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Visual Perceptual Organization: Lessons From lesions

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10 Visual Perceptual Organization: Lessons From Lesions

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The visual world consciously perceived is very different from the chaotic juxtaposition of different colors and shapes that stimulate the individual retinal receptors. Objects are seen as detached and separable from adjacent objects and surfaces despite the fact that parts of a single object may be spatially or temporally discontinuous, and have different colors or even transect several different depth planes. Additionally, because most surfaces are opaque, portions of objects are routinely hidden from view, and, as we move around, surfaces continually undergo occlusion and fragmentation. As is apparent from this description, the objects of phenomenal perception are not given in any direct way in the retinal image. Some internal processes of organization must clearly be responsible, then, for producing a single, coherent percept. Exactly what these processes are remains poorly understood despite the roughly 100 years since the Gestalt psychologists first articulated the principles of perceptual organization. Although the Gestalt work on perceptual organization has been widely accepted as identifying crucial phenomena of perception, there has been, until the last decade or so, relatively little theoretical and empirical emphasis on perceptual organization with a few exceptions. And, to the extent that progress has been made, there still remain many open questions. In this chapter, we explore some of these open issues in light of data we have obtained through a series of neuropsychological investigations with individuals who are impaired in perceptual organization following brain damage, hence the title of this chapter.

PERCEPTUAL ORGANIZATION: MONOLITHIC ENTITY?

A traditional view of most, although not all, theories of visual perception is that perceptual organization is a unitary phenomenon that operates at a single, early, preattentive stage, in a bottom-up fashion, to create units that then serve as candidate objects for later and more elaborated processing, including object recognition and identification (Marr, 1982; Neisser, 1967; Treisman, 1982, 1983). Implicit in this view is the idea that perceptual organization processes are not really differentiable in their attentional demands, time course, and relative contribution to object recognition. Several recent studies, however, challenged this view from a variety of perspectives. First, some researchers argued that grouping does not occur as early as had been widely assumed (Palmer, Neff, & Beck, 1996; Palmer, this volume; Rock & Brosgole, 1964; Rock, Nijhawan, Plamer, & Tudor, 1992). Second, in contrast to the standard view that assumes that grouping occurs preattentively (e.g., Neisser, 1967; Treisman, 1982, 1983), recent studies showed that grouping does, in fact, require attention (Mack, Tang, Tuma, Kahn, & Rock, 1992), though other recent studies suggest that certain forms of grouping can occur under conditions of inattention (Driver, Davis, Russell, Turatto, & Freeman, 2001; Moore & Egeth, 1997; Kimchi & Razpurker-Apfeld, 2001). Finally, the monolithic quality of grouping has been challenged, too; several studies demonstrated a temporal difference between various grouping processes showing, for example, an earlier of impact of grouping by proximity than by similarity of shape (Ben-Av & Sagi, 1995; Han & Humphreys, 1999; Han, Humphreys, & Chen, 1999; Kurylo, 1997).

Consistent with this last idea that there may be multiple processes involved in perceptual organization, two forms of grouping have been identified: the process of unit formation that determines which elements belong together or what goes with what and the process of shape formation or configuring that determines the shape of the grouped elements based on the interrelationships of the elements (Koffka, 1935; Rock, 1986). This distinction between grouping and configuring will turn out to be critical in understanding the neuropsychological data and the differential contribution of configuring in relation to object recognition. In particular, we show that the product of grouping (in the sense of element clustering) as reflected in grouping elements into rows and columns may be preserved following brain damage but that configuring the elements and apprehending the interrelationships of the grouped elements may be affected and have adverse consequences for the ability to recognize objects.

Along with presenting data to support the distinction between unit formation and configuring, we suggest that these processes are likely supported by different neural mechanisms. Although the lesions documented after brain damage in humans are notoriously poor for the purpose of establishing brain-behavior relationships and localizing very fine-grained processes, neuropsychological studies, in tandem with data from neuroimaging and neurophysiology, can provide important clues to the neural substrate involved in perceptual organization. We discuss these issues after the behavioral data are presented.

VISUAL AGNOSIA

To explore the psychological and neural mechanisms underlying perceptual organization, we conducted a series of studies with two individuals whose unfortunate impairment provides us with an ideal testing ground for investigating processes involved in perceptual organization and their relationship to object perception. The patients, SM and RN, suffer from a neuropsychological impairment, referred to as visual object agnosia, in which they are unable to recognize even familiar common objects presented to them in the visual modality (see Fig. 10.1 for examples of their error responses). This object recognition deficit cannot be attributed to a problem in labeling the stimulus per se (anomia) nor to a loss of semantics; presented with the same object in a different sensory modality, either haptically or auditorily, they have no problem in naming it or providing detailed and rich descriptions of it. The deficit in visual agnosia, then, is a specific failure to access the meaning of objects from the visual modality (Farah, 1990; Humphreys & Riddoch, 2001; Ratcliff & Newcombe, 1982).

The patients we chose to study have a specific form of agnosia, in which the deficit apparently affects intermediate vision. The impairment has been referred to as integrative agnosia because the patients appear to have available to them the basic features or elements in a display but are then unable to integrate all aspects into a meaningful whole. For example, patient HJA performs well on a search task when identifying a target that does not require a combination of elements (for example, differentiating '/' from '|') but performs poorly when required to bind visual elements in a spatially parallel fashion across a field containing multiple stimuli, such as searching for an upright *T* among misoriented *T*s (Humphreys, 1999; Humphreys & Riddoch, 1987; Humphreys, Riddoch, Quinlan, Price, & Donnelly, 1992).

The failure of these patients to integrate elements occurs equally with displays of two- and three-dimensional stimuli and with black-and-white and chromatic displays, although, in some cases, the presence of depth, color and surface cues may be of some assistance to the patients in segmenting the display (Chainay & Humphreys, 2001; Farah, 1990; Humphreys et al., 1994; Jankowiak, Kinsbourne, Shalev, & Bachman, 1992). These patients are also more impaired at identifying items that overlap one another compared with the same items presented in isolation. Interestingly and counterintuitively, in some patients, the presence of

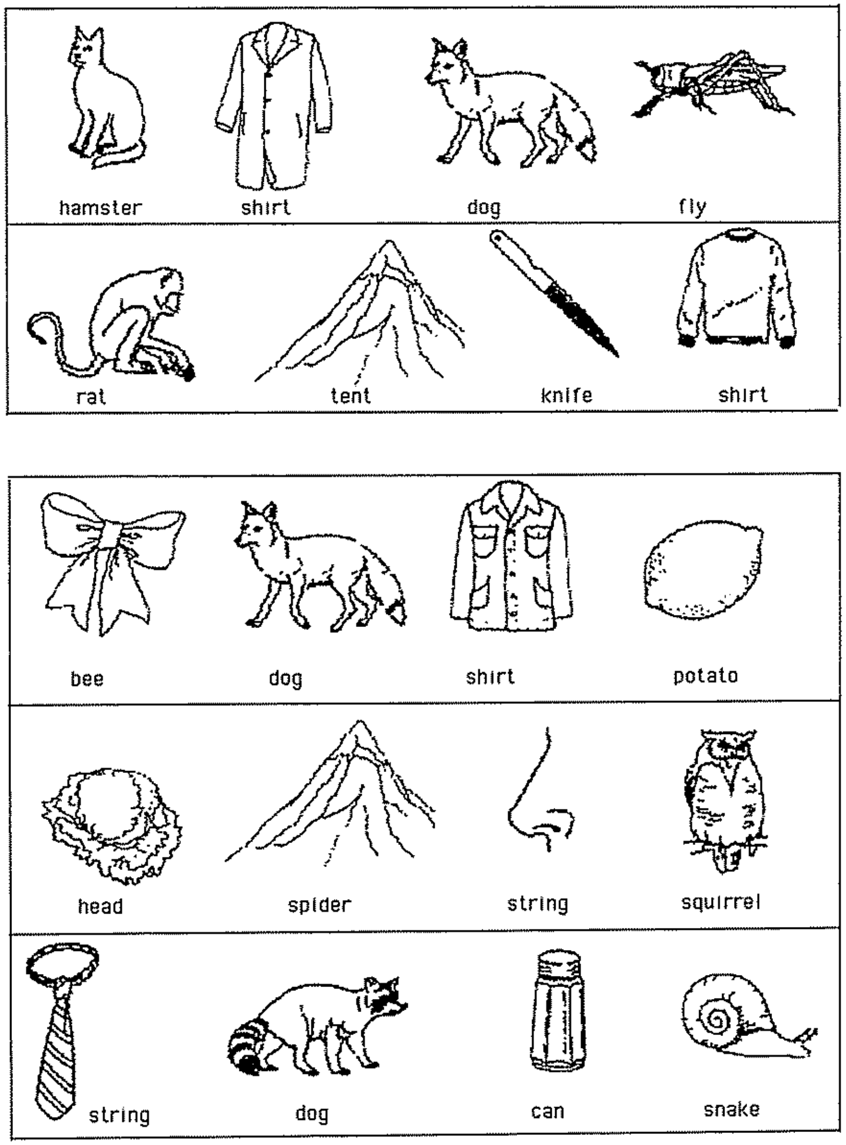

FIG. 10.1. Examples of black-and-white line drawings (from the Boston Naming test) and the responses of the patients to these pictures.

local information may even reduce the efficiency of visual recognition; in contras with normal perceivers, some integrative agnosic patients (Butter & Trobe, 1994 Humphreys et al., 1992; Lawson & Humphreys, 1999; Riddoch & Humphreys 1987) identified silhouettes better than line drawings whose internal details apparently led to incorrect segmentation. The silhouette advantage is thought to arise from the reduced need to segment and integrate elemental features relative to the line drawings. Another key feature of the disorder is the failure to carry out figure-ground segregation; patient FGP, for example, cannot even determine the presence of a *X* when it is superimposed on a noisy background (Kartsounis & Warrington, 1991). Finally, and critically for our purposes, these agnosic patients seem to be impaired at grouping; for example, patient NM was impaired at detecting the presence of a target letter when it was defined by multiple oriented line segments in a display with distractors of different orientations (Ricci, Vaishnavi, & Chatterjee, 1999). The same was true when the target was defined by color, luminance, or motion features relative to the distractors (Marstrand, Gerlach, Udesen, & Gade, 2000). Note that when the demands for element integration are low, as in making same/different judgments about two stimuli that share area and brightness but not shape (aspect ratio is manipulated from square to rectangle; Efron, 1968), the patients performed well.

Case Histories

Our two patients, SM and RN, are male, right-handed and English speaking. Both have been diagnosed as having visual agnosia and participated in several previous studies (Behrmann, 2003; Behrmann & Kimchi, 2003; Gauthier, Behrmann, & Tarr, 1999; Marotta, Behrmann, & Genovese, 2001; Williams & Behrmann, 2002). Neither patient has a field defect. SM has visual acuity corrected to 20/20, and RN has normal acuity.

SM sustained a closed head injury in a motor vehicle accident in 1994 at the age of 18. Despite extensive injuries, he recovered extremely well, and the only residual deficit is the visual agnosia. Fig. 10.2 presents MRI images for SM demonstrating the site and extent of his inferior temporal lobe lesion (Marotta et al., 2001). Note that, although SM is right-handed, he has some weakness on the right side because his arm was badly damaged in the accident, so he uses his left hand intermittently. RN suffered a myocardial infarction during bypass surgery in 1998 at the age of 39. He does not have a focal lesion on his MRI scan; the absence of a circumscribed lesion from a patient who has sustained brain damage following a myocardial infarction is not uncommon.[1] Because the neuropil is generally preserved after such an incident, even if the neurons themselves are affected, a circumscribed lesion may not be detectable even with high-resolution imaging.[2]

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[1] We thank Dr H. B. Coslett for discussing RN's neurological status with us.

[2] We attempted a functional imaging scan on RN, but he is too large to remain in the scanner for any length of time, so these data could not be obtained.

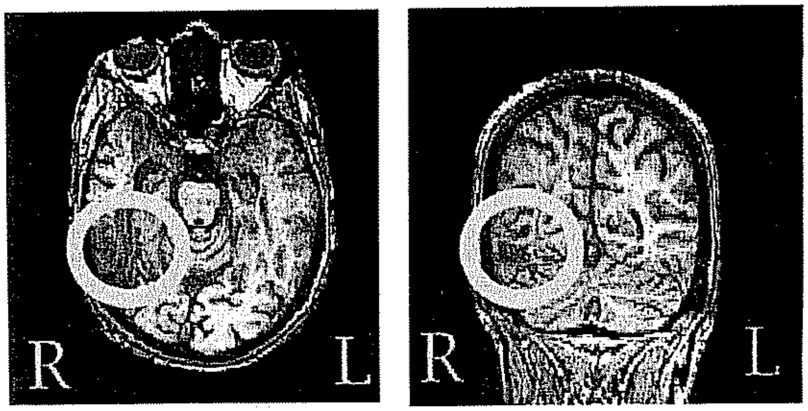

FIG. 10.2. Structural scan from SM showing the localization of the lesion to the right inferior temporal lobe. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi. 2003. *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

Both patients performed normally on those subtests of the Birmingham Object Recognition Battery (BORB; Riddoch & Humphreys, 1993) that tap low-level or early visual processes, including judging line length, orientation, size, and gap position. That both patients can derive considerable visual information is further supported by their copying performance; both patients produce reasonably good copies of a target object or a scene (see Fig. 10.3 and 10.4), although they do so slowly relative to normal subjects and in a labored and segmental fashion. Both patients also performed within normal limits on more complex visual tasks, such as matching objects based on minimal features or when one object was foreshortened. Importantly, however, both patients were impaired on the BORB subtests, which evaluate discrimination of overlapping shapes, and both performed in the impaired range on the object decision subtests (task: "is this a real object or not?"), as is usually the case with patients with integrative agnosia. In contrast with some integrative agnosic subjects, neither SM nor RN performed better with silhouettes than with line drawings. Examples of stimuli from these various perception tests are shown in Fig. 10.5.

Both patients performed normally in naming objects presented to them in the haptic modality, while blindfolded, or in the auditory modality, including naming the very objects they failed to recognize when presented visually. The preserved naming performance and ability to define the objects rule out both an anomia and a semantic deficit as the underlying cause of the agnosia. The patients also did not have available to them information about the display that they could indicate

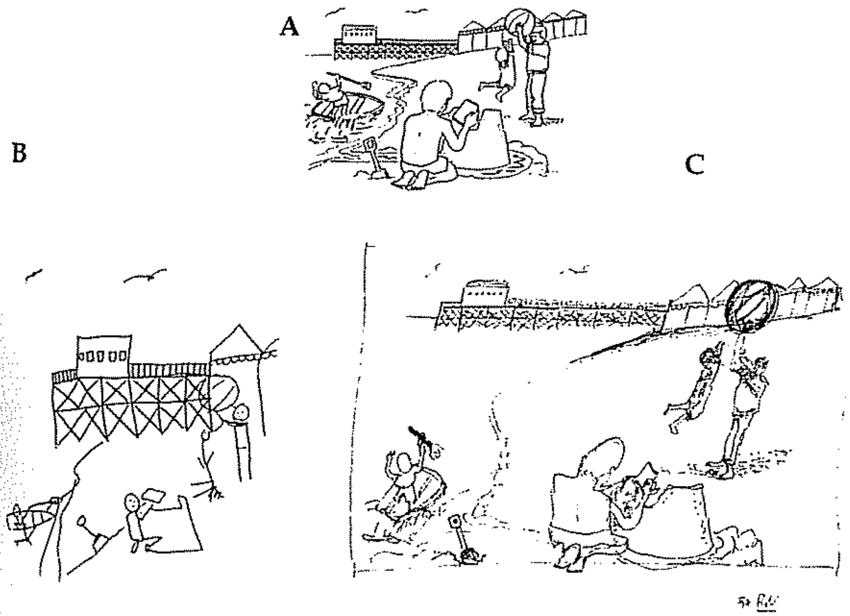

FIG. 10.3. Display of a beach scene with the (A) original and copies by (B) SM and (C) RN, who both took an extraordinary amount of time to complete this. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi. 2003. *Journal of Experimental Psychology: Human Perception and Performance. 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

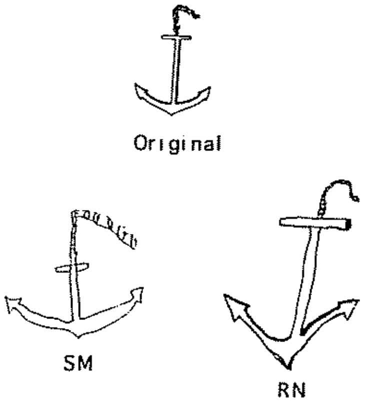

FIG. 10.4. Display of individual object (anchor) with the original and copies by SM and RN.

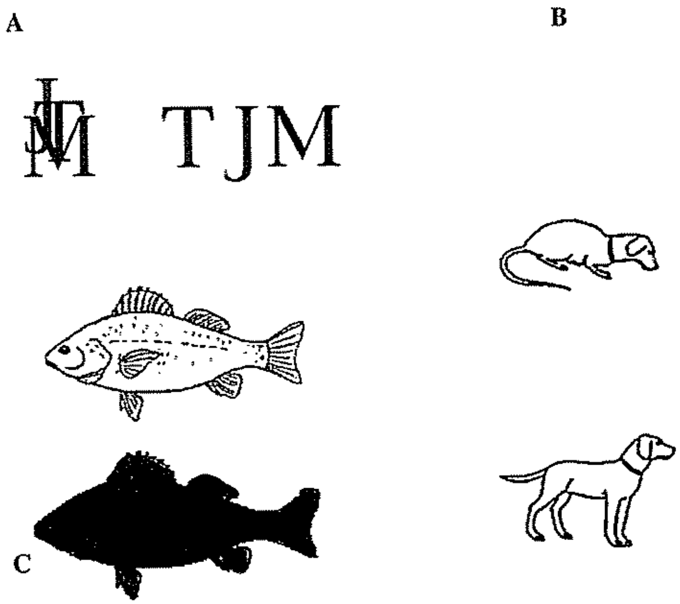

FIG. 10.5. Examples of (A) overlapping and individual letters, (B) line drawings for object decision and (C) silhouettes for object identification. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

through another output modality, such as gesture, as is the case in subjects with optic aphasia. The deficit for SM and RN is clearly in the inability to recognize images presented in the visual modality.

Both patients read accurately but slowly as tested in a naming latency task with words of different lengths presented individually on the computer screen. Whereas normal readers show minimal, if any, effect of the number of letters on word recognition within this range (three to eight letters in length), the subjects both showed raised intercepts as well as slopes, relative to control subjects. Whereas SM read 117/120 words correctly, with a slope of 104 ms for each additional letter, RN read 95/120 words correctly with a slope of 241 ms for each additional letter. In addition to the object and word agnosia, both patients are impaired at recognizing faces (i.e., suffer from prosopagnosia), and their face recognition deficit has also been explored in some of the previous publications (Gauthier et al., 1999; Marotta, McKeeff, & Behrmann, 2002).

Object Recognition Abilities

To document the object recognition deficits of the patients and compare this problem across the patients, we had them identify objects presented on a computer screen as black-and-white line drawings from the Snodgrass and Vanderwart (1980) set. Each object appeared individually for an unlimited exposure duration and the reaction time (RT) and accuracy were recorded. The patients differed in their ability: SM identified a total of 66% (171/260) of the objects, whereas RN identified only 51% (132/160). The errors made by the patients are mostly visual confusions (see Fig. 10.1). Neither subject appeared to be exhibiting a speed-accuracy trade-off because SM required an average of 2.14 s per image, whereas RN averaged 8.52 ms per image, confirming the greater impairment in RN than SM. We previously obtained naming data on the same stimulus set from a group of normal control subjects with no history of neurological illness whose mean accuracy was 96.4% and mean reaction time was 884.67 ms (Behrmann, Nelson, & Sekuler, 1998). Both patients showed accuracy and RTs more than 3 *SD* from the mean of these normal subjects.

As expected given their diagnosis of visual agnosia, both patients are impaired at object recognition as reflected in their accuracy and response times. Their long reaction times for correct identifications suggest that they build up their object representations slowly and in a segmental fashion. We also note that RN is significantly impaired relative to SM in both accuracy and RT, a finding that becomes important later.

DERIVATION OF GLOBAL SHAPE

Global/Local Processing in Hierarchical Stimuli

One obvious reason why integrative agnosic patients might fail to recognize objects is that they cannot derive the global form or shape because they fail to group or integrate the elements. We explored this possibility using the now-standard stimulus, the Navon-type hierarchical display, in which a global letter is made up of local letters having either the same or different identity as the global letter (see Fig. 10.6A). Half the trials consist of consistent letters, in which the global and the local letters shared identity (a large *H* made of smaller *H*s and a large *S* made of small *S*s), and the other half consist of inconsistent letters, in which the letters at the two levels had different identities (a large *H* made of small *S*s and a large *S* made of small *H*s). This type of paradigm has been used to tap grouping and element integration (Enns & Kingstone, 1995; Han & Humphreys, 1999; Han et al., 1999). In the version of the task we used, a stimulus appears on the computer screen, and, in different blocks of trials, subjects identify the letter at either the global or local level. All else being equal, in normal individuals, the global letter is identified

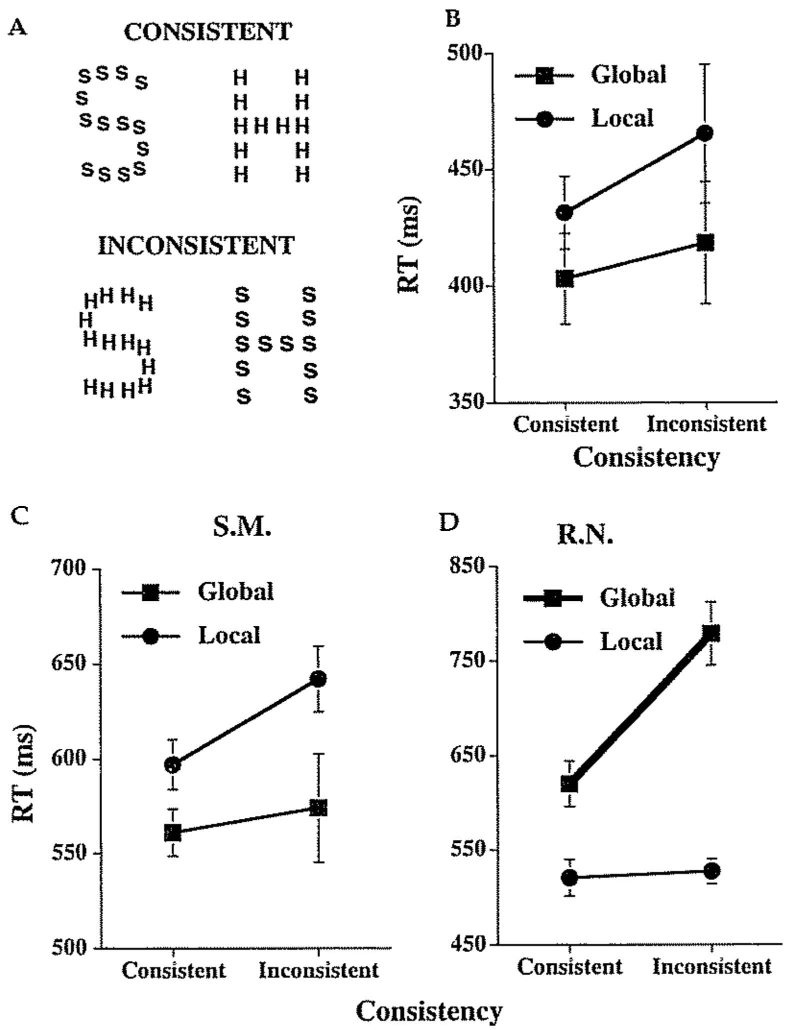

FIG. 10.6. (A) Hierarchical stimuli, made of two letters, *H* and *S*, which are composed of *H*s or *S*s. Mean millisecond responses times for (B) control subjects, (C) SM and (D) RN to indicate letter identify as a function of consistency between the local and global levels. Note the difference in the *y*-axis across the three graphs. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

faster than the local letter, and conflicting information between the global and the local levels exerts asymmetrical global-to-local interference (Navon, 1977). Although the mechanisms underlying this global advantage are still disputed, the phenomenon is robust and is observed under various exposure durations, including short ones (Navon, 1977; Paquet & Merikle, 1984; Yovel, Yovel, & Levy, 2001; see Kimchi, 1992, for a review), suggesting that normal subjects can easily and quickly perceive the global configuration of hierarchical patterns. If the patients are impaired at grouping the local letters, they would have problems deriving the global configuration and would therefore be slowed in detecting the global letter. Additionally, if their processing is driven mostly by the local elements, then we might observe interference from the local identity when subjects identify the global, inconsistent letter.

Along with the patients, we tested a group of nonneurological control subjects, all of whom had corrected-to-normal visual acuity by self-report and, with the exception of one, were right-handed. The normal participants completed 192 experimental trials, whereas the patients completed 384 experimental trials across two sessions. Before each block, participants were verbally instructed to respond to the global or local letters. Each trial was initiated with a central fixation cross of 500 ms duration. This was immediately replaced by one of the four possible stimuli, which remained on the screen until a response was made. Participants were instructed to press the right key on the button box to indicate a response of *S* or the left key for it H. The order of the blocks and response designation was counterbalanced across subjects. Mean correct RTs for the global and local identification are presented in Fig. 10.6 as a function of stimulus consistency, for the normal participants (Panel B) and for each of the patients (Panel C and D).

The normal subjects were extremely accurate in identifying the letters, reporting 96.3% correctly and showed a small but significant global advantage of 15 ms. There was no difference between consistent and inconsistent items and no significant interaction between globality and consistency, although numerically it looks like there is some interference from the global identity onto the local identification. The absence of strong interference effects is not unusual given the unlimited exposure duration (Paquet & Merikle, 1984), foveal presentation (Pomerantz, 1983), and spatial certainty (Lamb & Robertson, 1988).

Both patients were also highly accurate, with SM and RN achieving 98.9% and 99.1% accuracy, respectively, but they differed markedly in their pattern of performance as reflected in their RT data. SM's pattern of performance was not that different from that of the normal participants: He showed a significant global advantage of 58 ms, and no consistency effect nor an interaction between globality and consistency, although, as in the normal subjects, there was a numeric trend for global-to-local interference.

RN exhibited a dramatically different pattern, consistent with the predictions we made: There was a clear local advantage, with local letters identified 174 ms faster than global letters. He was also 149 ms faster for consistent over inconsistent stimuli, but this consistency effect was qualified by an interaction with globality.

Although there was only a 7-ms difference between consistent and inconsistent trials in the local condition, there was a 159-ms slowing for the inconsistent over consistent trials in the global condition, reflecting strong local-to-global interference. Thus, although RN was accurate, his performance was very different from that of normal observers. Instead of exhibiting a global advantage, he exhibited a clear local advantage. That RN's performance was nevertheless accurate may suggest that eventually he can derive the global configuration but it is a very laborious and time-consuming process for him. Alternatively, RN may be unable to derive a coherent global configuration but can perform global discrimination on the basis of some local cues or some partial global information. This may be a rather slow process, but, given enough time, it can lead to accurate performance.[3] As we discuss later, further investigations of RN's performance seem to support the latter rather than the former account.

The findings from the global/local task reveal a major discrepancy in the performance of the two patients. SM performed qualitatively similarly to normal participants: Responses were faster with global than local stimuli, and there was a trend toward global-to-local interference. RN, on the other hand, was faster with local than global letters and showed strong interference from the local letter onto global identification when there was inconsistency between the two.

A finer analysis of the data revealed another interesting difference between SM and RN. When making global identifications, both patients responded faster to *H* than to *S*. However, SM responded to the global *H* made of *H*s (537 ms) as fast as to the global *H* made of *S*s (544 ms). RN, on the other hand, was 133 ms faster in responding to the global *H* made of *H*s (605 ms) than to the global *H* made of *S*s (738 ms), and, furthermore, the former was the only case in which his global identification was nearly as fast as his local identification of *H* (565 ms).

Presumably, the discrepancy between the patients in their ability to apprehend normally the global configuration of patterns composed of elements reflects different types of deficits in perceptual organization or perhaps different levels of deficits. Assuming that the local elements of the hierarchical letters are grouped by proximity, or similarity, or both (the elements are identical and close to one another), RN seems unable to use these grouping principles to derive the global configuration; he can derive some global structure only when collinearity between elements is present (as in the case of *H* made of *H*s). SM, on the other hand appears able to derive a global configuration even when simple collinearity is not present in the image. We pursue this issue further in later experiments.

A similar discrepancy between global/local performance exists between two other patients in the literature. HJA, perhaps the most extensively studied patient with integrative agnosia, showed an advantage for global over local identification and showed no interference of any kind (Humphreys, 1999; Humphreys & Riddoch, 2001). In contrast, NM, who is also a very good example of an integrative agnosic patient, was almost unable to identify the global letter even at unlimited exposure duration (Ricci et al., 1999) and favored reporting the local components.

The variability observed across patients on this task suggests that a problem in deriving the global structure of hierarchical stimulus might not be a core element of integrative agnosia. This conclusion might be premature, however. It is now well-known that a variety of stimulus and task factors affect the balance between global and local processing, including the type of hierarchical stimuli used, the attentional task (divided or focused), and the mode of response (forced choice, go-no-go; Kimchi, 1992; Yovel et al., 2001). Thus, the variability in the pattern of results obtained across patients might be a function of the different testing conditions used with different patients. Alternatively, because perceptual organization refers to a multiplicity of processes, it is possible that patients do vary and that integrative agnosia might manifest in different ways across different individuals. Here, the testing conditions were the same for the two patients, and the stimuli used were favorable for perceiving the global configuration because they were made of many small elements, which increase the salience of the global over the local letters (e.g., Yovel et al., 2001). Under these conditions and with unlimited exposure duration, SM was able to derive the global configuration, but RN was not. As we show later, under more stringent testing conditions, even SM exhibits an impairment in global processing. These findings further support the claim that differences in testing conditions may lead to variability in outcome, but they also suggest that integrative agnosia might manifest in different ways across different individuals. Because such individuals are rare, the opportunity to systematically analyze all their perceptual skills in depth is not that easy, so the source of this cross-patient variability remains to be definitively determined.

Hierarchical Processing and Spatial Frequency Analysis

Before we describe the patients' abilities to derive global form in further detail, we need to explore an alternative interpretation for the findings we obtained, and this concerns the relationship between spatial frequency analysis and global/local processing. Several researchers suggested an involvement of spatial filters, based on spatial frequency channels, operating at early visual processing (Ginsburg, 1986) in the perception of global and local structures. For example, in a number of these studies, no latency advantage for global over local processing was found when low spatial frequencies were removed from hierarchical stimuli (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Hughes, Fendrich, & Reuter-Lorenz, 1990; Lamb & Yund, 1993; Shulman, Sullivan, Gish, & Sakoda, 1986; Shulman & Wilson, 1987), suggesting that the global advantage effect is mediated by low spatial frequency channels. Thus, one possible explanation for the patients' differential inability to perceive the global form of a hierarchical stimulus might concern a fundamental

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[3] This is why accuracy measures alone are coarse and do not reveal the whole story: There are many different ways in which one can achieve high accuracy.

limitation in processing low spatial frequency information. The obvious prediction from this in relation to the patients is that RN, who appears to process stimuli almost entirely at the local level, should be impaired at processing low-frequency displays, resulting in an increased low spatial frequency threshold, relative to control subjects, whereas SM, who shows some global form processing, should not show as much of an increase in this threshold.

To document the spatial frequency thresholds for the patients and controls, we established, for each individual, the log contrast thresholds at 1, 3, 5, 10, and 30 cycles per image (cpi) using Matlab. In each trial, a fixation point appeared on the screen for 1 s. After 200 ms, an image appeared for 200 ms, and this was replaced by a blank screen for an additional 200 ms (see Fig. 10.7A for example of images). A second image then appeared for 200 ms, and it, in turn, was replaced by a blank screen for 200 ms. At this point, the subject was required to decide whether the first or second image contained the grating. If the response was correct, a more difficult discrimination (decreased contrast by 0.2) was presented on the next trial. If the response was incorrect, the contrast was increased by 0.2. Feedback was provided after each trial, and subjects received practice trials at the beginning. A log contrast threshold was determined for each cpi using method of limits. In this particular Matlab function, threshold is defined as the value of contrast that makes the subject respond at 82% correct, and this is the value plotted for each subject in Fig. 10.7B for each cpi.

As is evident from Fig. 10.7B, neither patient showed any difficulty in detecting either low-or-high frequency gratings, performing well within the normal boundaries. There is also no obvious correlation between the patients' performance on the spatial frequency measure and the ability to perceive the local or global form of the stimulus. Both patients performed close to the control mean for the higher frequency displays. SM, who was able to perceive the global configuration and showed a global advantage with the Navon-type figures, showed the slightly poorer low-frequency threshold than the controls and than RN, whereas this should be the other way around to account for the hierarchical data. Also, RN, who processed the hierarchical stimuli locally, has thresholds for the low spatial frequency that are as good as the best control subject, and, therefore, this cannot account for his failure to perceive the global configuration.

Having ruled out the possibility that the discrepancy between the two patients in their perception of the hierarchical stimuli is due to differential limitations in analyzing spatial frequency information, we now examine more closely their performance on other tasks of perceptual organization.

Microgenetic Analysis of the Perceptual Organization of Hierarchical Stimuli

To explore in further detail the patients' abilities to group local elements, we focused more specifically on grouping processes and examined the time course of

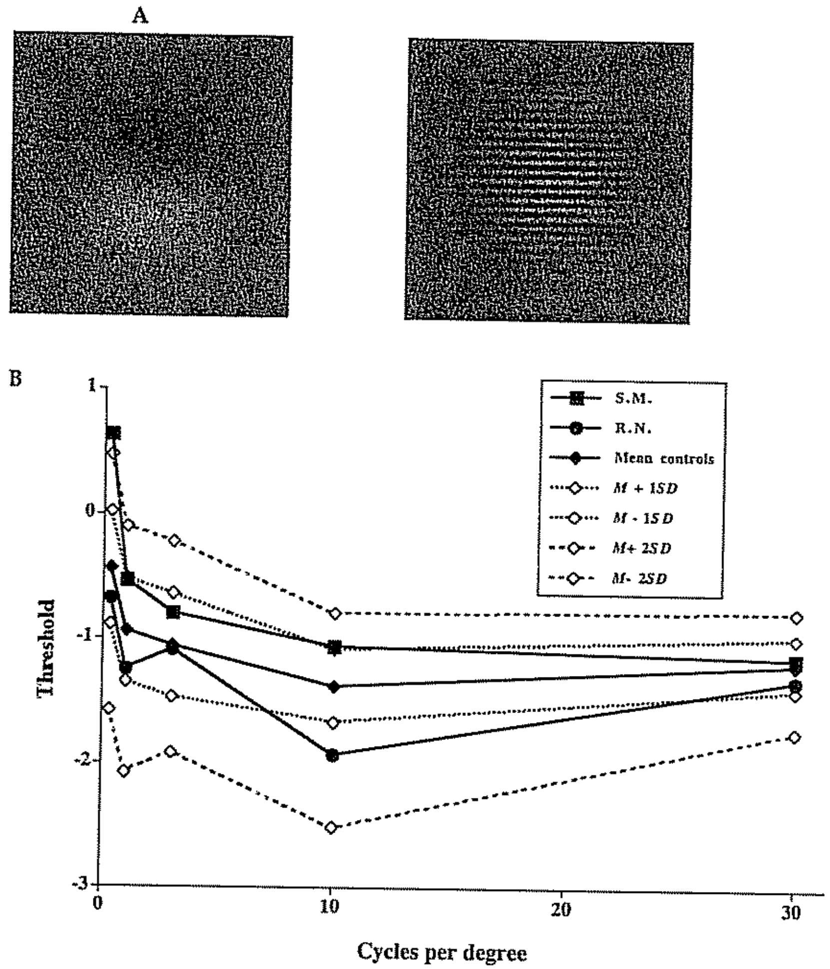

FIG. 10.7. (A) Examples of displays of 1 and 30 cycles per inch used for establishing spatial frequency thresholds. (B) Log contrast thresholds as a function of cycles per image, including the mean for normal participants (and 1 and 2 *SD*) and for SM and RN. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

the perceptual organization of hierarchical stimuli. This approach, often referred to as a microgenetic approach, involves examining the evolution of the percept rather than just the final outcome of the organizational processes. To conduct this analysis, we adopted the primed matching paradigm, which has been used successfully for this purpose (Kimchi, 1998, 2000, this volume). The basic procedure (Beller, 1971) is as follows: Participants view a priming stimulus followed immediately by a pair of test figures, and they must judge, as rapidly and accurately as possible, whether the two test figures are the same or different. The speed of same responses to the test figures depends on the representational similarity between the prime and the test figures: Responses are faster when the test figures are similar to the prime than when they are dissimilar to it. By constructing test figures that are similar to different hypothesized representations of the prime and varying the prime duration, we can tap earlier and later internal representations (Kimchi, 1998, 2000; Sekuler & Palmer, 1992). Thus we can assess implicitly the participants' perceptual representations and the time course of their organization.

The priming stimuli were hierarchical patterns (global diamonds made up of circles) of two types: a few-element pattern and a many-element pattern. The few-element prime was a diamond made of four relatively large circles, and the many-element prime was a diamond made of 16 relatively small circles. Each test stimulus consisted of two hierarchical patterns. There were two types of test pairs defined by the similarity relations between the test figures and the prime (see Fig. 10.8): the element-similarity (ES) test pairs, in which the test figures were similar to the prime in their local elements but differed in global configuration, and the configuration-similarity (CS) test pairs, in which the figures were similar to the prime in global configuration but differed in local elements. Priming effects of the configuration would manifest in faster correct same RTs for the CS than for the ES test pairs, whereas priming effects of the elements would manifest in faster same RTs for the ES than for the CS test pairs.

Each trial was initiated with a central fixation dot of 250-ms duration, followed by a priming stimulus. The presentation time for the prime was equally and randomly distributed among 40, 90, 190, 390, and 690 ms. Immediately after the presentation of the prime, the test display appeared and stayed on until the participant responded. The test display contained two figures presented on either side of the location previously occupied by the prime. At this point, participants had to decide whether the two figures were the same or different and to respond as accurately and quickly as possible using the response keys. All the combinations of the factors of prime duration, test type, and response were randomized within block with each combination occurring on an equal number of trials. Two sessions were administered, each on a separate day a few weeks apart, with two blocks (one of few-element and one of many-element patterns) in each session. Altogether each patient completed 640 trials. Sixteen practice trials were completed for each of the few- and many-element patterns before the experimental trials.

Mean correct same RTs for prime-test similarity (ES, CS) are plotted in Fig. 10.9 as a function of prime duration for each prime type (few-element and many-element patterns) for SM and RN (Panels B and C, respectively), and the normal data (from Kimchi, 1998) are in Panel A. Like the control subjects, both SM and RN performed well on this task, making very few errors (normal participants: 4.1%; SM 4%; RN 1%), and we do not examine the error data further.

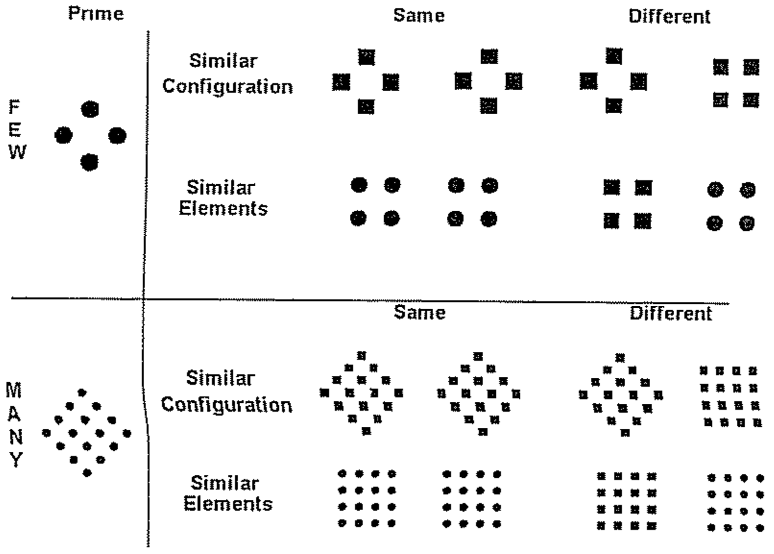

FIG. 10.8. Primed match paradigm: primes, consisting of few and many elements, are followed after varying stimulus onset asynchrony (SOAs) by test pairs which require same or different responses and which are similar to the prime in elements or configuration. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi. 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

As can be seen in Fig. 10.9A, few- and many-element patterns produced different patterns of results for normal participants. For the few-element patterns, responses to ES test pairs were faster than responses to the CS test pairs at 40-, 90-, and 190-ms prime duration, and the difference diminished at the longer prime durations of 390 and 690 ms. For the many-element patterns, responses to CS test pairs were faster than responses to ES at the early durations of 40 and 90 ms. The pattern of RTs reversed at the intermediate durations of 190 and 390 ms: ES produced faster responses than CS test pairs, and at 690 ms both element and configuration were available for priming with a tendency for faster RTs to CS test pairs. These results have been interpreted as suggesting that, for normal participants, the elements of the few-element patterns are represented initially, and the global configuration is then consolidated with time. In contrast, in the

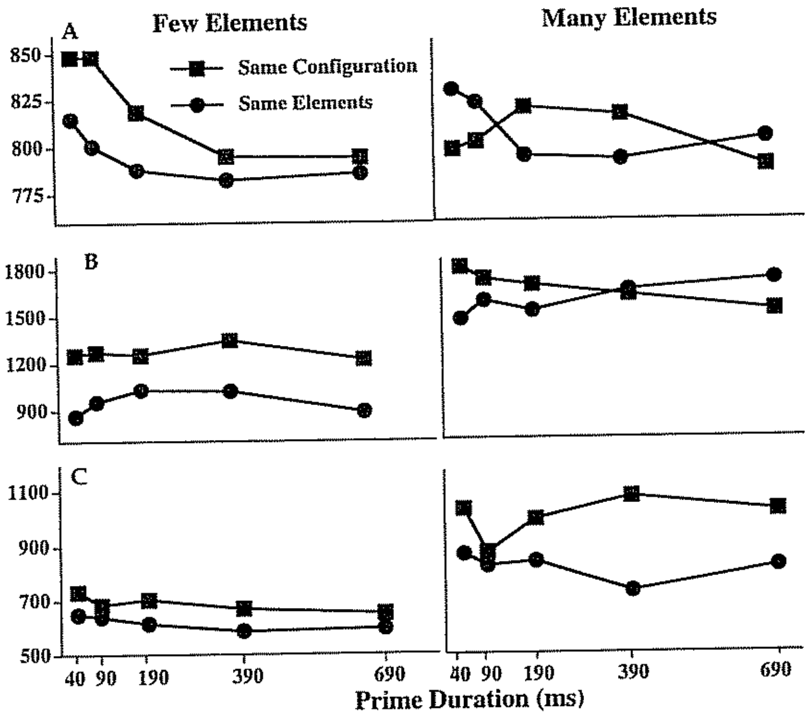

FIG. 10.9. (A) Mean of median correct same RTs for (A) the normal participants for few and many elements displays as a function of prime duration for the two prime-similarity conditions (element similarity, ES, and configuration similarity, CS) and mean responses for (B) SM and (C) RN under the same conditions. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

many-element patterns, there is early representation of the configuration (as in the forest before the trees; Navon, 1977), the elements then become individuated, and finally both the configuration and elements are represented and accessible (Kimchi, 1998, this volume).

For the few-element patterns, in contrast with the normal participants who seemed to derive the global configuration over time, neither SM nor RN appeared to be able to derive a global configuration, even at the longest exposure duration of 690 ms. Both patients showed faster RTs to the ES test pairs, and there was no effect of prime duration on this element advantage. Previous research suggested that for patterns composed of few, relatively large elements, the local elements are perceived by normal individuals as figural parts of the overall form (Goldmeier, 1936/1972; Kimchi & Palmer, 1982), and the local elements and the global form are perceptually integral (Kimchi, 1988; Kimchi & Palmer, 1985). The two patients, however, seem unable to integrate the local elements into a global entity, so they fail to perceive the local elements as figural parts of an overall form and, rather, perceive them as discrete, unrelated entities.

For the many-element patterns, again in contrast with the normal participants, neither patient exhibited an early advantage for the configuration. Rather, RN showed an advantage for the ES test pairs as early as 40 ms, and this element advantage remained fairly unchanged over the entire time course so that the global configuration was not available to him even at the longest duration of 690 ms. SM also did not show any early advantage for the CS test pairs either, although he eventually showed a tendency for faster RT for CS than ES test pairs at the longest duration of 690 ms.

In addition to the differences between the patients and the normal participants, there are also some differences between RN and SM. First, the difference in RTs for many- and few-element patterns was larger for RN (510 ms) than for SM (256 ms), reflecting the greater difficulty in processing the many-element patterns for RN than for SM.[4] Second, for RN, the ES advantage for the many-element patterns was larger than for few-element patterns, whereas the opposite was true for SM. Third, whereas no effect whatsoever of prime duration on prime-test similarity was observed for RN, a tendency for a reversal in the relative advantage of ES and CS was observed for SM at the longest duration for the many-element patterns.

Taken together, these differences between the patients suggest that in the case of SM, although there is no evidence for the early rapid grouping of many elements that characterizes normal perception, grouping processes do operate with many elements. Eventually these grouping processes can lead to the perception of the global configuration. This finding is consistent with his performance on the Navon-type figures, in which, with unlimited exposure duration, SM showed a global advantage, similar to normal participants. RN, on the other hand, seems unable to group the elements into a global configuration even when conditions and time favor grouping, and this, too, is consistent with his performance on the Navon-type figures.

Microgenetic Analysis of Line Configurations

Thus far, both patients are clearly impaired at grouping multiple elements (presumably by proximity and by similarity) into a global configuration, and RN seems to be more impaired at this than SM. Interestingly, the only instance in which RN

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[4] We have to be somewhat cautious about this statement in light of the fact that RN's RTs to the few-element patterns were rather short (almost shorter than those of the normal participants).

showed some indication of forming a global configuration was with the *H* made of *H*s in the Navon-type figures, in which collinearity between the local elements can be exploited. We examined further the patients' ability to group line segments into a configuration by collinearity and also by closure. Previous research demonstrated the perceptual dominance of configuration even for disconnected line segments (Kimchi, 1994; Pomerantz & Pristach, 1989; Rensink & Enns, 1995), suggesting that disconnected line segments are grouped into a configuration and that this grouping occurs early and rapidly (Kimchi, 2000; Rensink & Enns, 1995) and possibly even independently of the number of elements (Donnelly, Humphreys, & Riddoch, 1991). We again adopted a microgenetic approach using line segments and compared the performance of the patients to that of normal individuals (Kimchi, 2000, Experiment 1).

The priming stimuli used in this experiment (see Fig. 10.10) were line configurations (a diamond and a cross)[5] that varied in the connectedness of the line components (no gap, small gap, and large gap) and were presented at various exposure durations. We assumed that the line segments of the cross were likely to be grouped by collinearity, whereas the line segments of the diamond were more likely to be grouped by closure. The relatability theory (Kellman & Shipley, 1991; Shipley & Kellman, 1992), which formalizes the Gestalt principle of good continuation, suggests that the visual system connects two noncontiguous edges that are relatable so that the likelihood of seeing a completed figure increases systematically with the size of the angle that must be interpolated, with the 50% threshold occurring at around 90°. According to this criterion, the cross-configuration is characterized by high relatability (an angle of 180°—collinearity) and the diamond configuration by low relatability (an angle of 90°). The diamond configuration, however, possesses closure, whereas the cross does not.

In the experiment, there were two types of same-response test pairs defined by the similarity relation between the test figures and the prime. The figures in the configuration-similarity test pair were similar to the prime in both configuration and line components, whereas the figures in the component-similarity test pair were similar to the prime in lines but dissimilar in configuration. For this set of stimuli, we assumed priming effects of the configuration would manifest in faster correct same RTs for the configuration-similarity than for the component-similarity test pairs. No difference in RT between the two types of test pairs was expected due to component priming because both types of test pairs are similar to the prime in line components.

The sequence of events in each trial was the same as in the experiment (described previously), except that the prime was presented for one of only four durations: 40,

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[5] In addition to the diamond and cross prime, Kimchi (2000, Experiment 1) used a random array of dots for which prime-test similarity was considered neutral and served as a baseline condition. To simplify the experiment for the patients, we omitted the neutral prime because the performance of the normal participants serves as the control for the patients.

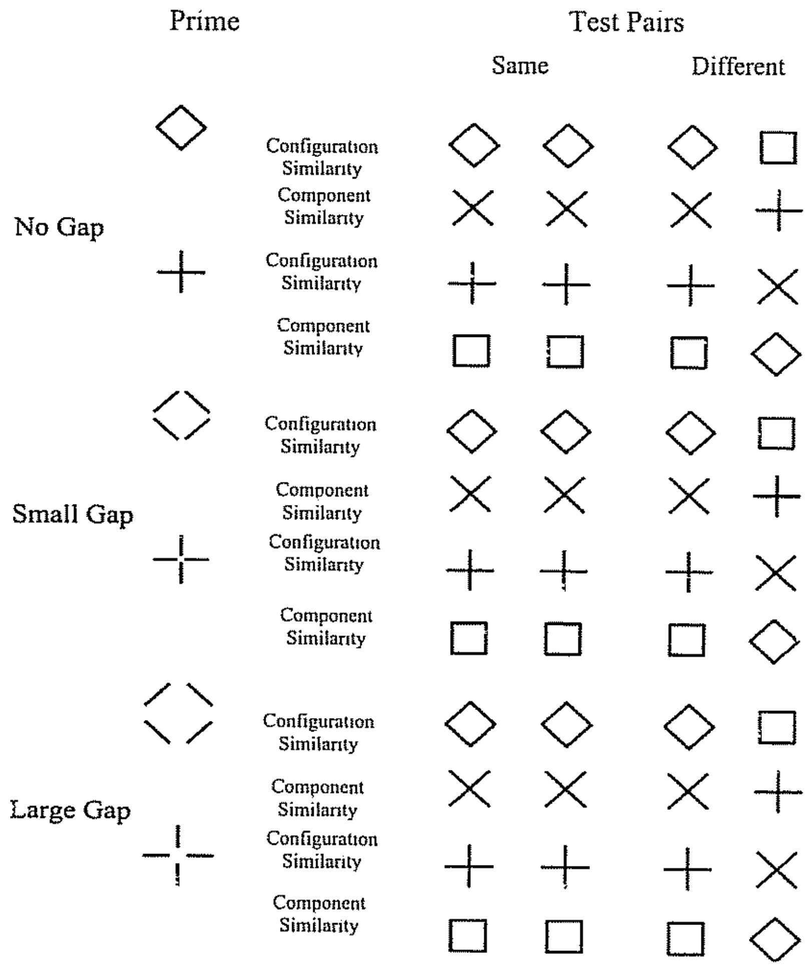

FIG. 10.10. The priming stimuli and the same- and different-response pairs used in the (a) no-gap condition, (b) small-gap condition, and (c) large-gap condition. When the prime is a diamond made of four oblique lines and the test pair is two outline diamonds, prime-test similarity is configuration similarity; when the test pair is two *X*s, prime-test similarity is component similarity. When the prime is a cross, made of two vertical and two horizontal lines, and the test pair is two outline crosses, prime-test similarity is configuration similarity and when the test pair is two outline squares, prime-test similarity is component similarity. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

90, 190, or 390 ms. The three different gap conditions were manipulated between blocks (between subjects for the normal subjects). All combinations of the factors of prime type, prime duration, test type, and response were randomized within block, with each combination occurring on an equal number of trials. For each gap condition, there were six blocks of 160 experimental trials each, preceded by a block of 15 practice trials.

Like the normal participants, SN and RN made very few errors on this task (errors: normal participants 1.4%; SM 0.2%; RN 0.7%). In light of the small number of errors, no further analysis is undertaken, and we turn to the RT data. Mean correct same RTs for each prime-test similarity relation (component similarity, configuration similarity) are plotted in Fig. 10.11 as a function of prime duration for each gap condition for the two prime types (diamond and cross) for SM and RN (Panels B and C, respectively). The results for the normal subjects are used as the benchmark against which to evaluate the patient data and are plotted in Fig. 10.11 (Panel A). Analyses of the correct same RTs for the normal participants (Kimchi, 2000, Experiment 1) showed that prime type (diamond or cross) did not interact significantly with priming effects, prime duration, and gap condition, and, therefore, the data for the normal participants are collapsed across prime type.

For the normal participants, configuration similarity produced faster RTs than component similarity as early as 40 ms for the no gap and the small gap conditions, and there was no effect of prime duration on this configuration advantage. No significant difference between configuration similarity and component similarity was observed for the large gap condition, but no relative dominance of the component was observed either (for details see Kimchi, 2000, Experiment 1; this volume).[6] These results have been interpreted as suggesting that for normal individuals, disconnected line segments are rapidly organized into configurations, provided collinearity (the cross prime) or closure (the diamond prime) is present. Strong proximity between the line segments (as in the no-gap and small-gap conditions) facilitates grouping by closure or collinearity more than does weak proximity (as in the large-gap condition), but connectedness does not seem to be necessary for rapid grouping.

The results for SM (Fig. 10.11B) showed a significant effect of prime type with faster RTs for crosses than diamonds and a significant effect of duration with faster RTs as duration increases. There was also a significant effect of prime-test similarity that interacted with prime type. As can be seen in Fig. 10.11B, RTs for configuration similarity were significantly faster (by an average of 117 ms) than RTs for component similarity for the diamond prime, but no difference between

the two test types was observed for the cross prime. The configuration advantage decreased with an increase in gap size, as indicated by the significant interaction between prime-test similarity and gap condition, and it increased with prime duration, as indicated by the significant interaction between prime-test similarity and prime duration.

The results for RN showed a significant effect of prime-test similarity that varied with gap condition. There was a significant advantage for configuration similarity over line similarity for the no gap condition (averaged 51 ms) and the small gap condition (averaged 33 ms), roughly equal across the two prime types, but no significant difference between configuration similarity and component similarity was observed for the large-gap condition. Like SM, RN's RTs were faster when the prime was a cross than a diamond, but prime type did not interact significantly with prime-test similarity, prime duration, and gap condition.

RN showed a priming effect of the configuration both for the diamond and for the cross primes that decreased with gap size. As long as the gaps between the line components were relatively small (i.e., relatively strong proximity), he was able to integrate them either by collinearity or by closure. SM, on the other hand, showed a priming effect of the configuration for the diamond prime but no priming effect for the cross prime. Because SM's responses, like RN's, were faster for the cross than for the diamond prime, it is unlikely that the absence of configuration advantage for the cross indicates that SM cannot use collinearity for grouping. Rather, this finding may result from SM's high sensitivity to closure. Given that the component-similarity test pair for the cross includes two squares and the configuration-similarity test pair includes two crosses (see Fig. 10.10), it is possible that although responses to the configuration-similarity test pairs were facilitated due to prime-test similarity, responses to the component similarity test pairs were facilitated due to closure, and, as a result, no difference between the two was obtained. It is not the case, then, that SM is impaired at grouping by collinearity, whereas RN is not, but rather that SM is more sensitive than RN to closure. Further support for this claim comes from the finding that the configuration advantage for the diamond is larger for SM (180, 125, and 48 ms, for the no-gap, small-gap, and large-gap, respectively) than for RN (54, 38, and −17 ms, for the no-gap, small-gap, and large-gap, respectively, see Fig. 10.11), and furthermore, RN, contrary to SM, does not show any configuration advantage but rather an element advantage for the large-gap condition. That is, strong proximity facilitated grouping by closure for RN, whereas, for SM, closure was strong enough to override weak proximity. Interestingly, the performance of the normal participants in the neutral prime condition also showed faster responses to the pair of squares than to the pairs of crosses (Kimchi, 2000, Experiment 1), suggesting a sensitivity of the normal participants to the property of closure.

To rule out the possibility that the difference between RN and SM in their responses to the cross prime is due to a difference in their ability to exploit collinearity, we compared their performance in an elementary contour interpolation task.

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[6] It is important to note that when RT for the component-similarity test pairs was compared with baseline performance, no facilitation for the component-similarity test pair was observed even for the large-gap condition, suggesting that even under relatively weak proximity between the lines, there was no relative dominance of the component lines.

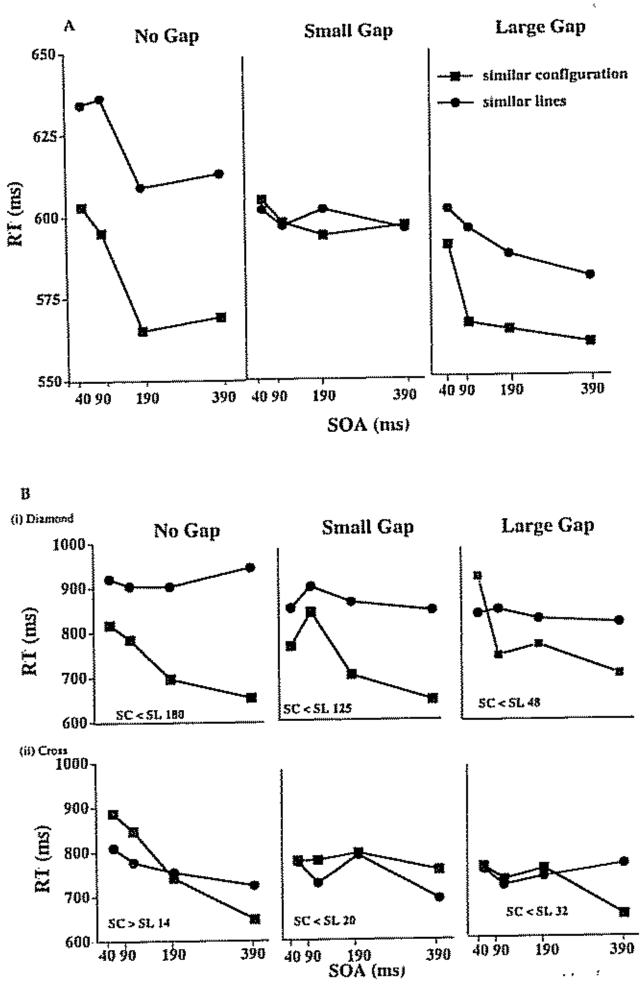

FIG. 10.11. (A) Mean of median correct same RTs for the component similarity and configuration similarity as a function of prime duration for each gap condition for control subjects and mean responses for diamond and cross primes for (B) SM and (C) RN. For SM and RN, the differences in ms between the component similarity (SC) and line similarity (SL) conditions are also provided. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

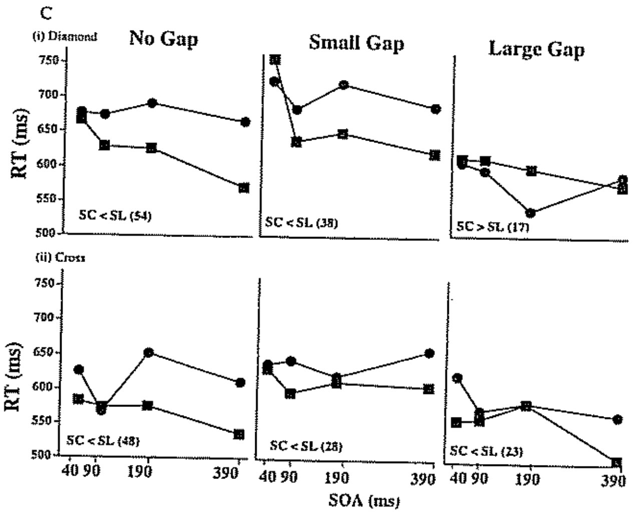

FIG. 10.11. *(Continued)*

CONTOUR INTERPOLATION

To test contour detection thresholds, we used a set of cards containing displays of a smoothly aligned, closed path of Gabor elements embedded in a random array of Gabor elements of the same spatial frequency and contrast, devised by Pennefather, Chandna, Kovács, Polat, and Norcia, (1999). In this test, cards containing the displays are presented individually to the subject, who is required to indicate the location of the contour formed by the Gabor patches. The critical manipulation or parameter, Δ, is the spacing between the adjacent elements in the background relative to the spacing between neighboring elements along the contour. The Δ ranges between 1.2 (card 2_1) to 0.5 (card 2_15) in steps of 0.05 (examples of these displays are presented in Fig. 10.12). This parameter expresses relative noise density and reflects, in a way, signal-to-noise ratio so that the smaller the Δ value, the easier detection. It has also been suggested that as Δ decreases, long range spatial interactions of oriented features, presumably mediated by low-level areas of visual cortex, are more involved. Given that early visual areas are preserved in both patients, we expect them both to perform normally. If they do so and there is no difference between them, this would further indicate that they both can exploit collinearity as a grouping heuristic. Establishing contour detection thresholds using this method has been successfully achieved previously with various pathological populations (Kovács, Polat, Pennefather, Chandna, & Norcia, 2000).

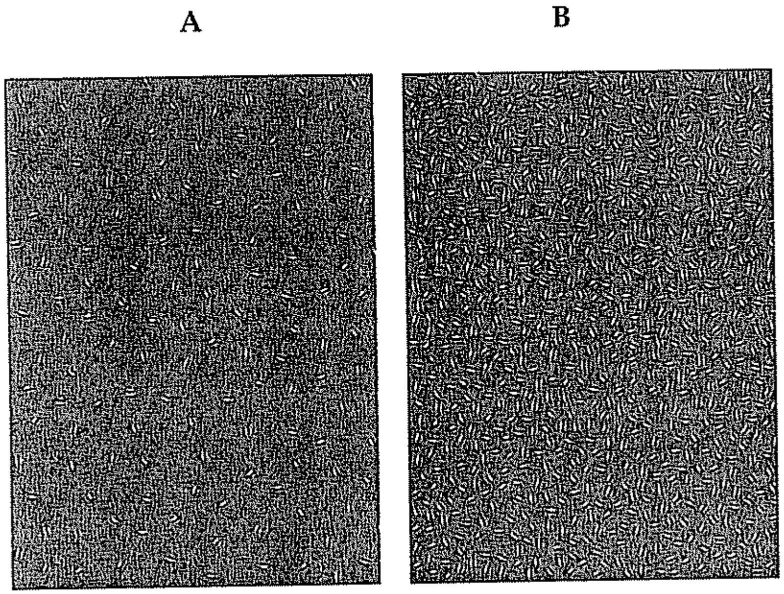

FIG. 10.12. Examples of displays from Kovács et al. (2000) of contours made of local Gabor units. (A) easy, (B) difficult. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

Both SM and RN completed this task easily and effortlessly. Importantly, both attained thresholds within normal limits, with Δs of 0.6 and 0.65, respectively. The norm is around 0.7 (Kovács et al., 2000). It is interesting to note, at this point, that patient HJA also performed well on the present task, obtaining a threshold of 0.65 (Giersch, Humphreys, Boucart, & Kovács, 2000). These findings indicate that both our patients have a normal ability to integrate collinear elements into contours and that there is no obvious difference between them in this ability. These data can explain the finding of faster responses for the cross prime (presumably grouping by collinearity) than for the diamond prime (presumably grouping by closure) that was observed in the previous experiment for both patients. Further support for their ability to integrate collinear elements comes from the results of the Navon-type figures, in which even RN, who was generally unable to derive the global configuration of the many-element patterns, was able to do so in the case of *H* made of *H*s. Furthermore, the present findings support the claim that the difference between RN and SM for the cross (see previous section) is unlikely to arise from a differential sensitivity to collinearity but rather to a difference in their sensitivity to closure: SM is more sensitive to closure than is RN. The consistency in performance across the patients (SM, RN, and HJA) in the contour interpolation task endorses the notion that the integration of contours in a task such as this likely relies on visual processes mediated by earlier or lower level regions of visual cortex and that these areas are preserved in integrative agnosic patients.

GROUPING BY SIMILARITY IN LUMINANCE AND PROXIMITY

We assumed that in the hierarchical stimuli we used, the local elements are grouped into a global configuration by proximity, or by similarity, or both, and the inability of the patients to apprehend the global configuration reflects an impairment in grouping. However, as mentioned previously, perceptual organization is thought to involve two operations: element clustering, which determines which elements belong together, and shape formation or configuring, which determines the shape of the grouped elements (Rock, 1986; Trick & Enns, 1997). It is possible, then, that our patients are not impaired in clustering but rather in shape formation or configuring. That is, it is possible that they are able to group the elements of the hierarchical stimuli into a unit, but are unable to apprehend the relationships among the grouped elements so that the unit is not organized for them into a whole that has unique qualities such as shape. To explore this possibility we examined the performance of the two patients in simple grouping tasks: grouping into columns or rows by proximity and by similarity in luminance.

A display consisting of small circles, each 4 mm in diameter, appeared centered on a computer screen (see Fig. 10.13 for examples). In the proximity condition, the display contained 32 solid black circles, and the distance between them horizontally or vertically was manipulated to yield an organization of either rows or columns, respectively. The distance was either 4 or 8 mm from the center of one circle to the next, and, depending on the distance, the arrangement obeyed a rows or column organization. In the similarity condition, the elements were solid black or white circles, equally distant (4 mm), and the organization was determined by the alternation of the two colors, either in rows or columns. The subjects were instructed to indicate, for each display, whether an arrangement of rows or columns is present. There were 50 trials in each of the two organization conditions, rows or columns, and we measured both accuracy and RT.

Both patients performed well on this task as was true of the normal control subjects (controls: 93.3% in both cases). SM was correct 90% and 94% of the time in the proximity and similarity conditions, respectively, and RN was correct 100% of the time in both cases. That is, when proximity favored an organization of rows, the patients perceived rows, and when it favored an organization of columns, they

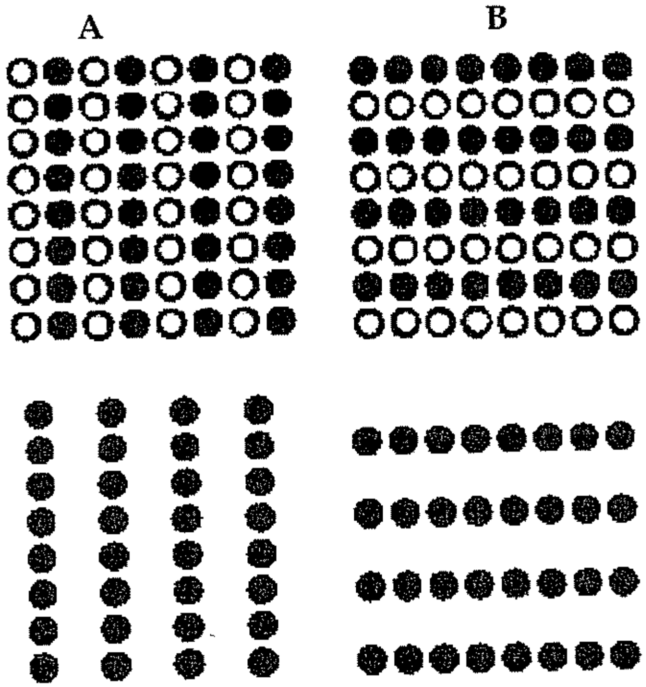

FIG. 10.13. Arrangement of dots into (A) columns and (B) rows for grouping by similarity and by proximity. From "What Does Visual Agnosia Tell Us About Perceptual Organization and Its Relationship to Object Perception?" by M. Behrmann and R. Kimchi, 2003, *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), pp. 19–42. Copyright 2003 by APA. Reprinted with permission.

perceived columns. The same was true when organization was based on similarity in luminance. These findings indicate that both patients are sensitive to grouping by proximity and by similarity in luminance and are able to determine the orientation of the grouped elements. If anything, whereas RN scored perfectly, SM made a few errors, possibly due to a speed accuracy trade-off because SM was much faster (proximity: 603 ms; similarity: 659 ms) than RN (proximity: 917 ms; similarity: 862 ms).

However, grouping by proximity and by similarity may not suffice for deriving the shape of the grouped elements. Interestingly, Kimchi and Razpurker-Apfeld (2001) found that grouping by similarity of luminance and color into columns or rows occurred earlier than grouping into arrows or triangles and that the former, but not the latter, occurred under conditions of inattention. This finding suggests that grouping is not a single process even when it is based on the same heuristic,

but, rather, it involves operations that differ in their time course and attentional demands.

The findings of the present experiment suggest that the difficulty of our patients, and in particular RN, to apprehend the global configuration of hierarchical stimuli is not due to an impairment in simple grouping (i.e., in the sense of what goes with what) but presumably to an impairment in the ability to apprehend the interrelationships of the elements and to derive the emergent structure or shape.

SUMMARY OF FINDINGS

The goal of our research was to explore the psychological and neural processes involved in deriving structure and coherence from visual input. Many traditional theories of visual perception assume that perceptual organization processes operate early and preattentively to deliver candidate units for further processing, such as object identification. These theories make no attempt to distinguish in detail between the different perceptual organization processes nor to evaluate their relative contribution to object recognition. To address these issues, we investigated the behavior of two individuals with acquired integrative visual object agnosia, on tasks of object recognition and perceptual organization, with a specific emphasis on grouping elements into global forms. By understanding how the system breaks down, and how a perceptual organization deficit is related to impaired object recognition, we hoped to obtain insight into the normal processes of perceptual organization and object identification.

When required to integrate many small elements into a global configuration, SM, but not RN, was able to derive the global form, although he required more time to do this than did the normal participants. A microgenetic analysis of this integration process confirmed that, given enough time and sufficient data-driven support, he was eventually able to derive the global form. Importantly, normal perceivers unify a multielement stimulus early and quickly, reflecting their spontaneous bias to deal with such a stimulus as a unit rather than as disparate components, and only later do they individuate the elements. SM did not show this early and fast grouping of the many elements displays and only, with time, was he able to laboriously derive a global form. Even under optimal circumstances, RN failed to derive the global form from the image. When the stimulus was composed of only a few, relatively large elements, neither SM nor RN was able to extract a global structure. Under these conditions, normal subjects can apprehend the global structure despite the relative salience of the individual elements, and the global configuration becomes further consolidated with time. Note that the differences between the two patients and the difference between them and the normal participants in apprehending the global configuration of hierarchical stimuli cannot be attributed to a differential sensitivity to low spatial frequency information because both patients displayed spatial frequency threshold functions within normal limits.

In an investigation of the time course of the ability to group simple line segments into configurations by collinearity and by closure, we found that both patients were able to exploit these properties early on, as is also true of normal participants. However, SM was more sensitive to closure than was RN. Strong proximity facilitated grouping by closure for RN, but SM was able to group by closure even when proximity was weak. We should note that RN's performance here might even be mediated by collinearity at its limits (relatability at 90°), indicating that he might be even less sensitive to closure than we have suggested. Indeed, in a task that was designed specifically to evaluate the ability to integrate collinear elements into simple contours, both SM and RN performed like normal perceivers and did not differ from one another.

The final result was that, presented with the classic, simple Gestalt displays requiring grouping into rows or columns, both patients were able to group by proximity and by similarity of luminance and did not differ from one another or from the normal individuals.

In sum, both patients are able to group collinear elements into a contour, elements into simple rows or columns by proximity and by similarity in luminance or color, and simple line segments into simple configurations by closure. It is important to note, however, that although the basic grouping abilities of both patients seem intact under simple conditions, they nevertheless encounter difficulties under more difficult conditions as in segmenting overlapping shapes. In contrast with the seemingly intact basic grouping, there is a significant impairment in both patients in deriving global structure and apprehending a multielement stimulus as a whole with a specific shape, and the impairment is more marked in RN than in SM. RN fails to derive a global structure even under the most favorable conditions and unlimited time and is also less sensitive to closure than is SM. Critically, the patients differed from each other in the severity of their object recognition deficit, with SM performing significantly better than RN in both accuracy and latency.

DISCUSSION AND CONCLUSION

We now return to our original three questions, namely, the differences between various forms of perceptual organization, the relative contribution of these different processes to object recognition, and the neural systems subserving these mechanisms.

The first important conclusion is that not all organizational processes are created equal. Clearly, grouping by collinearity, proximity, and similarity by luminance and color was easily and equally well achieved by the patients, whereas this was not the case for grouping by closure. The relative preservation of grouping by collinearity is also evident in other agnosic patients, such as HJA (Giersch et al., 2000) and NM (Ricci et al., 1999), who are impaired at integrating low-level elements into a whole but are nevertheless able to extract contours from an image (see also patient FGP; Kartsounis & Warrington, 1991). The present data also clearly show that, although the patients are sensitive to basic grouping, they are not equally able to derive a global structure and shape, suggesting that they may be impaired (and to different degrees) in configuring shape formation (see also Humphreys, this volume).

The differential sensitivity to different forms of grouping is consistent with the idea that some perceptual organization processes may precede others; for example, some processes operate on fairly local components, such as edges, and map onto basic neurophysiological interactions quite early in the visual pathway (Kellman, 2000, this volume; Kovács, Kozma, Feher, & Benedek, 1999; Shipley & Kellman, 1992). This also fits well with recent neuroimaging and neurophysiological work (Lamme & Roelfsema, 2000; Lee, 2002; Sugita, 1999; Westheimer, 1999) suggesting that the ability to interpolate across discrete collinear elements arises from the lateral connections and long-range interactions in early (V1 and V2) visual cortex. Time constants associated with the V1 and V2 operations have been estimated at 45–50 ms and 70–90 ms in V1 and V2, respectively (Doniger et al., 2000; von der Heydt & Peterhans, 1989). Unfortunately, as is often the case in neuropsychological investigations and is true in our case, too, the lesion localization in our patients is not precise enough to yield definitive evidence for the neural structures that are involved, but our results are consistent with the neurophysiological and imaging findings. We know, for instance, that the early visual areas are preserved in SM and, although not definitely established, are likely intact in RN, too, given the absence of low-level deficits. It is these preserved visual regions that probably mediate the patients' ability to exploit collinearity and grouping by proximity and similarity in luminance.

In contrast with these rather simple forms of grouping, other forms of organization have more global influences, as in the case of closure and deriving a structured whole, and these more complex forms are probably mediated by more anterior regions of the visual system. Some evidence to support this claim, for example, comes from a recent high-density event-related potential study (Doniger et al., 2000) in which the amount of visual information in the image was incrementally increased with each subsequent presentation. The critical result was the existence of a bilateral occipito-temporal negative potential that tracked the amount of closure in the image; activation did not manifest in an all-or-none fashion at the point of closure but, rather, built incrementally over a number of preidentification levels. This finding suggests that this region is involved in the computation of closure rather than just registering its presence. Importantly, the peak of activation in this region occurred at approximately 290 ms, much later than the estimated onset of V1 or V2 activity. That perceptual closure is subserved by ventral occipito-temporal areas is also supported by recent hemodynamic and metabolic data (Gerlach et al., 2002) showing that the inferior occipital gyri (perhaps even including area V2) are involved in the integration of visual elements into perceptual wholes, irrespective of whether the wholes were familiar objects or not (see Georgopoulos et al., 2001, for similar evidence, and Gauthier & Tarr, 2002, for behavioral evidence on different forms of configuring and associated neural substrates).

The hypothesis we put forward entails that some organization processes precede others, and we linked these to brain structures on a continuum from more posterior to anterior regions. We do not, however, propose that the system operates in a purely serial and feedforward fashion. There is now ample evidence for bidirectional connectivity and mutual bottom-up and top-down reciprocity (Bullier & Nowak, 1995; Lee, 2002; von der Heydt, Zhou, & Friedman, this volume; Zhou, Friedman, & von der Heydt, 2000) and processing operating in a cascaded and interactive fashion in the visual system (see also Peterson, this volume). We do suggest, however, that there is a temporal advantage for some processes over others, and the order in which these processes takes place follows a posterior-anterior brain organization.

The finding that SM and RN are similar to one another in more basic, presumably low-level grouping operations, but show marked differences in their ability to derive a global form from a multielement display, strongly suggests that perceptual organization involves not only grouping in the sense of element clustering but also, presumably higher level, configuring and shape formation. It is in these more configural forms of grouping that the two patients differ from one another and in which RN is more impaired than SM. The distinction we made between grouping and shape formation/configuring may also help to clarify some confusion found in the literature on perceptual organization. For example, understanding the attentional demands of perceptual organization may depend on whether we refer to grouping (i.e., element clustering) or to configuring (i.e., shape formation). The former is more likely to occur under conditions of inattention than is the latter, and a failure to distinguish between the two organizational processes may lead to seemingly conflicting results. Also, when a task that is designed to assess grouping performance also requires shape formation, caution is necessary in interpretation. For example, Ricci et al. (1999) reported that patient NM is impaired in grouping (by luminance, color, and line orientation). However, the test that was administered to examine NM's grouping ability required her to identify a hierarchical letter embedded in a background of elements. Clearly, grouping alone (i.e., determining which elements belong together) is not sufficient for deriving the structure or the shape of the grouped elements in this case, and shape formation is also necessary. It is unclear, then, whether NM is impaired in grouping or in shape formation or in both.

The differences between the patients in their sensitivity to closure and their ability in configuring and shape formation parallels the difference between their object recognition performance in that RN is more impaired than SM in both accuracy and speed of object identification. Clearly both patients are able to group collinear elements into a contour, but there is more to an object than a contour, and it appears that it is the higher level processes that are critical for object recognition. This is supported by RN's object recognition errors, which reflect his inability to derive form with extent and surfaces and the reliance on simple contours to extract the outline of the shape. For example, shown a black-and-white line drawing of a tie, he identifies it as a string and, on another occasion, refers to a drawing of a nose as a string. In contrast to simple contours, objects are considered to be complex wholes: They have contours, but they also have extent, closure, and internal structure (Feldman, 1999, 2000; Sanocki & Sellers, 2001). Indeed, some studies have shown that, under some circumstances, the global shape outline (and perhaps some surface properties, as revealed for example when silhouettes are used as stimuli) may automatically induce activation of object representations (Boucart & Humphreys, 1992b; Boucart, Humphreys, & Lorenceau, 1995; Dell'Acqua, Job, & Grainger, 2001).

At the same time, it is conceivable that there are circumstances in which certain lower level grouping may suffice for object recognition; for example, when grouping by collinearity provides contours, and the object is easily recognizable from the contours. It may be also the case that object recognition may occur without a full apprehension of the whole (Davidoff & Warrington, 1999). For example, a real, familiar object may be recognized by a distinctive feature or part that is uniquely diagnostic of the object's identity. Thus, we do not claim that all forms of grouping and configuring (or shape formation) are always necessary for object recognition but rather that simple grouping is not sufficient for object recognition, whereas shape formation and configuring are critical for it.

Before concluding, we need to consider a final issue that emerges from the present findings and that concerns the relationship between spatial frequency analysis, performance on tasks evaluating global/local processing, and the relationship between these and the two cerebral hemispheres. With regard to spatial frequency and global/local processing, one view assumed a direct relationship between spatial frequency filters and global/local bias: High spatial frequency information supports the local analysis of the image, and low spatial frequency information supports the global analysis of the image (Hughes et al., 1990; Shulman et al., 1986; Shulman & Wilson, 1987). The data from our two patients challenge this assumption. Both patients exhibit normal spatial frequency thresholds in both the high- and low-frequency range, yet both are impaired (and differentially so) at deriving the global shape from multielement displays.

A rather different view on this matter focused on relative spatial frequency. According to Ivry and Robertson (1998; also Robertson & Ivry, 2000), there is a secondary stage of processing that is sensitive to the relative rather than absolute spatial frequencies in the image, and this stage is functionally asymmetric and associated with more cortical anterior regions than those that register the absolute frequencies. In this account, the difference between global and local information is a difference along a continuum of spatial frequency. With respect to the hemispheres, the claim is that the two hemispheres are biased toward different information along the same dimension of spatial frequency (Lamb, Robertson, & Knight, 1990; Robertson & Ivry, 2000), with the result that the right hemisphere is preferentially biased to process global information and the left hemisphere local information. Although our finding that the patients have normal spatial frequency thresholds is not incompatible with Ivry and Robertson's approach, within their perspective, there does not appear to be a clear way to accommodate the finding that the few- and many-element displays are processed differently by normal subjects and by one of our patients (SM) given that the spatial frequency of the elements is relatively higher than that of the configuration for both displays within their view. A potential further complication is that SM, who has a clearly defined right hemisphere lesion, is still able to derive the global form. In light of these findings, we suggest that the processing of global and local components is tied more to organizational processes than to differences along a continuum of spatial frequency and its relation to hemispheric biases.

This is not to say that the two hemispheres play equivalent roles in perceptual organization, because they apparently do not, but we suggest that the means whereby organization occurs is not primarily dependent on hemispheric-tuned spa- ial frequency filters. Although the neuroimaging studies obtain bilateral activation n posterior cortex in many integration tasks (Gerlach et al., 2002), this does not necessarily imply that there is an equal contribution of both hemispheres to this pro- cess. As revealed by patient HJA, a lesion to the right hemisphere alone can impair he ability to derive closure (Boucart & Humphreys, 1992a, 1992b). Moreover, the elatively greater contribution of the right hemisphere to perceptual organization is lso observed in split-brain patients: Corballis, Fendrich, Shapley, and Gazzaniga 1999) showed that whereas both hemispheres seemed to be equally capable of erceiving illusory contours, amodal completion is more readily achieved by the ight hemisphere.

In conclusion, we examined the perceptual organization and object recogni- on abilities of two visual agnosic patients to shed light on the nature of these sychological processes, how they relate to one another, and the possible under- ing neural substrates. Our findings indicate that perceptual organization is not unitary phenomenon but rather a multiplicity of processes, some of which are mpler, operate earlier, and are instantiated in lower level areas of visual cortex, ch as grouping by collinearity. In contrast, other processes are more complex, perate later, and rely on higher order visual areas, such as grouping by closure nd shape formation. It is these latter processes that are critical for object recogni- on. The failure to exploit these more complex, configural processes, despite the eserved ability to do basic grouping, gives rise to a deficit in object recognition. he implication of these findings is that the ability to organize elements into visual its is necessary but not sufficient for object identification and recognition. To preciate the identity of an object, one must necessarily apprehend the internal ructure and its emergent global form.

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