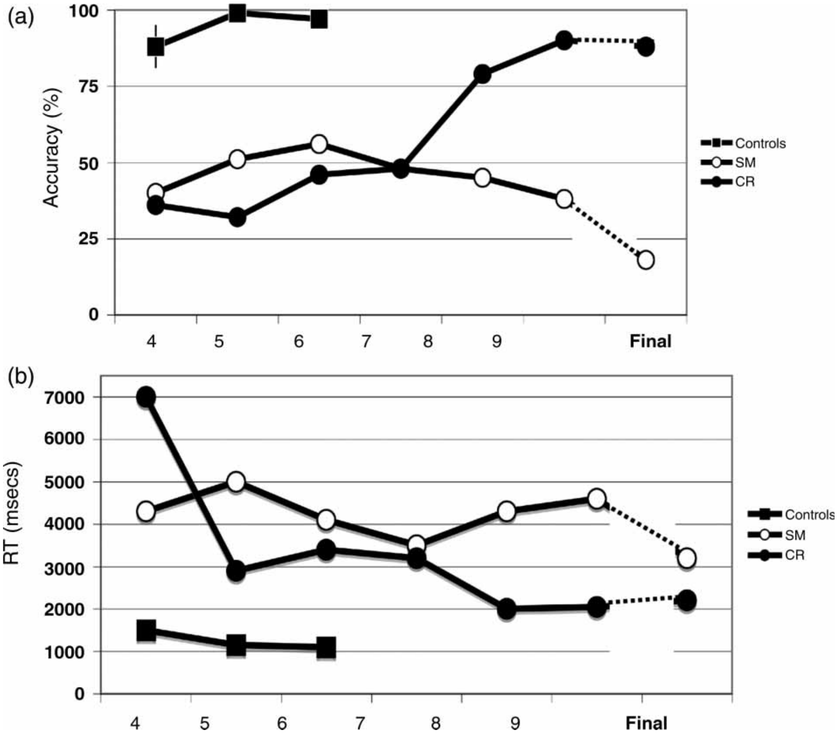


Figure 4. *Categorization accuracy (a) and reaction time (b) for S.M., C.R., and control participants (mean and one standard error on either side of mean) in learning to categorize Fribbles.*

prototypes (which were not seen during training), and other novel exemplars differing by between one and four parts from prototypes. Recall that participants reported whether each stimulus was old or new and then judged the confidence of their responses; these two responses were combined to form a confidence score that ranged from 1 (sure the object was new—that is, it was not seen during training) to 6 (sure the object was old—it was seen during training). Table 6 shows results from this part of the experiment.

In addition to performing well on the trained exemplars, normal perceivers exhibit a

Table 5. *Proportion of errors for the controls, C.R., and S.M. for training phase of Experiment 4*

		SOGI	*KEZA*	*FIPO*	*LORO*	*DUVA*	*JARU*
Prop. errors	Controls	.02	.04	.04	.07	.06	.08
	C.R.	.08	.46	.46	.46	.63	.54
	S.M.	.46	.67	.83	.17	.75	.38
Prop. main body errors	Controls	.33	.50	.5	.4	.63	.58
	C.R.	.50	.09	.18	.09	.20	.31
	S.M.	.09	.5	.2	.0	.11	.33

Table 6. *Recognition confidence scores for C.R., S.M., and controls*

		Novel exemplars differing from species prototype by		
Participants	*Trained exemplars*	*0 parts*	*2 parts*	*4 parts*
C.R.	3.5	4.8	3.5	2.9
S.M.	2.7	2.7*	2.7*	2.6
Controls[a]	3.44 (0.18)	4.4 (0.21)	3.4 (0.20)	2.7 (0.27)

*Indicates that the patient data fall more than 2 standard deviations from the mean of the control group. [a]Means; standard errors in parentheses.

characteristic pattern of greater recognition confidence the more similar a test item is to its species prototype. On average, the controls gave the stimuli that were prototypes a high score of 4.35 and stimuli that differed from the exemplars by 4 parts a score of 2.69. This pattern indicates that they have encoded information about the exact three-dimensional shapes of the trained exemplars, since species prototypes are defined as the exemplars with the most common shapes in each appendage part socket and have implicitly derived an internal representation of the common invariance of the category.

C.R. also performed well on the trained exemplars and produced the same prototype effect as that observed in the control data. By the end of training, he had encoded fairly specific information about the part relations of the training exemplars, and his scores also fell off with increasing distance from the prototype. In fact, his performance fell within the normal range in all conditions. S.M., on the other hand, gave virtually identical mean recognition and confidence scores to all types of test items, and the scores assigned were uniformly low. These results are consistent with S.M.'s poor performance at learning species labels: He apparently was impaired in perceiving and/or encoding exactly which appendage parts he saw during training. Thus, while C.R. may have implicitly encoded the information about the exemplars so as to assign high confidence ratings to the prototype, this is not true for S.M. Note again that the differences between the two patients is consistent with the differences in severity of their neuropsychological profile, with S.M. being more markedly agnosic than C.R.

Retention and generalization

C.R.'s reasonably good performance and S.M.'s poor performance were also apparent in the final testing stage. This test included novel (untrained) Fribble exemplars to evaluate the patients' ability to use their acquired knowledge and was separated from the training blocks by the approximately 25-minute old/new recognition test so as to examine their retention of the original knowledge. C.R.'s 88% accuracy rate on this test was only slightly lower than his accuracy rate on the final training block, while S.M.'s 19% accuracy rate was indistinguishable from the chance rate of 16.7%.

Discussion

The first major result from this experiment was that, given the amount of training necessary for all 12 control participants to reach greater than 90% accuracy in categorizing six Fribble species, neither patient exceeded 55% accuracy on the same classification task. This indicates, in the first instance, the severity of their impairment in deriving an efficient and reliable set of visual representations. However, given additional training, C.R. eventually reached a relatively high accuracy rate. C.R. also retained his knowledge of the Fribble categories across a short delay and was able to generalize this knowledge to new category exemplars, performing about as well on the final naming test as on the last training block. He also showed a prototype effect, demonstrating good knowledge of exactly which shapes had been present in training exemplars. In contrast, S.M. showed no improvement whatsoever in either naming accuracy or RT even after the additional training. Moreover, his performance level on the final naming test was indistinguishable from chance, and, in the old/new recognition test, he judged all test exemplars to be about equally recognizable.

The errors made by the patients are also diagnostic of their performance. In contrast to the normal participants who demonstrated a predominant error type in which they confused the stimulus with the second species type that shared the same main body (see also Table 5), both patients appeared to respond more randomly. The findings support two main conclusions: The first is that the patients perform more poorly than the controls, need more time on task, and derive much more impoverished representations than the normal perceivers. The second conclusion is that C.R. is somewhat less impaired than S.M. in that he is able to improve his accuracy and to generalize his acquired knowledge and derive an implicit representation of the category mean. It is also the case that in Experiments 2 and 3 above, we also see somewhat better performance for C.R. than for S.M., consistent with the relative severity differences between them.

Before we ascribe differential severity to the two patients, there are a number of other possible explanations for S.M.'s marked impairment in this task. It remains a possibility that S.M. (but not C.R.) is unable to map perceptual representations to a label—he might potentially perceive Fribble species normally during training but simply be unable to form the association between this visual information and a symbolic representation such as the species label. This hypothesis was tested in the final experiment by requiring S.M. to learn the names of one object from the six Fribble species not tested in any of the previous experiments. A further possibility is that S.M.'s performance results not from a perceptual deficit but from an impairment in visual memory—given that the task used in the previous experiments is a variant of change-detection, the data may be explained by a more general deficit in visual short-term memory. Specifically, S.M. may represent the information initially but then loses the details of the encoded image as time passes—moreover, the more information to be retained, the more evident the memory attrition. Indeed, we already know that, in the absence of intact perception, visual representations may decay over the long-term (Riddoch, Humphreys, Blott, Hardy, & Smith, 2003).

EXPERIMENT 5: RULING OUT ALTERNATIVE EXPLANATION FOR S.M.'S IMPAIRMENT

In this final experiment, in Experiment A, we ensure that S.M. could learn the mapping between a single Fribble and a single label in which case his failure to do so in Experiment 4 would be a function of the agnosia rather than of a perceptual-conceptual mapping limitation. We also present data in Experiment B to demonstrate that S.M.'s failure to learn (or even match over delay) does not result from an obvious visual memory loss.

EXPERIMENT 5A

In this experiment, S.M. saw a single exemplar from each of the six Fribble species on the right of Figure 1 (novel species for him) and tried, as above, to learn species names for each object. As above, the training phase was followed by an old/new recognition test and a final naming test including novel exemplars from the six trained species. C.R. was not tested in this experiment, as he was able to learn species names for multiple exemplars in Experiment 4.

Method

Apparatus and procedure

Fribbles from the six species not used previously (see Figure 1) were used. The procedure was similar to that in Experiment 4 except that fewer exemplars were trained and tested. The training phase consisted of six blocks: in Block 1, S.M. saw each object (one exemplar of each of the six species) three times each along with its species name but made no response; in Block 2 he saw each object three times each with its name and pressed the keyboard key corresponding to the

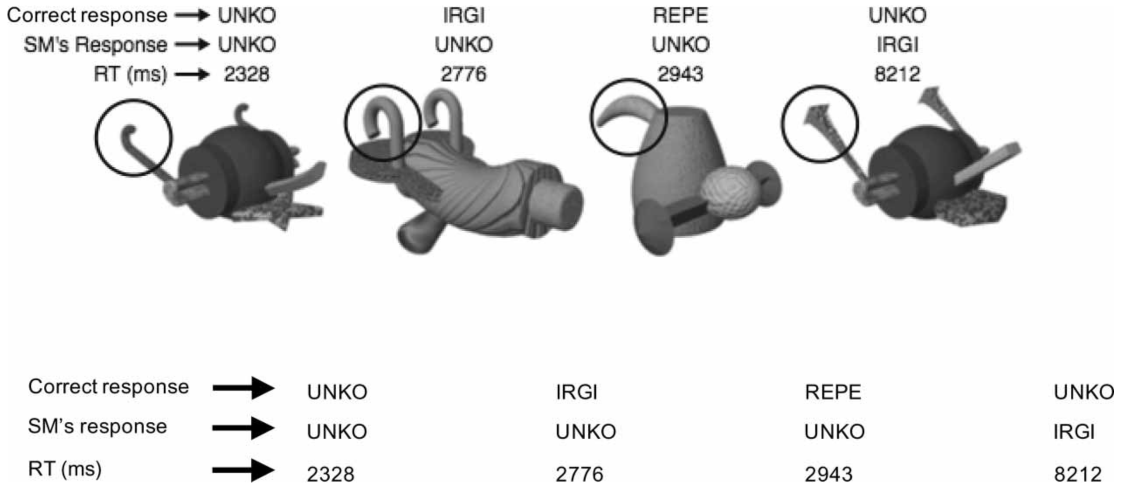


Figure 5. *Four untrained exemplars seen by S.M. in the final naming test of Experiment 5, along with the correct responses, S.M.'s responses, and S.M.'s response times to make these responses. Based on his own phenomenological report, he seems to have based his decision on the circled portions of each object.*

first letter of the name; in Block 3 he saw each object three times each without its name, attempted to press the corresponding key, and saw the correct name if incorrect; in Block 4 he saw each object three times each with its name, tried to press the correct key, and heard only a beep if incorrect; Block 5 was identical to Block 3 except each object was shown only once; and Block 6 was identical to Block 4. Had S.M. got more than one trial wrong on Block 6, we would have repeated the final two blocks up to 10 times, but as we see, this repetition was not necessary. In the old/new recognition task and final naming test, S.M. saw the six trained exemplars: two exemplars from each species that differed by two parts from the trained exemplar of the species, and two exemplars differing from the trained exemplars on all four appendage parts. Trial timing for all tasks was identical to the analogous tasks of Experiment 4.

Results

Training

The training results were unequivocal: Of the 60 naming trials in Blocks 3–6 of training, S.M. made only one error, indicating success at learning single object–label mappings. When asked how he learned these mappings, S.M. reported that he associated features of each object with the labels. As examples, he said that the curved part on the back of the REPE looked like a snake (a reptile) and the "hooks" on the UNKO looked like U's (see Figure 5) and the leftmost object in Figure 5. Note that this strategy of focusing in on local parts is entirely consistent with his performance on all the previous experiments and previous findings (Behrmann et al., 2006): This local bias is successful in the training phase but affects performance adversely in the generalization phase, as described below.

Old/new recognition test and confidence rating

S.M. correctly claimed that he had previously seen 83% (5/6) of the trained exemplars and that he had not seen 50% (6/12) of the untrained exemplars differing by two parts and 25% (3/12) of the untrained exemplars differing by four parts from trained items (mean confidence scores were 4.83, 3.75, and 2.50, respectively).

Retention and generalization

As a consequence of the local strategy he exploited, S.M. was inaccurate and very slow on novel exemplars in the final naming test, correctly naming all six trained items with a mean RT of 2,542 ms, but correctly identifying only 75% of items differing by two parts and 33% of items differing by all four appendage parts from the trained items, with mean RTs of 4,412 ms and 4,380 ms, respectively. For comparison, 32 university undergraduates trained on single exemplars of the six species (Williams, 1997) correctly classified 91%, 87%, and 81% of trained items and items differing by two and four parts from trained items, respectively, with mean RTs of 1,067, 1,072, and 1,190 ms.

As in Experiment 4, S.M.'s confusions on the final naming test showed no tendency to occur between species with the same main bodies. In fact, S.M. never made such a confusion in any of his 11 errors on this test. Intriguingly, several of his errors can be traced to his reported strategy for remembering the name of the UNKO: Two of the untrained IRGI exemplars (e.g., the second object in Figure 5) contained the same hook shapes as the trained UNKO exemplar, and one of the untrained REPE exemplars also contained a vaguely hook-shaped part (third object in Figure 5). S.M. called all three of these objects UNKOs and incorrectly classified the three UNKOs that did not contain the hook shape (calling all three IRGIs; e.g., the rightmost object in Figure 5).

EXPERIMENT 5B

To explore whether the difficulties exhibited by S.M. in change detection might result from a visual memory deficit, we presented S.M. with the well-used Rey–Osterreith complex figure (see Figure 6a for model) and examined his ability to encode it and then to reproduce it immediately and after a 5-minute delay.

Results

S.M. was able to copy the model well when it was displayed to him for unlimited exposure duration (see Figure 6b). He took over 16 minutes to complete this rendition, however, and copied the segments slowly and slavishly, consistent with other observations of his laborious copying and reflecting the lack of integration into a holistic image (Behrmann & Kimchi, 2003b). Of importance is that after a delay of 5 minutes, S.M.'s performance, while obviously poorer than that of the immediate copy condition, still retains most aspects of the model—most segments are present, albeit not in the correct arrangement (see Figure 6c). Note that it is not the case that S.M. can always produce a good copy of a visual image as in Figure 6b. When an image needs to be segmented or there is overlap that interferes with segmentation and integration, his performance is poor. As is evident from Figure 6d, in which S.M. was instructed to colour each of the four different superimposed objects in different colours, he was unable to do so. He apparently only noted the presence of two objects, one coloured in purple and one in green, and failed to segment the image fully. This confirms the diagnosis of integrative agnosia, while, at the same time, showing that he is not grossly impaired in his visual memory ability.

Discussion

S.M. was clearly able to learn object–label associations for novel objects and to use them for old–new discriminations, ruling out a failure to map perceptual to conceptual knowledge. It is worth noting that in Experiment 5A, deriving an association between object and label in this experiment can be successfully achieved by attending only to a local component and associating that with the appropriate label. However, such a procedure would adversely impact any generalization, and this is precisely the case here. These results suggest that when viewing an object, S.M. has difficulty integrating information across multiple components of the object at a time. He is apparently quite good at analysing the shapes of single Fribble parts and at using these parts to identify objects when they are present. However, the fact that he produced false alarms to the three objects containing hook-shaped parts in different orientations and different relative object positions indicates that S.M. has little idea of the context in which these parts exist. That is, S.M. can carefully

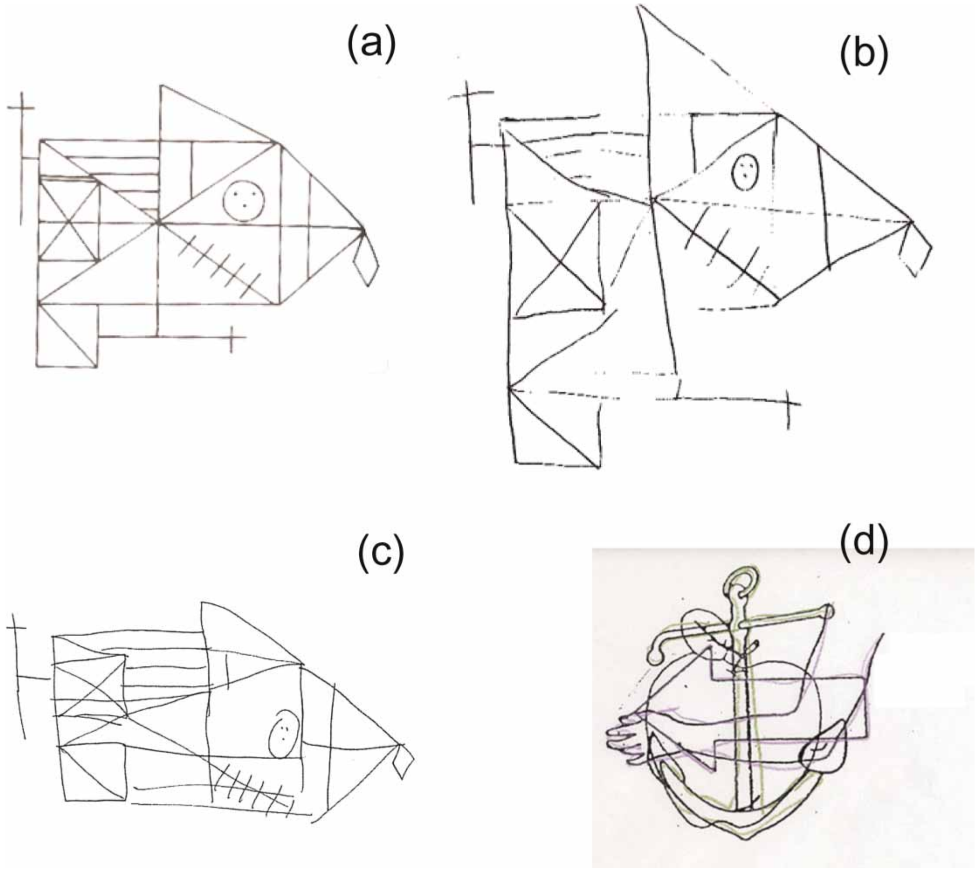


Figure 6. *Copying performance of S.M. on the Rey–Osterreith figure. (a) Model of the figure. (b) Copy done immediately with unlimited exposure duration. (c) Copy done after 5-minute delay filled with random activity. (d) S.M.'s attempt to outline the overlapping objects in different colours. Note the failure to segregate the object even though he had unlimited time in which to execute this task. [To view the figure in colour, visit the Journal's website (http://www.psypress.com/cogneuropsychology) and navigate to the online version of the paper.]*

analyse object parts but apparently lacks the ability to relate these parts to each other. Such a deficit accounts well for S.M.'s failure to map multiple exemplars onto the same species label in Experiment 4, since no one shape (except the main body) was ever present in more than one half of the eight training exemplars of a species. It also accounts for his extreme slowness in the naming tasks of both Experiments 4 and 5A: S.M. needs to search the image painstakingly for a distinguishing feature, while normal perceivers take in the whole object at once and make an efficient decision based on the general relationships between parts.

S.M.'s failure to match sequentially presented objects and to learn category membership also cannot easily be attributed to a short-term visual memory impairment. His ability to retain most of the segments in the copy even over a delay rules out a profound visual memory problem. It is a possibility, however, that his Rey–Osterreith performance might be mediated by spatial memory whereas his object memory might still be impaired. In this regard, we note that in a subsequent study in which S.M. participated (Behrmann et al., 2006), his performance was better in the memory than in the perception condition—when S.M. had to classify a display into one of four target responses, performance was poorer when the response types were displayed on the screen, and he was lured by the similarity of the target to the responses and performed substantially better when the responses were not displayed and he classified the target using his memory of the response types.

Taken together, these findings rule out an obvious visual memory deficit as an explanation of his impairment. Whether a more complicated or specific form of the memory deficit may still be at play remains to be determined. For example, patient H.J.A., a well-studied agnosic man, showed similar impairments in visual short-term memory as in perception (Riddoch et al., 2003)—that is, he could perform tasks relatively well if they concerned a single object or part of an object but experienced difficulty on tasks that required processing the relations between the parts. This is essentially the same pattern evinced by S.M. What is important in the case of H.J.A., however, is that the same problems were evident in perceptual as well as in visual short-memory tasks, leading the authors to conclude that the bottom-up coding of visual images is influenced by the same intermediate visual processes that serve object recognition (note also the behavioural literature suggesting that visual short-term memory might be part based, and, hence, integrating parts into a whole may rely on visual short term memory; Xu, 2002). The implication of this is that separating out a perceptual versus memorial contribution to the impairments shown by S.M. may not be that straightforward, and it remains to be determined whether, with more-fine grained evaluation, a mnemonic deficit might possibly be uncovered.

GENERAL DISCUSSION

This paper reports a series of five experiments designed to examine the nature of object perception in two individuals with integrative visual agnosia (IA). Using photorealistically rendered novel objects, Fribbles, we explored both the object discrimination and categorization ability of patients C.R. and S.M. who exhibit the characteristic pattern of failure to integrate components of a visual input into a coherent whole. The stimulus set is particularly appropriate for this purpose in that Fribbles lend themselves to careful experimental manipulation of both the number of parts and their part relations. Also, because the Fribble stimuli are novel for both the control participants and the patients, they allow us to compare the patients' and control participants' abilities to encode, represent, and learn these objects de novo. In particular, we were interested in examining the possibility that IA patients may have access to a small number of parts of visual objects but that the ability to represent a somewhat larger number may be contingent on the ability to represent the spatial relations between the parts. To explore these issues, we manipulated the similarity between a target Fribble and choices by varying the number of parts in common. We also examined the extent to which the patients could assign category membership to these visual objects, which requires abstracting the spatial relations between exemplars. A final question concerned the extent to which the patients are able to integrate the elements at a covert level given a recent report that it is not an impairment in integration per se that might underlie IA but rather the conscious access to the covertly integrated representations. To answer this last question, we documented the patients' sensitivity to the prototype of the displayed exemplars.

Parts and their relations: Implications for normal object recognition

Both S.M. and C.R. were impaired at assessing identity relations (Experiments 1–3) between pairs of exemplars, especially as the differences between the exemplars became increasingly fine grained: While the patients appear able to encode information about a small subset of parts of the image, which suffices under conditions where the exemplars are easily discriminable, differentiating between Fribbles where multiple parts are shared and only one or two parts differ is disproportionately difficult for the patients. These findings suggest that the patients do not have available to them the information about the parts beyond knowledge of just 1 or 2 parts. We also note that S.M. is somewhat more impaired in these visual abilities than is C.R.—and this is supported by other evidence (Behrmann & Kimchi, 2003b)—although the discrepancy between them is not very marked in these initial experiments. These findings suggest that there is an upper bound on the ability of the patients to represent local parts of a display and that, although up to 2 parts may be available to the patients, they in fact do not have all the elements accessible.

The remaining experiments explore the ability of the patients to learn to map exemplars onto category labels where category membership here is defined by the spatial relations between the parts of a set of exemplars. We note that both patients were impaired relative to the control individuals in learning how to assign category membership (Experiment 4), suggesting that they do not have obvious information about the spatial relations of the components of the exemplars. With additional training, however, C.R. was eventually able to associate multiple exemplars with a single category label, to extend the label to novel exemplars and to exhibit the standard prototype effect. S.M., on the other hand, was unable to approximate normal performance even with extended training. His failure to do so could not be attributed to a fundamental impairment in associating a percept with a concept per se as he was able to do so when only a single exemplar needed to be assigned to a single category label (Experiment 5). That he could do so under the single-object–single-label condition but not with multiple exemplars suggests that his deficit arises more from the failure to represent fully the Fribbles and to use this information to derive similarity across exemplars of Fribbles in order to classify them as belonging to specific species. Note too that S.M. lacked sensitivity to the prototype, suggesting that even at an implicit level, he failed to extract information about the exemplars and their part integration. Recall too that S.M.'s simple but informative copying of the Rey–Osterreith figure indicates that a visual memory deficit is unlikely to be at the root of his integration deficit.

What can account for the apparent failure to integrate all the elements into a single coherent and unified object? Recently, we have confirmed that it is the failure to integrate that is impaired in integrative agnosia—that is, that the patients do have the components available, and it is the failure to relate these parts into a single coherent whole that is problematic (Behrmann et al., 2006). Note, however, that this conclusion was reached based on a previous study in which S.M. initially learned to identify and discriminate objects made only of two local components. On subsequent testing, S.M. was able to perceive the two local components well but was apparently unable to represent their spatial relationship. This result was taken to indicate that he has the parts but not the whole, and it is a failure to relate the parts to each other spatially that precludes the derivation of a holistic representation.

The findings from the current study indicate that this conclusion must be qualified. When the number of parts to be encoded is limited, S.M. is indeed able to represent them. It is the case though that, as the number of parts shared between two exemplars increases, so his performance at detecting the differences worsens. S.M. (and C.R. to a lesser degree) does not seem able to encode all the local elements even with extended training or exposure duration. This, together with his errors reflecting a local emphasis and his phenomenological report, suggests that his ability to represent all the parts may not be normal and may reflect a limitation in his part representation or a decreased capacity to hold multiple (more than two) disparate parts simultaneously.

One interpretation of the findings is that the representation of parts and their relations might well be independent provided there are only a few parts to be represented. However, in accord with the idea of "chunking", it is the integration or binding together of the multiple parts that allows multiple parts to be concurrently represented. This view is analogous to ideas in which memory capacity can be enhanced when items can be chunked into slightly larger units. The analogy here is that it is the chunking that is impaired, and the consequence of this is that only a few parts can be encoded independently. The idea that binding is needed to integrate multiple parts is also consistent with theories in which deriving a higher order representation can modulate the nature of the perceptual encoding (Goldstone, 2000, 2001). On this account, the patients' failure to distinguish between exemplars that are visually similar (1 or 2 parts only are changed from target to choice), is a direct result of the failure to integrate and suggests that part- and spatial-relations representation may not be fully independent when more complex or multipart objects are involved (Arguin & Saumier, 2004; Carlson-Radvansky, 1999; Thoma & Davidoff, 2006).

The difference between S.M. and C.R. appears to be a matter of degree. C.R. is also limited in the number of parts he can represent but his upper bound is not as limited as that for S.M. C.R. clearly exhibits a parametrically milder form of the disorder than is the case for S.M.

Implicit representations of parts

Is it the case that the patients might be able to represent all the parts and their relations implicitly but be unable to use this integrated output explicitly (Aviezer et al., 2007)? To start with, let us consider whether C.R. is able to implicitly integrate the elements. The answer seems to be "yes" given his ability to derive the prototype from incidental exposure to a range of Fribble exemplars and the fact that his confidence ratings in classifying novel exemplars falls off with distance from the prototype, as is true for normal observers. But it is also the case that whatever information C.R. has implicitly appears to be available at an explicit level as well, as revealed by his equally good performance, relative to S.M. and to the controls, on the prototype matches and the trained and new exemplar decisions. In light of this, there is no obvious evidence for a dissociation between implicit and explicit knowledge. C.R. does have more information available than is the case for S.M. but this knowledge can apparently be used to support explicit as well as implicit decisions.

S.M., on the other hand, shows no evidence of prototype derivation—exposure to the Fribble exemplars is not aggregated to yield a prototype, and to the extent that S.M. is impaired in his explicit classification or discrimination of Fribbles, so too is he impaired on this implicit measure. Again, these findings do not reveal any dissociation between implicit and explicit object representation. Of course simply examining prototype derivation is only one way of exploring the ability of the patients to represent object information covertly, and more detailed investigation is necessary before noting definitively that there is no dissociation between implicit and explicit processing.

Before concluding, there is one remaining issue that must be addressed, and that concerns the possibility that the patients are impaired on the various tasks not because of a perceptual deficit with multiple parts per se but because of the memory load required for these experiments—the more parts, the greater the memory load. In the case of S.M., where the issue is more pressing given his severity, we show that his performance on a visual memory task is not grossly abnormal. His ability to copy the Rey–Osterreith figure and then to reproduce it after a delay is reasonably good, indicating that if he is able to encode the image initially, he is likely to be able to represent it rather well. In light of this, it seems that a simple explanation of impaired visual memory is unlikely to be able to account for the findings, and so it seems more parsimonious to assume that he cannot represent complex Fribbles. We do recognize, however, that further investigation of this issue is warranted before we can definitively rule out an impairment in visual short-term memory as a contributing factor.

Learning to recognize Fribbles and even to discriminate them clearly requires that one bind/relate the features to each other, and so any difficulty in deriving the spatial relations should affect Fribble processing in S.M. and C.R., and it does. The ability to bind objects and to derive a configural or integrated representation is often attributed to inferotemporal cortex (Baker, Behrmann, & Olson, 2002; Kourtzi & DiCarlo, 2006), and failures to extract a holistic representation are observed following damage to this region (Barton, Press, Keenan, & O'Connor, 2002; Behrmann & Kimchi, 2003a, 2003b; Joubert et al., 2003). Both S.M. and C.R. have damage to the inferotemporal cortex, consistent with these previous results. While S.M. and C.R. are both impaired at Fribbles, the paradigmatic stimulus set that apparently demands this form of part binding is face processing (Farah, 1996; Gauthier & Tarr, 2002; Leder & Bruce, 2000; Singer & Sheinberg, 2006). The obvious prediction one might make then is that both S.M. and C.R. should be impaired at face processing, with S.M. being somewhat more impaired. This is indeed the case (Gauthier et al., 1999; Marotta, McKeeff, & Behrmann, 2002), and both patients are profoundly prosopagnosic and perform poorly in face recognition but also in face discrimination. Note that other integrative agnosic patients, although not all, are also impaired at face processing (for example, Delvenne et al., 2004; Riddoch & Humphreys, 1987).

Taken together, these experiments shed light on the visual processes that have been disrupted in integrative visual agnosia. There is a clear impairment in deriving a unified representation of the components of an input image, and this has widespread impact on visual object, word, and face processing in these individuals. Their discrimination of individual exemplars is impaired, and both patients tested here are unable to abstract commonalities across exemplars to be able to derive category-level information. A possible interpretation of the finding is that the failure to integrate parts of an object has dire consequences for the ability to represent the parts when there are multiple parts. In both patients the lesion is to inferotemporal cortex, lending further support to the idea that this region of the visual system is critical for binding together disparate parts of an image and that the patients are impaired at binding. These findings are taken to suggest that in normal object recognition parts and relations may be independently coded if the number of parts is small but that it is critical for the part relations to be derived in order to represent the full complement of parts when the object contains many parts and is complex. This claim remains to be verified further in normal observers.

Manuscript received 21 July 2006
Revised manuscript received 13 August 2007
Revised manuscript accepted 10 September 2007

REFERENCES

Arguin, M., & Saumier, D. (2004). Independent processing of parts and their spatial organization in complex objects. *Psychological Science*, *15*, 629–633.

Aviezer, H., Landau, A. N., Robertson, L. C., Peterson, M. A., Soroker, N., Sacher, Y., et al. (2007). Implicit integration in a case of integrative visual agnosia. *Neuropsychologia*, *45*, 2066–2077.

Baker, C., Behrmann, M., & Olson, C. (2002). Impact of visual discrimination training on the representation of parts and wholes in monkey inferotemporal cortex. *Nature Neurosciences*, *5*, 1210–1216.

Bartolomeo, P., Bachoud-Lèvi, A., De Gelder, B., Dalla Barba, G., Brugieres, P., & Degos, J. D. (1998). Multiple-domain dissociation between impaired visual perception and preserved mental imagery in a patient with bilateral extrastriate lesions. *Neuropsychologia*, *36*, 239–249.

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

Behrmann, M., & Kimchi, R. (2003a). Visual perceptual organization: Lessons from lesions. In R. Kimchi, M. Behrmann, & C. Olson (Eds.), *Perceptual organization in vision: Behavioral and neural perspectives* (pp. 337–376). Mahwah, NJ: Lawrence Erlbaum.

Behrmann, M., & Kimchi, R. (2003b). What does visual agnosia tell us about perceptual organization and its relationship to object perception? *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 19–42.

Behrmann, M., Marotta, J., Gauthier, I., Tarr, M. J., & McKeeff, T. J. (2005). Behavioral change and its neural correlates in visual agnosia after expertise training. *Journal of Cognitive Neuroscience*, *17*, 554–568.

Behrmann, M., Peterson, M. A., Moscovitch, M., & Suzuki, S. (2006). Integrative agnosia: Deficit in encoding relations between parts. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1169–1184.

Benton, A. L., Sivan, A. B., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Contributions to neuropsychological assessment* (2nd ed.). Oxford, UK: Oxford University Press.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*, 115–147.

Black, S. E., Ebert, P., Leibovitch, F., Szalai, J., Blair, N., & Bondar, J. (1994). Recovery in hemispatial neglect. *Neurology*, *45*, A178.

Butter, C. M., & Trobe, J. D. (1994). Integrative agnosia following progressive multifocal leukoencephalopathy. *Cortex*, *30*, 145–158.

Carlson-Radvansky, L. A. (1999). Memory for relational information across eye movements. *Perception & Psychophysics*, *61*, 919–934.

Chainay, H., & Humphreys, G. W. (2001). The real object advantage in agnosia: Evidence for a role of shading and depth in object recognition. *Cognitive Neuropsychology*, *12*, 175–191.

Chase, W. G., & Simon, H. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55–81.

Davidoff, J., & Warrington, E. K. (1993). A dissociation of shape discrimination and figure–ground perception in a patient with normal acuity. *Neuropsychologia*, *31*, 83–93.

Delvenne, J.-F., Seron, X., Coyette, F., & Rossion, B. (2004). Evidence for perceptual deficits in associative visual (prosop)agnosia; A single case study. *Neuropsychologia*, *42*, 597–612.

Edelman, S. (1999). *Representation and recognition in vision*. Cambridge, MA: MIT Press.

Efron, R. (1968). What is perception? *Boston Studies in Philosophy of Science*, *4*, 137–173.

Farah, M. J. (1996). Is face recognition "special"? Evidence from neuropsychology. *Behavioural Brain Research*, *76*, 181–189.

Farah, M. J. (2004). *Visual agnosia* (2nd ed.). Cambridge, MA: MIT Press.

Gauthier, I., Behrmann, M., & Tarr, M. J. (1999). Can face recognition really be dissociated from object recognition? *Journal of Cognitive Neuroscience*, *11*, 349–370.

Gauthier, I., & Tarr, M. J. (2002). Unraveling mechanisms for expert object recognition: Bridging brain activity and behavior. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 431–446.

Giersch, A., Humphreys, G., Barthaud, J. C., & Landmann, C. (2006). A two-stage account of computing and binding occluded and visible contours: Evidence from visual agnosia and effects of lorazepam. *Cognitive Neuropsychology*, *23*, 261–277.

Giersch, A., Humphreys, G., Boucart, M., & Kovacs, I. (2000). The computation of occluded contours in visual agnosia: Evidence for early computation prior to shape binding and figure–ground coding. *Cognitive Neuropsychology*, *17*, 731–759.

Goldstone, R. L. (2000). Unitization during categorization learning. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 86–112.

Goldstone, R. L. (2001). Learning to perceive while perceiving to learn. In R. Kimchi, M. Behrmann, & C. Olson (Eds.), *Perceptual organization: Behavioral and neural mechanisms*. Hillsdale, NJ: Erlbaum.

Goodglass, H., Kaplan, E., & Weintraub, S. (1983). *Boston Naming Test.* New York: Lea and Febiger.

Hummel, J. E., & Biederman, I. (1992). Dynamic binding in a neural network for shape recognition. *Psychological Review*, *99*, 480–517.

Hummel, J. E., & Stankiewicz, B. J. (1996). An architecture for rapid, hierarchical and structural description. In T. Innui & J. L. McClelland (Ed.), *Attention and performance XVI* (pp. 93–121). Cambridge, MA: MIT Press.

Humphreys, G. W. (1999). Integrative agnosia. In G. W. Humphreys (Ed.), *Case studies in vision* (pp. 41–58). Hove, UK: Psychology Press.

Humphreys, G. W., & Riddoch, M. J. (1984). Routes to object constancy: Implications from neurological impairments of object constancy. *Quarterly Journal of Experimental Psychology*, *36A*, 385–415.

Humphreys, G. W., & Riddoch, M. J. (2006). Features, objects, action: The cognitive neuropsychology of visual object processing, 1984–2004. *Cognitive Neuropsychology*, *23*, 1–28.

Humphreys, G. W., Riddoch, M. J., Donnelly, N., Freeman, T., Boucart, M., & Muller, H. M. (1994). Intermediate visual processing and visual agnosia. In M. J. Farah & G. Ratcliff (Eds.), *The neuropsychology of high-level vision* (pp. 63–101). Hillsdale, NJ: Lawrence Erlbaum Associates.

Humphreys, K., Avidan, G., & Behrmann, M. (2007). A detailed investigation of facial expression processing in congenital prosopagnosia as compared to acquired prosopagnosia. *Experimental Brain Research*, *176*, 356–373.

Jankowiak, J., Kinsbourne, M., Shalev, R. S., & Bachman, D. L. (1992). Preserved visual imagery and categorization in a case of associative visual agnosia. *Journal of Cognitive Neuroscience*, *4*, 119–131.

Joubert, S., Felician, O., Barbeau, E., Sontheimer, A., Barton, J. J., Ceccaldi, M., et al. (2003). Impaired configurational processing in a case of progressive prosopagnosia associated with predominant right temporal lobe atrophy. *Brain*, *126*, 2537–2550.

Kartsounis, L., & Warrington, E. K. (1991). Failure of object recognition due to a breakdown in figure–ground discrimination in a patient with normal acuity. *Neuropsychologia*, *29*, 969–980.

Kourtzi, Z., & DiCarlo, J. J. (2006). Learning and neural plasticity in visual object recognition. *Current Opinion in Neurobiology*, *16*, 152–158.

Lawson, R., & Humphreys, G. W. (1999). The effects of view in depth on the identification of line drawings and silhouettes of familiar objects. *Visual Cognition*, *6*, 165–195.

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

Lissauer, H. (1890). Ein Fall von Seelenblindheit nebst einem Beitrage zur Theorie derselben [A case of visual agnosia with a contribution to theory]. *Archiv Fur Psychiatrie und Nervenkrankheiten*, *21*, 222–270.

Marotta, J. J., McKeeff, T. J., & Behrmann, M. (2002). The effects of inversion and rotation on face processing in prosopagnosia. *Cognitive Neuropsychology*, *19*, 31–47.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.

Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience*, *9*, 555–604.

Osswald, K., Humphreys, G. W., & Olson, A. (2002). Words are more than the sum of their parts: Evidence for detrimental effects of word-level information in alexia. *Cognitive Neuropsychology*, *19*, 675–695.

Palmeri, T. J., & Gauthier, I. (2004). Visual object understanding. *Nature Reviews. Neuroscience*, *5*, 291–303.

Peterson, M. A., de Gelder, B., Rapcsak, S. Z., Gerhardstein, P. C., & Bachoud-Lévi, A. C. (2000). Object memory effects on figure assignment: Conscious object recognition is not necessary or sufficient. *Vision Research*, *40*, 1549–1567.

Posner, M. I., & Keele, S. (1968). On the genesis of abstract ideas. *Journal of Experimental Psychology*, *77*, 353–363.

Posner, M. I., & Keele, S. (1970). Retention of abstract ideas. *Journal of Experimental Psychology*, *83*, 304–308.

Ricci, R., Vaishnavi, S., & Chatterjee, A. (1999). A deficit of intermediate vision: Experimental observations and theoretical implications. *Neurocase*, *5*, 1–12.

Riddoch, M. J., & Humphreys, G. W. (1987). A case of integrative visual agnosia. *Brain*, *110*, 1431–1462.

Riddoch, M. J., & Humphreys, G. W. (1993). *Birmingham Object Recognition Battery*. Hove, UK: Lawrence Erlbaum Associates.

Riddoch, M. J., & Humphreys, G. W. (2003). Visual agnosia. *Neurologic Clinics*, *21*, 501–520.

Riddoch, M. J., Humphreys, G. W., Blott, W., Hardy, E., & Smith, A. D. (2003). Visual and spatial short-term memory in integrative agnosia. *Cognitive Neuropsychology*, *2*, 641–671.

Rosenthal, O., & Behrmann, M. (2006). Acquiring long-term high-level visual representations following extensive extrastriate damage. *Neuropsychologia*, *44*, 799–815.

Saumier, D., Arguin, M., Lefebvre, C., & Lassonde, M. (2002). Visual object agnosia as a problem in integrating parts and part relations. *Brain and Cognition*, *48*, 531–537.

Singer, J. M., & Sheinberg, D. L. (2006). Holistic processing unites face parts across time. *Vision Research*, *46*, 1838–1847.

Snodgrass, S. G., & Vanderwart, M. A. (1980). A standardised set of 260 pictures: Norms for name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *6*, 174–215.

Thoma, V., & Davidoff, J. (2006). Priming of depth-rotated objects depends on attention- and part-changes. *Experimental Psychology*, *53*, 31–47.

Thomas, R., & Forde, E. (2006). The role of local and global processing in the recognition of living and nonliving things. *Neuropsychologia*, *44*, 982–986.

Ullman, S. (2007). Object recognition and segmentation by a fragment-based hierarchy. *Trends in Cognitive Sciences*, *11*, 58–64.

Xu, Y. (2002). Encoding color and shape from different parts of an object in visual short-term memory. *Perception & Psychophysics*, *64*, 1260–1280.

Warrington, E. K., & James, M. (1991). *The Visual Objects and Space Perception Battery*. Bury St. Edmunds, UK: Thames Valley Test Company.

Williams, P. (1997). *Prototypes, exemplars, and object recognition.* New Haven, CT: Yale.