Spatial Processing in Bálint Syndrome and Prosopagnosia: A Study of Three Patients

Jason J. S. Barton, MD, PhD, FRCPC, George L. Malcolm, MA, and Rebecca L. Hefter, MSc

Background: Spatial analysis may be subdivided into between-object and within-object spatial coding. We investigated the contribution of various visual cues to grouping processes that might determine whether single or multiple objects were perceived and therefore which type of spatial coding would be used for a stimulus.
Methods: We asked three patients to make shape judgments with a series of displays showing triangular arrangements, moving from more implicit triangles defined by separate objects at the apices (between-object spatial coding) to more explicit triangles with line edges or surface texture (within-object spatial coding).
Results: In two patients with prosopagnosia, within-object spatial judgments were impaired, whereas between-object spatial judgments were normal. In a patient with Bálint syndrome, the reverse pattern was obtained. Surface texture but not outline closure led to mandatory within-object coding in the prosopagnosic patients, whereas outline or surface texture was sufficient to support intact within-object spatial judgments in the patient with Bálint syndrome. Illusory contours were ineffective in promoting within-object coding in either condition.
Conclusions: These findings support the existence of parallel representations of space for within-object and between-object processing and reveal the efficacy of different cues in determining which representation is potentially accessible.

(***J Neuro-Ophthalmol*** **2007;27:268–274)**

Department of Neurology (JJSB, RLH), Beth Israel Deaconess Medical Center, Harvard Medical School, Boston Massachusetts; and Division of Neurology, Department of Ophthalmology and Visual Sciences (JJSB, GLM), University of British Columbia, Vancouver, British Columbia, Canada.

Support for this work was provided by Canada Research Chair, Michael Smith Foundation for Health Research Senior Scholarship, National Institutes of Mental Health (R01-MH069898), and Canadian Institutes of Health Research (MOP-77615).

Address correspondence to Jason Barton, MD, PhD, FRCPC, Neuro-ophthalmology Section D, VGH Eye Care Center, 2550 Willow St., Vancouver, BC, Canada; E-mail: jasonbarton@shaw.ca

The term "visuospatial analysis" traditionally refers to the processing of the spatial positions and spatial relations of objects in a scene or display. Such information is useful for visually guided hand or eye movements and for navigation in the environment. Classic models of cerebral organization hypothesize that this visuospatial analysis is a key function of the dorsal occipitoparietal cortices, recognized as part of the "where" stream (1). Damage to occipitoparietal structures typically results in Bálint syndrome, a triad of simultanagnosia, optic ataxia, and ocular motor apraxia (2,3).

However, object recognition also relies heavily on the analysis of the spatial structure of stimuli. In this sense, space is important not only for "where" but also for "what," a function that is attributed to the ventral occipitotemporal cortices. This point has been recognized recently by a conceptual division of spatial representation into within-object and between-object categories (4). Neuropsychologic studies have shown that within-object and between-object spatial representations can be disturbed independently in patients with hemi-neglect (5,6). A study of a subject with Bálint syndrome suggested that between-object representations may be selectively impaired in this condition (7). In that regard, we have recently provided evidence from a series of patients with prosopagnosia, the inability to recognize familiar faces, that their perception of the fine metrics of within-object and within-face spatial relations is impaired, but their between-object spatial judgments are normal (8).

In their study, Cooper and Humphreys (7) used grouping effects to manipulate the likelihood that a stimulus was seen as a single object or as two separate objects. Performance of their patient with Bálint syndrome was better if factors such as collinearity fostered the perception of a single object rather than multiple objects. The methods in that study raise the issue of what factors promote the grouping of visual elements into a single object as opposed to multiple independent elements. This issue is relevant to the binding problem, in particular, the aspect of parsing of the visual scene (9). In other words, what determines which elements of a visual scene belong together as part of a single object and which elements should be segregated as belonging to separate objects? In the context of spatial representation, what are the visual elements that promote a within-object over a between-object representation?

Examining a neuropsychologic sample may be particularly revealing on this point. By using stimuli that vary in the cues that pit one perceptual representation against the other, we can determine which visual properties are sufficient to effect a transition from between-object to within-object representation. In patients with selective deficits of one form of spatial representation but not the other, this transition should be marked by a performance transition between success and failure on a spatial task using these stimuli.

We devised a task using a series of very similar triangular configurations that varied in the elements that defined the triangle. At one extreme, these elements could promote the perception of separate objects at the triangle's apices; at the other they could promote the perception of a single triangular object. By systematically varying the elements in the stimulus, we wished to discover the features that were most likely to create a transition from within-object to between-object coding. We examined three patients' abilities on this task. Two had occipitotemporal lesions causing prosopagnosia, a selective defect in face recognition, which we showed to be associated with failures in perceiving within-object spatial relations. One had occipitoparietal lesions causing Bálint syndrome.

METHODS

Subjects

Subject 005 is a 59-year-old man examined 10 months after a right medial occipitotemporal stroke. He has difficulty recognizing faces, more so for people met since or in the years just before his stroke but not for long-familiar friends. He complains of decreased brightness but not loss of color perception. He has topographagnosia. Snellen acuity was 20/20 in both eyes, and he had a complete left homonymous hemianopia. His eye movements were normal. Neuropsychologic testing revealed a verbal IQ of 150. He copied the Rey-Osterreith figure normally. He had memory difficulties, which were worse for nonverbal items. His Benton Face Recognition Test score was 35/54. Brain MRI showed a large right medial occipitotemporal infarct (Fig. 1).

Subject 010 is a 41-year-old man with bilateral posterior occipitotemporal lesions from a car accident 20 years earlier that caused a subdural hematoma. He had been cortically blind for a few weeks immediately after the event but his sight recovered partially. He now has prosopagnosia, some mild object agnosia, and complaints of partial dyschromatopsia. Snellen visual acuity is 20/20 in both eyes, and he has a right homonymous hemianopia. Eye movements are normal. MRI showed bilateral occipitotemporal and right frontal lesions.

Subject B.001 is a 48-year-old woman who had bilateral occipitoparietal infarctions from primary central nervous system vasculitis 5 months before testing. Examination at onset of the strokes showed a left inferior quadrantanopia, left hemi-neglect, inaccurate saccades with impersistence of fixation, and poor pursuit. She had optic ataxia with either hand and simultanagnosia, as tested with the Cookie Theft picture and other displays. Examinations over the following months showed a visual acuity of 20/40 in both eyes and resolution of the inferior quadrantanopia and hemineglect. She saw multiple items on the Cookie Theft picture but could not relate the elements to each other. Saccadic accuracy was better, and there was only mild misreaching to visual targets with the left hand. Recognition of single objects as tested with line drawings was normal.

Testing

Subjects sat facing an Apple Multiscan 1705 monitor (Apple Inc., Cupertino, CA) in standard dim room lighting at a viewing distance of approximately 57 cm. Experiments were run on a G4 Powermac (Apple Inc.) using Superlab 1.71 (Cedrus, Phoenix, AZ).

All stimuli were based on an equilateral triangle with sides of 6.1° (175 pixels). One apex was moved farther away from the other two, by 4, 6, or 8 pixels. The task was to indicate which apex was farther away. In our prior report, we showed that prosopagnosic subjects with or without hemifield defects (including subjects 005 and 010) could make accurate judgments of similar spatial distances between stimuli under time-limited viewing conditions (8). The six stimuli were designed to approximate a progression from between-object to within-object spatial coding (Fig. 2). The first stimulus ("Discs-Only") consisted of three "Pac-Man"-like objects (discs of 2.5° diameter with wedges cut out) located at the apices of the triangle. Each disc had a different texture to foster classification as distinct objects and to promote between-object spatial coding. The second stimulus ("Kanisza") had the apical discs rotated 180°, so that the wedges defined an illusory triangle, with the discs all possessing the same texture. The illusion is compelling, and the distances involved in our stimuli are within the range of human perception of illusory contours (10). In the third stimulus ("Line+Discs"), the triangle was made explicit by a line drawing. In the fourth stimulus ("Surface+Discs"), the surface of the triangle was filled with a texture. The fifth and sixth stimuli ("Line-Only" and "Surface-Only") were similar to the third and fourth, except that the apical discs were absent. These last stimuli were most likely to involve within-object spatial coding. For each degree of change, we presented 18 trials,

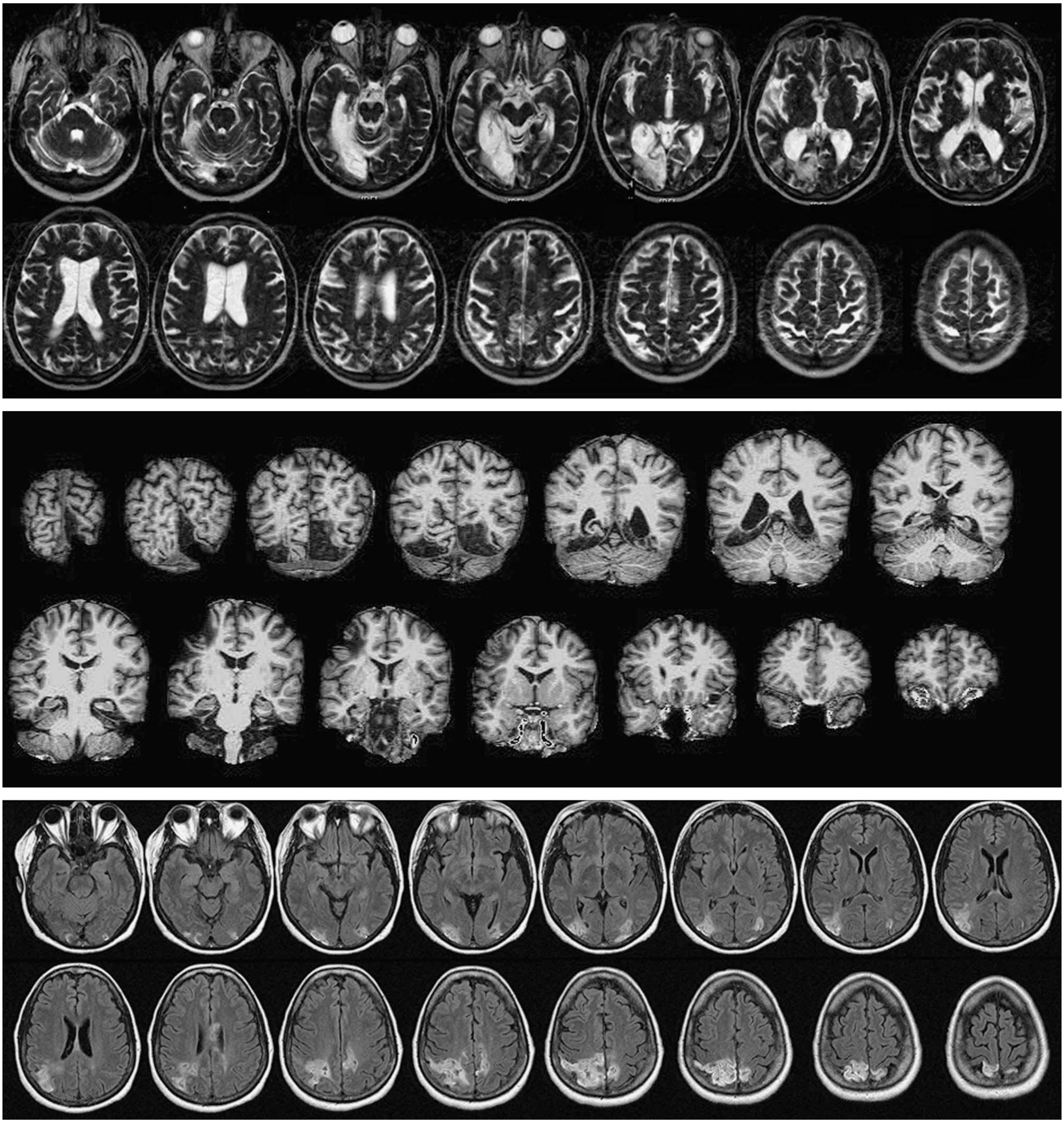

FIG. 1. Brain MRI of the three subjects. **Top:** T2 axial images of prosopagnosic subject 005 show a unilateral right occipitotemporal infarct. **Middle:** T1 coronal images of prosopagnosic subject 010, taken from a functional MRI session, show bilateral medial occipitotemporal lesions. **Bottom:** Axial FLAIR images of Bálint syndrome subject B.001 show bilateral occipitoparietal lesions.

for a total of 324 trials. These were presented in random order in 3 blocks of 108 trials, with each block containing two stimulus types; the order of blocks was also randomized. Viewing duration was limited to 1 second per trial.

Subjects 005 and 010 performed this experiment. We tested 10 control subjects (5 men and 5 women) ranging in age from 17 to 43 years. For each of the six stimuli we chose the two levels of change that, averaged together, yielded a mean accuracy between 90% and 95%. We used

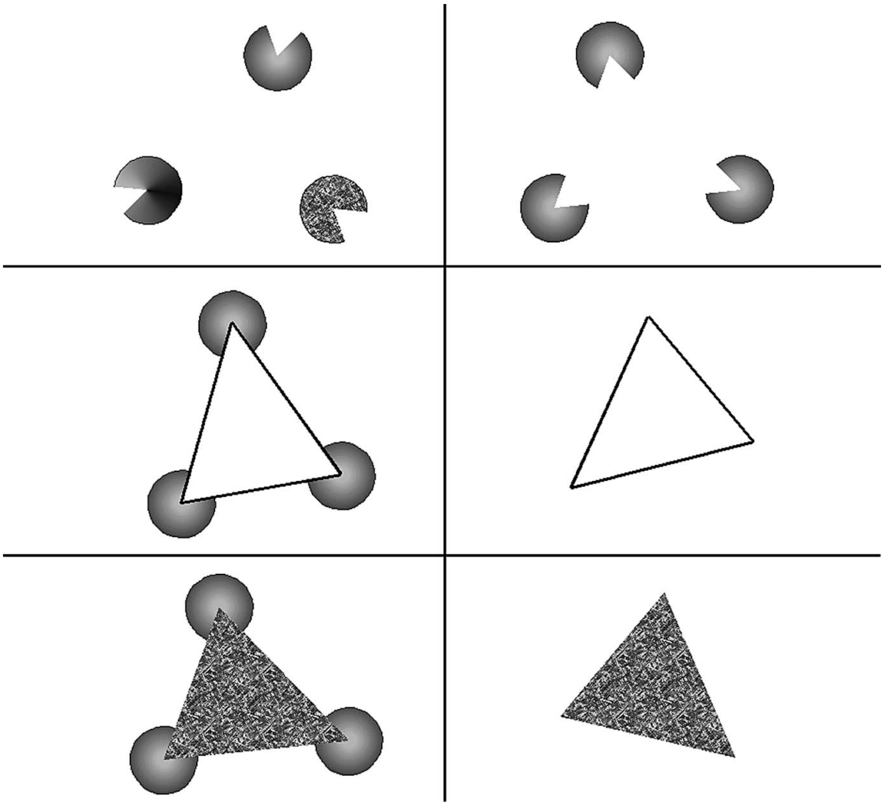

FIG. 2. Examples of stimuli. **Top row:** Discs-Only stimulus on left and Kanisza stimulus on right. **Middle row:** Line+Discs stimulus on left and Line-Only stimulus on right. **Bottom row:** Surface+Discs stimulus on left and Surface-Only stimulus on right. In each stimulus, one apex of the triangular arrangement is farther away from the other two by 8 pixels.

these data to construct 95% prediction intervals, to which the patient data were compared.

For subject B.001, we altered the task and stimuli slightly. Our concern was that the instructions in the above paradigm might promote a strategy of inspecting each apex and would require the subject to assign a spatial label to the target, both of which could be a methodologic limitation in someone with both simultanagnosia and deficient saccadic targeting. Rather, we devised a version that used both equilateral triangles and "asymmetric triangles," with one of the two lower apices displaced farther away from the other two. For this test we used the same size triangular configurations, with sides of 175 pixels (6.1°), but with slightly easier changes to detect, using apical shifts of 24, 26, or 29 pixels. A third of the trials showed an equilateral triangle and the rest showed an asymmetric triangle, with equal numbers of asymmetric triangles having the right vs left lower apex displaced outward. The subject was asked to indicate whether the triangle on a given trial was symmetric or asymmetric around a vertical axis. A similar series of six different types of triangular stimuli were used, in separate blocks, with randomized order. Eighteen trials were shown for each of the six types of stimuli, for a total of 108 trials. Viewing duration was not limited. One male control subject aged 45 performed this experiment, confirming that the task was easily completed with perfect accuracy for all six stimuli.

RESULTS

Prosopagnosic subjects 005 and 010 performed well with the Discs-Only, Kanisza, and Line + Discs stimuli (Fig. 3). Subject 005 had a borderline low performance for the Discs-Only stimulus, but otherwise performance was in the normal range. Performance for both subjects decreased with the remaining three stimuli: Surface + Discs, Surface-Only, and Line-Only. This decline was more dramatic for subject 010, who had bilateral occipitotemporal lesions, than for subject 005, who had a unilateral right occipitotemporal infarct. For subject 005, the score for the Surface + Discs condition was just within the normal range, due in part to a larger variance in the normal scores for this stimulus compared with other stimuli. The most dramatic contrast in subject 010 was between the Line + Discs and Surface + Discs stimuli. Whereas his accuracy with the Line + Discs was a normal, near-ceiling 92%, adding surface texture caused his score to plummet to a below-threshold level of 61%.

The patient with Bálint syndrome had a dramatically different performance pattern. She performed flawlessly when a line or surface was explicitly defined but performed at chance with the Discs-Only and Kanisza conditions. Although these were easier tests than those used for the prosopagnosic patients (to mitigate potential problems with

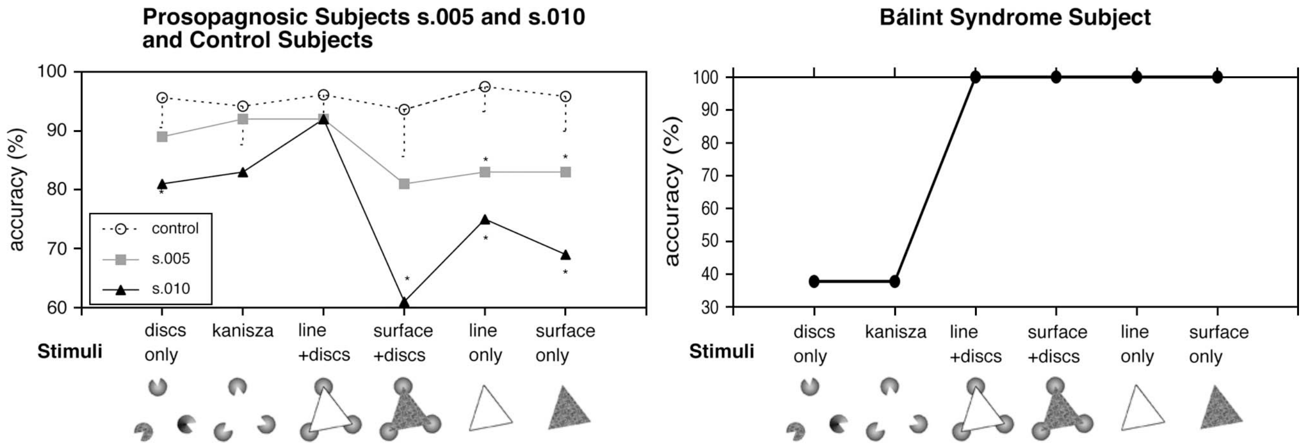

FIG. 3. Test results for two prosopagnosic subjects and their control subjects (left) and for the patient with Bálint syndrome. The six different stimuli, identified by name and graphic examples, are shown below the horizontal axis. On the left, control subjects performed equivalently on all stimuli, with accuracy around 95% (1 SD shown by error bars); the two prosopagnosic subjects do relatively well with the three stimuli on the left side of the graph but have more difficulty with stimuli on the right side of the graph. Note that the deficit is greater for the subject with bilateral lesions (S.010). Asterisks indicate performance below the 95% prediction intervals for control subjects. On the right are the results for the subject with Bálint syndrome, confronted with similar stimuli but a different type of task (distinguishing symmetric from asymmetric triangles), which a control subject performed with 100% accuracy. The subject with Bálint syndrome shows the reverse result: she does well with stimuli on the right side and performs at chance with the two stimuli on the left.

spatial attention and localization in Bálint syndrome), the reversal in results compared with the prosopagnosic data cannot be attributed solely to test difficulty, as the six tests had equivalent spatial manipulations and were performed at a similar high level by an age-matched control subject. Rather, they indicate a fundamentally different pattern of spared vs affected abilities than that in prosopagnosia.

DISCUSSION

Our results support the existence of distinct between-object and within-object spatial representations, with the former supported by occipitoparietal processing and the latter by occipitotemporal processing. The patient with Bálint syndrome from occipitoparietal lesions was impaired when evaluating a triangle defined solely by distinctly separate discs located at its apices and normal when evaluating a triangle defined by outlines or surface texture. In contrast, the patients with prosopagnosia from occipitotemporal lesions had the opposite performance pattern. They were impaired when evaluating a triangle defined by outlines or surface texture and normal when evaluating a triangle defined by discs at its apices. Their deficit with evaluating the metrics of object spatial structure is consistent with our prior documentation of their impaired perception of the spatial relations of facial features (11–14).

Dissociations between within-object and between-object spatial coding have been described in other disorders. Reversing patterns of hemi-neglect have been described, for example (4–6). When viewing words, these patients omit or substitute the first letter of words (left-sided within-object neglect) yet ignore words on the right side of the page (right-sided between-object neglect). When naming the letters of words they neglect the right-sided letters, even though they make left-sided errors when reading the word. With abstract patterns, the side neglected depends upon whether the pattern's elements are grouped into a single object. Other studies have since described patients with within-object but not between-object neglect or vice versa, supporting a dissociation between these processes (15).

The parallel existence of between-object and within-object spatial representations has been linked to the concept of two processing streams in cerebral cortex (4). Ventral occipitotemporal cortex is involved in object recognition (1), and within-object spatial coding may be important in the specifying object structure. Between-object spatial coding is relevant to spatial localization and direction for action (16), functions assigned to the dorsal occipitoparietal cortex. A few studies have provided neuropsychologic evidence supporting these links. The impairment of a patient with bilateral parietal lesions in comparing the spatial length of two objects was ameliorated if these could be grouped into a single structure (7), implying normal within-object but abnormal between-object coding. Reaction time studies have shown faster processing for counting individual letters than for reading words in two patients with ventral occipitotemporal lesions and vice versa in two patients with dorsal occipitoparietal lesions (15). Our accuracy data clearly complement these findings, with impaired analysis of relations between separate objects in Bálint syndrome and impaired analysis of relations in a single form in prosopagnosia, a selective type of object agnosia.

Our experiment also provides some additional data on the binding or grouping process involved in segmenting elements into objects. Aspects such as continuity, collinearity, and closure within stimuli promote low-level grouping of elements (17). Our triangular stimuli pitted some of these features in competition with the presence of separable individual elements (the discs at the triangle's apices). In our prosopagnosic patients, collinearity in the Kanisza stimulus and closure in the Line + Discs stimulus were not sufficient to override the presence of the discs, which allowed for normal between-object processing. However, making the surface explicit with texture (Surface + Discs) did lead to a dramatic reduction in accuracy, especially in subject 010. We thus speculate that, in the presence of distinct separable elements such as the discs, explicit surface representation but not just collinearity or closure leads to a mandatory induction of grouping into a single object, which in our patients had the consequence of failure of spatial coding within this object.

In the patient with Bálint syndrome, accuracy was flawless as long as outline or surface texture was present. One might have expected her to fail on the stimulus that combined the discs with an outlined triangle (Line + Discs), as the prosopagnosic subjects had performed well with this stimulus. The success of the prosopagnosic subjects suggests that they were able to access between-object representations to make perceptual judgments about the Line + Discs stimulus. However, the patient with Bálint syndrome also succeeded with this stimulus, suggesting that she was able to access within-object representations for the Line + Discs stimulus. This stimulus thus appears to be a flexible "hinge" point, where within-object or between-object spatial representations are equally accessible. In the competition between these two spatial representations, patients with one weakened representation can access the remaining normal representation, whichever one it is. Once the triangular surface is filled in with texture, though, access to between-object spatial coding is no longer possible, and the stimulus is mandatorily processed by within-object spatial coding, given the prosopagnosic data. Given the data from the patient with Bálint syndrome, the separate discs cannot access within-object representations and must be processed by a between-object spatial coding.

The results from both types of patients agree on the failure of illusory contours to promote a grouping effect sufficient to counteract between-object spatial representations. Although the illusion of a single triangle is a powerful one, the prosopagnosic subjects continued to process the spatial relations of the illusory triangle efficiently, whereas the patient with Bálint syndrome failed to do so, indicating the primacy of between-object spatial representations with this stimulus despite the vivid illusion. Others have argued that illusory contours are seldom encountered naturally (18), and perhaps this ecologic infrequency limits the power of their contribution to internal decisions about spatial representation. Nevertheless, illusory contours emerge at relatively early levels in the neurophysiologic hierarchy, with neuronal discharges at illusory edges occurring in V2 (19). One could speculate that this finding implies that grouping effects are at least partly determined at even earlier levels of visual processing, perhaps even at V1, where illusory contours may actually be de-emphasized (20). Indeed there is some evidence for grouping processes that may affect the salience of object boundaries in monkey V1 (21,22). Whether these early processes are responsible for triaging spatial analysis to between-object vs within-object processing mechanisms deserves further investigation.

Acknowledgments

We thank D. Press for referring subject 005, M. Alexander for subject 010, and R. G. Robinson for subject B.001. S.-Y. Moon assisted with processing magnetic resonance images.

REFERENCES

1. Ungerleider L, Mishkin M. Two cortical visual systems. In: Ingle DJ, Mansfield RJ, Goodale MA, eds. *The Analysis of Visual Behaviour*. Cambridge, MA: MIT Press; 1982:549–86.
2. Rizzo M. Bálint's syndrome and associated visuospatial disorders. In: Kennard C, ed. *Bailliere's International Practice and Research*. Philadelphia: WB Saunders; 1993:415–437.
3. Bálint R. Seelenlahmung des 'Schauens', optische Ataxie, räumliche Storung der Aufmerksamkeit. *Monatschrift Psychiatrie Neurol* 1909; 25:51–8.
4. Humphreys GW. Neural representation of objects in space: a dual coding account. *Phil Trans R Soc Lond B Biol Sci* 1998;353:1341–5.
5. Humphreys GW, Riddoch MJ. Attention to within-object and between-object spatial representations: multiple sites for visual selection. *Cogn Neuropsychol* 1994;11:207–41.
6. Humphreys GW, Riddoch MJ. Separate coding of space within and between perceptual objects: evidence from unilateral visual neglect. *Cogn Neuropsychol* 1995;12:283–311.
7. Cooper AC, Humphreys GW. Coding space within but not between objects: evidence from Balint's syndrome. *Neuropsychologia* 2000; 38:723–33.
8. Barton JJ, Cherkasova MV. Impaired spatial coding within-objects but not between-objects in prosopagnosia. *Neurology* 2005;65:270–4.
9. Treisman A. Solutions to the binding problem: progress through controversy and convergence. *Neuron* 1999;24:105–10.
10. Ringach DL, Shapley R. Spatial and temporal properties of illusory contours and amodal boundary completion. *Vision Res* 1996;36: 3037–50.
11. Barton JJ, Press DZ, Keenan JP, et al. Lesions of the fusiform face area impair perception of facial configuration in prosopagnosia. *Neurology* 2002;58:71–8.
12. Barton JJ, Cherkasova M. Face imagery and its relation to perception and covert recognition in prosopagnosia. *Neurology* 2003;61:220–5.
13. Barton JJ, Cherkasova MV, Press DZ, et al. Developmental prosopagnosia: a study of three patients. *Brain Cogn* 2003;51:12–30.

14. Joubert S, Felician O, Barbeau E, et al. Impaired configurational processing in a case of progressive prosopagnosia associated with predominant right temporal lobe atrophy. *Brain* 2003;126(Pt 11): 2537–50.
15. Humphreys GW, Heinke D. Spatial representation and selection in the brain: neuropsychological and computational constraints. *Visual Cogn* 1998;5:9–47.
16. Milner AD, Goodale MA. *The Visual Brain in Action*. Oxford, UK: Oxford University Press; 1995.
17. Donnelly N, Humphreys GW, Riddoch MJ. Parallel computations of primitive shape descriptions. *J Exp Psychol Hum Percept Perform* 1991;17:561–70.
18. Spillman L, Werner JS. Long-range interactions in visual perception. *Trends Neurosci* 1996;19:428–34.
19. von der Heydt R, Peterhans E, Baumgartner G. Illusory contours and cortical neuron responses. *Science* 1984;224:1260–2.
20. Ramsden BM, Hung CP, Roe AW. Real and illusory contour processing in area V1 of the primate: a cortical balancing act. *Cereb Cortex* 2001;11:648–65.
21. Kapadia MK, Ito M, Gilbert CD, et al. Improvement in visual sensitivity by changes in local context: parallel studies in human observers and in V1 of alert monkeys. *Neuron* 1995;15:843–56.
22. Yen SC, Finkel LH. Extraction of perceptually salient contours by striate cortical networks. *Vision Res* 1998;38:719–41.