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Neuropsychologia 44 (2006) 1724–1736

NEUROPSYCHOLOGIA

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Illusory conjunctions in simultanagnosia: Coarse coding of visual feature location?

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Received 26 August 2005; received in revised form 9 March 2006; accepted 13 March 2006

Abstract

Simultanagnosia is a disorder characterized by an inability to see more than one object at a time. We report a simultanagnosic patient (ED) with bilateral posterior infarctions who produced frequent illusory conjunctions on tasks involving form and surface features (e.g., a red T) and form alone. ED also produced "blend" errors in which features of one familiar perceptual unit appeared to migrate to another familiar perceptual unit (e.g., "RO" read as "PQ"). ED often misread scrambled letter strings as a familiar word (e.g., "hmoe" read as "home"). Finally, ED's success in reporting two letters in an array was inversely related to the distance between the letters. These findings are consistent with the hypothesis that ED's illusory reflect coarse coding of visual feature location that is ameliorated in part by top-down information from object and word recognition systems; the findings are also consistent, however, with Treisman's Feature Integration Theory. Finally, the data provide additional support for the claim that the dorsal parieto-occipital cortex is implicated in the binding of visual feature information.

Keywords: Simultanagnosia; Visual attention; Perception; Balint's syndrome; Illusory conjunctions

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Simultanagnosia is a disorder characterized by an inability to see more than one object at a time. The disorder was originally attributed to a deficit in visual attention by Retzo Balint in his description of the syndrome that bears his name (Balint, 1909; see also Husain and Stein, 1988). Discrepancies in the behavioral deficits exhibited by simultanagnosics, however, suggest that different processing impairments may cause the disorder. Consistent with this view, Farah (2004); Farah, Brunn, Wong, Wallace, and Carpenter (1990) distinguished between "dorsal" and "ventral" simultanagnosia. More recently, Coslett and Chatterjee (2003) suggested that at least two types of dorsal simultanagnosia may be identified. In one subtype, the syndrome was attributed to a deficit in linking stored information regarding object identity and location whereas in another subtype the deficit was attributed to a lower level impairment in the ability to represent and/or bind visual information.

Even within the latter putative subtype of simultanagnosia, however, substantial differences may be identified. For example, investigations motivated by Posner's influential account of visual attention have explored subjects' ability to "shift" visual attention (Verfaellie, Rapcsak, & Heilman, 1990). We recently reported a patient who was unable to disengage attention (Pavese, Coslett, Saffran, & Buxbaum, 2002). When presented with two stimuli, he typically reported only one item; when the reported item was eliminated, however, the patient quickly and accurately reported the second item in the array.

Patients with simultanagnosia (e.g., Friedman-Hill, Robertson, & Triesman, 1995; Humphreys, Cinel, Wolfe, Olson, & Klempen, 2000; Pavese et al., 2002; Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997; Valenza, Murray, Ptak, & Vuilleumier, 2004) as well as patients with unilateral parietal lesions (Arguin, Cavanagh, & Joanette, 1994; Cohen & Rafal, 1991) have also been reported to produce illusory conjunction errors. These errors are characterized by the recombination of features of objects in an array to form percepts that are not present in the original stimulus display. For example, when shown an array containing red Xs and

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0028-3932/$ – see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2006.03.017

green Ts, subjects may report seeing a green X; although such errors might occur because of guessing or impaired perception of virtual features (Donk, 1999), a number of investigations employing formal modeling of results from normal subjects (e.g., Ashby, Prinzmetal, Ivry, & Maddox, 1996; Prinzmetal, Ivry, Beck, & Shimizu, 2002) demonstrate that many of these errors reflect an inaccurate combination of visual feature information. On Treisman's Feature Integration Theory (Treisman & Schmidt, 1982), illusory conjunctions arise because visual feature information (e.g., color, form and closure) is processed independently in distinct visual feature maps. In order to distinguish a red T from a green T, the information regarding color and form is co-registered at a representation of space termed the "master map of locations". Treisman's account postulates that spatial attention serves as the "glue" that binds together visual feature information to form a unified and coherent perceptual and conceptual world (Treisman, 1998). Consistent with this view, illusory conjunctions occur in normal subjects under conditions of high attentional demands (e.g., brief exposure, large and complex arrays).

Although the incidence of illusory conjunctions in normal subjects is clearly influenced by perceptual properties, such as similarity and common fate (Baylis, Driver, & McLeod, 1992; Ivry & Prinzmetal, 1991; Prinzmetal & Keysar, 1989), the role of spatial proximity in the genesis of illusory conjunctions has been controversial. In a task involving narrowly focused attention in foveal vision, Treisman and Schmidt (1982) found that illusory conjunctions were just as likely to involve (relatively) distant as opposed to adjacent items; on their view, visual features were "free-floating" and recombined randomly within the attended region. In contrast, Cohen and Ivry (1991) demonstrated a significant effect of distance in that illusory conjunctions were more likely to involve nearby items, even within the attended region (Ashby et al., 1996). Consistent with this view, Prinzmetal, Henderson, and Ivry (1995) reported illusory conjunctions in the periphery of the visual field where spatial information is less precise even with relatively long exposure durations. We return to this issue in Experiment 5.

We report a patient (ED) with simultanagnosia caused by bilateral posterior strokes. ED produces frequent illusory conjunction errors in which elements of one "object" appear to migrate to a different object. Unlike many patients with simultanagnosia (e.g., GK and MP) whose deficits are apparent only with brief presentation, these errors are produced with unlimited exposure time and under conditions in which demands on binding of visual feature information is minimal. Additionally, he often reports seeing words when shown scrambled letter strings (hmoe > "home"). We suggest that ED's deficits are attributable at least in part to impaired marking of visual location that is compensated in part by top-down information from object and word recognition systems.

1. Subject ED

ED was a 72-year-old right-handed man who sought medical attention because of the sudden onset of the inability to "see". Although able to recognize family members and objects, he experienced great difficulty finding his way as he continually bumped into furniture or walls while walking. He stated that when actively looking at a single object his peripheral vision seemed to 'fade out' so that only one object remained salient.

Neurological examination 1 month after the right hemisphere stroke revealed him to be alert and oriented with normal speech. He exhibited normal ocular movements but prominent optic ataxia (misreaching under visual guidance) that was much worse with the left hand. With eyes closed he reached to sounds normally on both the right and left with both hands. An incomplete right homonymous hemianopia was noted. A mild right-sided neglect was present on a line bisection task. He performed very poorly on a variety of cancellation tasks but there was no tendency to respond to stimuli more reliably on the right or left. ED exhibited a mild left spastic hemiparesis.

He was unable to feed himself, for example, because when gazing at his food he did not know the location of his fork; when gazing at his fork, he did not know the location of his food except when he used his left hand to mark the location of the food proprioceptively. He required assistance dressing. Although strength was sufficient, he was unable to walk in his home without assistance as he bumped into furniture and walls.

Medical evaluation revealed that ED's deficits were attributable to two independently occurring strokes (see below). He had suffered a left hemisphere infarction from which he had made a good recovery several years before the onset of simultanagnosia. His profound visual perceptual deficits were noted at the time of the right hemisphere stroke. CAT scan 10 days after symptom onset revealed three regions of infarction. One involved the right lateral and superior occipital lobe as well as the superior parietal lobule; a second right hemisphere infarction in the anterior cerebral artery distribution involved the anterior and posterior cingulate cortex as well as underlying white matter. The left hemisphere stroke involved the lateral and superior occipital lobe, the superior parietal lobule and posterior portions of the angular gyrus (see Fig. 1).

Finally, it should be noted that ED's performance was quite stable over the 6 months of testing reported here as judged not only by reports of the patient and his family but also be repeated administrations of several experimental tasks as much as 5 months apart. Only minor differences in performance were noted, for example, across repeated administrations (and variations of) tasks reported in Experiments 1–3.

2. Neuropsychological assessment

2.1. *Object recognition*

ED named 32/60 items on the Boston Naming Test. Many errors appeared to be perceptually based, involving the report of one element of the object; for example, he responded "dust" when shown a drawing of a volcano. To assess the effect of stimulus size, ED was asked to name familiar, high frequency line drawings with no discontinuous elements presented, on different occasions, in both large (8–12 cm) and small (2–3 cm) sizes; he correctly identified 19/19 of these high frequency objects in both conditions. Thus, in contrast to at least some patients with

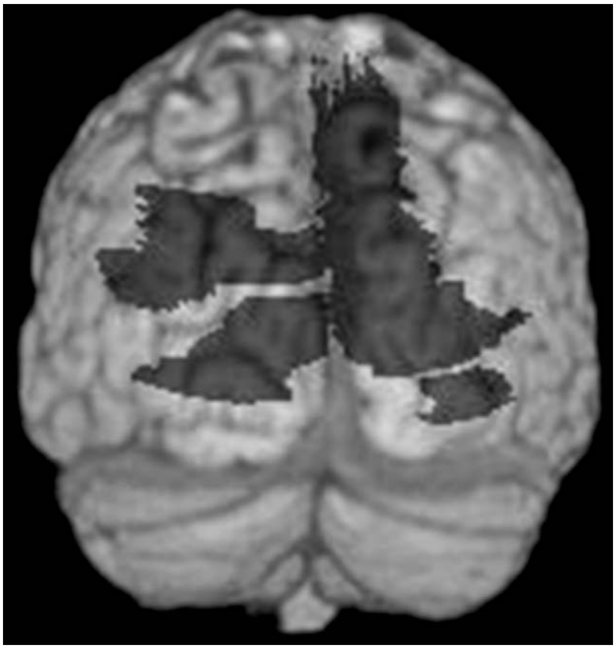

Fig. 1. A posterior view of a normal brain on which ED's infarcts are depicted. The figure was generated with MRIcro.

simultanagnosic-like syndromes with posterior cortical atrophy (e.g., Rajaram, 1996), he exhibited no effect of stimulus size. ED performed poorly on an object decision task involving 20 line drawings of real objects and 20 line drawings of non-objects generated by combining parts of real objects. He responded correctly to 20/20 of real objects but indicated that 7/20 non-objects were real for an overall score of 27/40.

2.2. Reading

ED read many single words accurately. Like a number of other simultanagnosic subjects (Baylis, Driver, Baylis, & Rafal, 1994; Coslett & Saffran, 1991; Robertson et al., 1997), he tended to lexicalize "word-like" non-word letter strings (e.g., *flig* read as "flag"); when shown consonant letter strings (e.g., "grth") he tended to report a single letter (cf., Baylis et al., 1994; Coslett & Saffran, 1991). When shown scrambled words, he often responded quickly and confidently with a real word; for instance, the letter-string 'hmoe' was read as "home". We return to this issue in Experiment 6.

2.3. Evidence for simultanagnosia

ED's response to the Cookie Theft Picture from the Boston Diagnostic Aphasia Examination demonstrating a complex social scene was laborious and disjointed. He reported individual items, such as the stool, window, sink, cookie jar and woman but failed to appreciate the relationships between the items. After approximately 10 min of scrutiny, he reported seeing only one person although he had, in the course of his description actually pointed to two people.

ED performed abnormally on a number of tasks involving arrays. Given unlimited time to respond, he responded correctly on only 10/24 trials on Warrington and Taylor's Dot Counting subtest. On another task, two vertically aligned line drawings separated by approximately 2° of visual angle were presented with a computer for 5 s. ED correctly identified both stimuli on only 1/31 trials. On 24 of the 31 trials, he identified one of the two objects but claimed not to see the second object. On 18 of the 24 trials the one object correctly reported was in the upper hemifield.

ED was shown Navon figures in which a large single letter was comprised of multiple smaller letters (Navon, 1977). ED reported both the large (global) and small (local) letters on only 2/15 trials. He reported only the small letter in 12 of 15 trials and was unable to report either letter in one trial. If the small letters were connected with a line ED immediately and accurately reported the large letter on all trials.

Finally, a task was performed to explore the degree to which ED's ability to process multiple items in an array was restricted to vision. To this end, ED was asked to make judgments regarding the relative spatial location of items in an array. Stimuli included 30 10 cm × 15 cm white cards on which a circle (1.5 cm in diameter) and bold horizontal black line had been drawn. The horizontal line was in one of three different positions: 3.5 cm from the top, 5 cm from the top (midline) or 6.5 cm from the top. The circle was either below or above the line but never overlapped the line. ED was asked to determine if the circle was above or below the line. Stimuli were presented until ED responded.

In one condition, ED looked at the cards. In the second condition, ED closed his eyes and the examiner placed ED's right index finger on the line and his left index finger on the circle. When looking at the cards ED responded at chance (14/30 correct). With eyes closed but his fingers touching the line and the circle ED responded correctly on 26/30 trials (Fisher's Exact Test, $p < 0.01$). In conjunction with his normal performance reaching to auditory stimuli, these data suggest that ED's deficits were largely restricted to the visual modality.

3. Experiment 1: pre-attentive and attention requiring visual search

As previously described, ED exhibited striking deficits on a variety of tasks requiring visual search. The first experiment was performed to formally evaluate ED's visual search. We employed a task assessing "pre-attentive" and "attention-requiring" processes, a distinction that is common to some (e.g., Sagi & Julesz, 1985; Treisman, 1998) but not all models of visual search (see Wolfe, 2003 for discussion). Pre-attentive visual search is parallel in the sense that the entire visual array is processed simultaneously (or nearly so). This type of search is characterized by a "pop-out" effect in that reaction times to identify a target are not substantially influenced by the number of distractors in the array. In contrast, attention-requiring search is a serial process in which RTs are directly related to array size. On Treisman's Feature Integration Theory (Treisman, 1998; Treisman & Gelade, 1980; Treisman & Schmidt, 1982), pre-attentive search may be mediated by "maps" of individual visual features (e.g., color, line orientation, etc.) that are instantiated in low-level visual cortex. Pop-out is observed because the presence of the feature in question (e.g., the color red) at any location(s) is associated with activity in the feature map; thus, the presence of the feature in question can be inferred from any activity at the level of the relevant feature map.

In contrast, attention-requiring search entails the detection of stimuli defined by the presence of two or more features; as information from different feature maps is assumed to be integrated at the level of the master map of locations, attention-requiring search requires a serial scrutiny of possible sites of conjunction at the "master map of locations". Attentive processing appears to rely on the integrity of the parietal lobules (Friedman-Hill, Robertson, Desimone, & Ungerleider, 2003; Friedman-Hill et al., 1995; Pavese et al., 2002; Shafritz, Gore, & Marois, 2002).

3.1. Methods

Stimuli for the pre-attentive task included 12 10 cm × 15 cm white cards on which 4 blue T's and 5 green S's had been drawn as well as 12 cards on which 4 blue T's, 4 green S's and 1 red S had been drawn. Letters were 2 cm in height and were randomly arrayed on the cards. For this and subsequent experiments, the viewing distance was approximately 50 cm; thus, each letter subtended approximately 2.3° of visual angle. Unlike some patients with simultanagnosia, ED did not move his head toward or away from the stimuli in an apparent attempt to improve resolution. ED's task was simply to indicate if a red S was present. Cards were presented free-field until ED responded.

Attention-requiring visual search was assessed by asking ED to detect a red T among red Xs and blue Ts. Stimuli included 40 10 cm × 15 cm white cards on which 9 letters had been drawn. Twenty cards contained a red T as well as four red Xs and four blue Ts; target absent stimuli included five red Xs and four blue Ts. On target present stimuli the target appeared in each of the four quadrants on five stimuli. The cards were presented free-field until ED responded.

3.2. Results

ED responded relatively quickly (typically in 1–2 s) and accurately (24/24 correct) on the pre-attentive task. In contrast, on the attention-requiring task he responded slowly with a mean of approximately 10 s. He was correct on 16/20 trials on the target present trials and on 5/20 on the target absent trials for an overall correct response rate of 21/40 ($d' = 0.1542$).

3.3. Discussion

ED performed perfectly on the pre-attentive task but at chance on the attention-requiring search task. As stimuli were presented free-field for several seconds, the data do not prove that ED's pre-attentive processing was normal but they suggest that his ability to register the presence of a visual feature is at least relatively preserved. In contrast, his performance on the attention-requiring visual search was quite poor. Given free-field presentation for an unlimited time, ED detected the target on 80% of trials but produced false positive responses on 75% of trials in the target absent condition. His perfect performance on the pre-attentive task strongly suggests that this performance cannot be attributed to a failure to understand the task, memory limitations or other "non-specific" factors.

Several possible explanations for his poor performance on the attention-requiring visual search task may be identified. For example, ED may have been impaired in "disengaging" attention from the stimuli; that is, ED may have "locked onto" the first attended stimulus and then been unable to shift his attention from this item. We (Pavese et al., 2002) and others (Verfaellie et al., 1990) have reported simultanagnosic subjects who exhibited a "disengage" deficit. While such an impairment would explain the facts that ED's search was extremely slow and that he missed the target on 20% of trials, it would not explain the fact that he reported seeing a target on 75% of target absent trials.

An alternative account is that ED was unable to efficiently bind color and form information. On this account, both false positive responses or illusory conjunctions, and misses would reflect the miscombination of form and color information. More specifically, illusory conjunctions would reflect the fact that when attending to a location at which a non-target was present, the color of a non-target miscombined with the shape of a non-target to generate the percept of a target. Misses would reflect the same miscombination except that in this instance when attending to the target, the color from a nearby non-target would miscombine to generate the percept of a non-target.

The two accounts briefly described above are not mutually exclusive and both factors may be contributing to ED's deficit. The presence of frequent illusory conjunctions, however, provides strong evidence that the binding of color and form information is impaired. We address one possible reason for this binding deficit in the next experiment.

4. Experiment 2: illusory conjunctions

A number of accounts of illusory conjunctions may be identified. On Feature Integration Theory, illusory conjunctions are attributed to impaired spatial attention. If, as suggested by Treisman and colleagues (Treisman, 1998; Treisman & Schmidt, 1982), visual features are processed in parallel in discrete "feature maps" and spatial attention directed to locations at the "master map of locations" serves to bind the visual feature information into a coherent, perceptual unit, a disruption of spatial attention would be expected to disrupt the binding of visual features to a common location with the result that the "free-floating" visual features miscombine to generate percepts that are not present in the array. Consistent with this account, illusory conjunctions are observed in normal subjects under conditions in which the attentional resources are exceeded, such as with short stimulus exposure (Treisman & Schmidt, 1982) or conditions with high attentional demands (Prinzmetal, Presti, & Posner, 1986; Wheeler & Treisman, 2002).

A second possibility is that illusory conjunctions are attributable to spatial imprecision; on this account, illusory conjunctions are not caused by a disruption of the attention-requiring process by which the relevant locations in the multiple visual feature maps are linked together but instead reflects an inability to precisely register the location of the visual feature information. A loss of precision in spatial representations might be expected to cause illusory conjunctions because nearby but distinct visual features would be perceived as being coterminous.

A third possibility is that illusory conjunctions are attributable to a disruption in the process by which information in different visual feature maps is linked to a common spatial reference (the "master map of locations"); on this account, the deficit is attributed to a pathologic reduction in the number of visual feature maps that may be maintained in registration with the master map of locations; we previously offered a similar account for the deficits of a simultanagnosic subject (Coslett & Saffran, 1991).

In an attempt to distinguish between these explanations for illusory conjunctions ED was asked to determine if a "T" was present in an array of horizontal and vertical lines. There are several relevant differences between this task and the attention-requiring task in Experiment 1. First, based on an analysis of the task demands, we suggest that the binding requirements – that is, the capacity to link information represented in visual feature maps to a common spatial reference frame – are reduced in this experiment as compared to Experiment 1. In Experiment 1, maps of the following visual features are relevant: red, green, vertical lines, horizontal lines and oblique lines. In Experiment 2, only two feature maps are relevant: vertical and horizontal lines. We reasoned that if ED produces illusory conjunctions because of a deficit in the processes by which information in relevant feature maps is selected and linked to a common site, one would expect to observe relatively few illusory conjunctions in this experiment because binding requirements may be less in this task than in the previous experiment. In contrast, if, for ED at least, illusory conjunctions are attributable to imprecise coding of spatial location or deficit spatial attention as postulated by Feature Integration Theory, one would expect a substantial number of illusory conjunctions in this task because the limiting factor on these accounts – precision in location marking or an inability to direct spatial attention at the master map of locations – is not influenced by the number of relevant visual feature maps.

4.1. Methods

The four types of stimuli employed are shown in Fig. 2. All stimuli contained 20 vertical and/or horizontal lines 10 mm in length on white 7.5 cm × 12.5 cm cards. Twenty cards contained nine vertical and nine horizontal lines as well as a 'T' composed of horizontal and vertical lines. The T was located in each quadrant of the respective cards on five trials. Twenty cards contained 10 randomly placed vertical and 10 randomly placed horizontal lines. All lines were separated by at least 10 mm. Finally, 20 cards contained 20 lines of the same orientation; 10 cards included only vertical and 10 only horizontal lines. Cards were presented free-field in random sequence for an unlimited time; on each trial, ED was asked to say yes if a T was present.

4.2. Results

ED responded 'yes' to 17/20 cards with a 'T'; 15/20 cards with a vertical and horizontal line but no 'T'; and 3/20 cards containing only vertical or horizontal lines. ED was unable to reliably discriminate between cards containing a 'T' and those not containing a 'T'. ED was, however, significantly more likely to indicate the presence of a T in the presence of both vertical and horizontal lines as compared to trials on which lines of a single orientation were present (Fisher's Exact Test, $p < 0.001$).

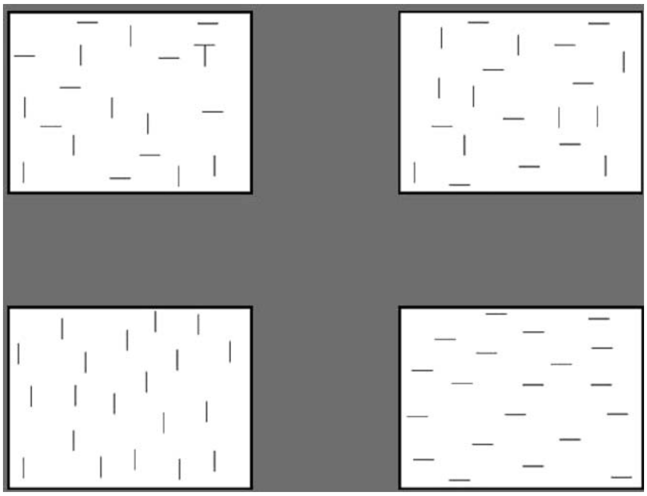

Fig. 2. Illustrations of the stimuli used in Experiment 2.

4.3. Discussion

ED was as likely to report a T on trials when only horizontal and vertical lines were present as when a T was in the display. These responses are unlikely to reflect a failure to understand the task or a response bias because he rarely reported a "T" when the constituent elements were not present. As previously noted, if ED's illusory conjunctions arise as a consequence of a failure to bind visual feature information represented in multiple maps to a common spatial reference, one would expect fewer illusory conjunctions on this task as compared to the task employed in Experiment 1. Thus, these data do not support the hypothesis that ED's illusory conjunctions are attributable to a pathologic reduction in the number of visual features that can be maintained in registration. Instead, the results are consistent with the hypothesis that ED suffers from imprecise marking of location because of a primary deficit in spatial resolution or an impairment in spatial attention. We return to an attempt to distinguish between these hypotheses in Experiment 5.

5. Experiment 3: illusory conjunctions in letter naming

The presumed illusory conjunctions reported in Experiments 1 reflected the incorrect conjunction of color and form whereas in Experiment 2 illusory conjunctions were attributable to the fact that line segments combined to form an apparently holistic perceptual unit, a T. Experiment 3 was performed to explore the possibility that ED would produce illusory conjunctions in which elements of one integrated perceptual unit miscombined with another integrated perceptual unit. This type of illusory conjunction has been reported by a number of investigators with letter stimuli (Butler et al., 1991; Treisman & Gelade, 1980). Treisman and Gelade (1980), for example, reported an experiment in which letter pairs that differed by the presence of an oblique line served as stimuli (e.g., R/P, Q/O, Y/X). They found that when attentional demands were high, the oblique line present in one letter could recombine to generate a different letter; for example, subjects sometimes reported an R when presented an array containing P and X. Similar results were reported by Butler et al. (1991) in partial report and two-alternative forced choice tasks in normal subjects.

To determine if ED would generate illusory conjunction errors in which one element of a familiar perceptual unit miscombined with another familiar perceptual unit, he was asked to name two letters presented simultaneously. If visual feature information is not precisely marked with respect to location one might expect that visual features from one letter might be integrated with the visual features of the other letter, thereby generating a "blending" of the visual features.

Stimuli included letter pairs that differed in several important dimensions. First, on the logic motivating the studies of Treisman and Gelade (1980) and Butler et al. (1991), one might expect ED to report a letter that was not present in the array if shown letter pairs from which a different letter could be generated by shifting one visual feature (e.g., an oblique line or curved segment) from one letter to another. In contrast, letter pairs for which a translocation of a single feature would not generate a different letter would not be expected to be associated with incorrect reports of letters not in the array.

Letter case was also manipulated. On some trials, block, upper case letters were employed whereas on other trials, lower case letters were presented. We reasoned that the former are comprised of a limited number of elements: vertical, horizontal and oblique lines as well as rounded segments. Lower case letters, in contrast, are more variable with respect to the number and size of their constituent elements (see Treisman & Souther, 1986 for a similar view). On this logic, reports of letters that are not in the array would be expected to be less frequent with lower case letters as compared to upper case block letters.

5.1. Methods

Stimuli included 12.5 cm × 17.5 cm white cards on which two letters measuring approximately 1.25 cm in height and 5 mm apart were printed. At ED's viewing distance of approximately 50 cm. The letters were approximately 1.4° of visual angle in height and were separated by 0.6° of visual angle. There were two conditions, one involving block, upper case letters and the other lower case letters. There were, in turn, two types of stimulus pairs. "Blend Pairs" were operationally defined as letter pairs for which the shift of one letter segment (e.g., vertical line and horizontal line) from one letter to another could generate a different letter pair; for example, the letter pair "RO" was regarded as a blend pair because shifting the oblique segment from the "R" onto the "O" would generate a "Q). "Non-Blend pairs" were letter pairs for which a letter could not be generated by shifting one letter element from one letter to another (e.g., "SM"). There were a total of 8 non-blend and 12 potential blend pairs. The same 20 pairs of letters were also presented in lower case.

Table 1
Two letter naming

Independent variables	Two letters cor.	One letter cor.	Blends	Probability of blends	
				High	Low
Upper case	16/40	22/40	15/40	13/24	2/16
Lower case	28/40	10/40	2/40	2/24	0/16
Red/black	27/40	11/40	6/40	4/24	2/16

Upper case letter pairs were presented in one session and lower case letter pairs in a second session. Each card was presented free-field until ED responded. He was told that two letters were present on all trials and was asked to name the letters. The 20 pairs of upper and 20 pairs of lower case were both presented on two occasions separated by weeks.

5.2. Results

Stimuli and ED's responses are presented in Appendix A. As performance was similar across the two administrations for both the upper and lower case letters, the data were collapsed. As indicated in Table 1, ED reported both upper case letters correctly on 16/40 trials. He reported one letter correctly and one letter incorrectly on 22/40 trials; on 2 trials he reported both letters incorrectly. Of greatest relevance is that he produced errors that may have reflected a feature of one letter 'migrating' to the other letter on 15/40 trials. These possible blend errors were not randomly distributed; ED produced possible blend errors on 13/24 (54%) potential blend trials but only 2/16 (13%) non-blend pairs, a difference that is significant (Fisher's Exact Test, $p = 0.0095$).

ED reported both lower case letters correctly on 28/40 trials. He reported one letter correctly and one letter incorrectly on 10/40 trials and neither letter correctly on 2/40 trials. He reported both letters correctly on a significantly higher proportion of trials with lower as compared to upper case letters (16/40 versus 28/40; Fisher's Exact Test, $p = 0.0129$). Moreover, ED made fewer possible blend errors with lower case letters (2/40 versus 15/40, Fisher's Exact Test, $p = 0.0007$). Finally, in contrast to the upper case stimuli, there was no difference in the rate of potential blend errors for the blend as compared to non-blend pairs (Fisher's Exact Test, $p = 0.5077$).

5.3. Discussion

ED reported letters that were not present in the array and may have been generated by a letter component migration on a substantial number of trials. As predicted, his performance was modulated by letter case as well as the blend/non-blend distinction. These responses were unlikely to be attributable to deficits in the registration of visual feature information or in the retrieval of letter names; neither of these factors would explain the fact that ED performed more reliably with lower as opposed to upper case letters or the significant effect of the blend/non-blend distinction.

These data are consistent with studies involving normal subjects in demonstrating that features from one familiar perceptual unit may re-combine with visual information from another familiar perceptual unit to generate a stimulus not present in the array (Butler et al., 1991; Treisman & Gelade, 1980). The substantial difference in performance on the blend as compared to non-blend pairs suggests that top down influences limit the consequences of the coarse coding. More specifically, we assume that the tendency for letter features to migrate is present with both blend and non-blend stimuli; for the latter, however, stored information about letter identity interacts with "bottom up" perceptual information such that there is a bias to perceive familiar letters (cf., Humphreys, 1998).

These data do not adjudicate between accounts that attribute ED's illusory conjunctions to coarse coding as opposed to a deficit in spatial attention.

6. Experiment 4: two letter naming with color

Although the systematic effects of letter case and the blend/non-blend distinction support the claim that many of ED's errors were illusory conjunctions, one might still argue that ED's performance reflected a guessing strategy or deficits in higher level cognitive operations, such as word retrieval or memory. Ivry and Prinzmetal (1991) found that illusory conjunctions occurred more frequently between letters that were similar in color as compared to letters that were different colors, perhaps because color is perceptually salient and therefore serves to effectively segregate visual feature information. In light of this observation, we reasoned that if the blend errors described in the previous experiment were attributable to a miscombination of visual feature information, the use of different colors would serve to segregate the letters, thereby increasing ED's overall level of performance and reducing blend errors. In contrast, if the errors reflected guessing strategies or other types of deficits, this manipulation would not be expected to influence performance.

To address this issue the same 20 pairs of upper case block letter pairs employed in Experiment 3 were administered on two other occasions more than 1 month later; in this task, however, one of the letters was written in red ink whereas the other was in black ink. As indicated in Table 1, ED reported both letters significantly more frequently in the red/black condition as compared the black/black condition (27/40 versus 16/40; Fisher's Exact Test, $p = 0.024$). Furthermore, errors that could be interpreted as 'blends' were observed significantly less frequently with the red/black as compared to the black/black condition (6/40 versus 16/40, Fisher's Exact Test, $p = 0.023$). These results suggest that ED's difficulty with upper case letters was not attributable to guessing or post-perceptual deficits.

7. Experiment 5: blend errors as a function of distance

Data presented to this point confirm that ED produces a substantial number of illusory conjunctions on a wide range of tasks. In Experiment 2, several possible explanations for these illusory conjunctions were discussed. We argued that the results of Experiment 2 were inconsistent with an account that attributed ED's deficits to a reduction in the number of feature maps that could be maintained in registration with the master map of locations; the data were consistent with Feature Integration Theory as well as the theory that illusory conjunctions reflect coarse coding of visual feature information.

This experiment was undertaken in an attempt to discriminate between these accounts of illusory conjunctions in ED. We reasoned that if ED's illusory conjunctions are attributable to coarse coding of visual features, one might expect that the frequency of errors reflecting a miscombination of visual feature information – that is, blend errors – would decrease as a function of the distance between the letters. In contrast, if blend errors are attributable to a profound spatial impairment such that visual features are "free-floating", as predicted by Feature Integration Theory, one might expect to find that the distance between the letters did not influence performance.

The effect of proximity on visual feature miscombination has been explored in both normal and brain lesion subjects. As noted briefly in the introduction, data from normal subjects are inconclusive. Robertson et al. (1997) explored the effect of distance on illusory conjunctions in a series of investigations involving the simultanagnosic subject RM. With smaller stimuli separated by 2°, 4° or 6°, RM exhibited an inverse relationship between degree of separation and number of illusory conjunctions on a task in which he was asked to name both stimuli; illusory conjunctions were observed on 20%, 17% and 8% of trials at 2°, 4° and 6°, respectively. In contrast, with larger (1.75°) stimuli in a full report task with letters separated by 2°, 6° and 10°, he produced more illusory conjunctions as the degree of separation increased (0%, 8% and 30% respectively). Finally, on a task requiring that he report either one of two stimuli separated by 2°, 6° and 10° he exhibited no effect of stimulus separation, producing illusory conjunctions on 24%, 29% and 23% of trials.

Gilchrist, Humphreys, and Riddoch (1996) explored a somewhat related issue, the effect of stimulus separation on extinction, in the simultanagnosic subject GK. These investigators demonstrated that GK's ability to report both items in an array was significantly influenced by stimulus properties, such as collinearity that promoted "grouping" of the items. GK's extinction increased significantly as the distance between the stimuli increased.

To explore the effect of distance between the letters on the production of blend errors, the same 20 pairs of upper case letters described above were presented in two additional sessions. In one session, the letters were separated in the horizontal dimension by 2 cm (approximately 2.3° of visual angle) whereas in another session the letters were separated by 4 cm (approximately 4.6°). Performance in these conditions was compared to the condition in which the letters were adjacent (that is, separated by approximately 0.5 cm [0.6°]; see Experiment 3). Errors were scored as described in Experiment 3.

As can be seen in Table 2, ED produced significantly fewer blends when letters were separated by 2.0 and 4.0 cm as compared to the condition in which the letters were 0.5 cm apart (Fisher's Exact Test, $p = 0.034$ and 0.011, respectively). These data are consistent with the coarse coding account in that the incidence of blend errors is clearly influenced by the proximity

Table 2
Two letter naming: effect of distance

Distance (cm)	Two letters cor.	One letter cor.	Blends	Probability of blends	
				High	Low
0.5	16/40	22/40	15/40	13/24	2/16
2.0	1/20	19/20	2/20	1/12	1/8
4.0	2/20	18/20	1/20	1/12	0/8

of the letters. If blend errors reflected the miscombination of "free-floating" visual feature information, one would not expect a substantial effect of distance between the letters on the tendency to generate blends.

We recognize that the use of a block design in which different conditions were tested on different occasions can present problems by virtue of variability in performance across time or practice effects. As previously described, ED was quite stable across the months of testing reported here. In fact, the baseline condition in this task (letters separated by 0.5 cm) was assessed on two occasions approximately 3 months apart. The conditions involving 2.0 and 4.0 cm letter separation were administered in the interim. Performance was extremely similar on both administrations of the 0.5 cm separation condition, arguing that there was no significant effect of practice and demonstrating the stability of his performance across time.

Unfortunately, however, the data do not definitively adjudicate between the coarse coding and "free-floating" accounts. As indicated in Table 2, ED was significantly more likely to report both letters correctly in the 0.5 cm condition as compared to the 2.0 and 4.0 cm conditions (Fisher's Exact Test, $p = 0.005$ and 0.019, respectively). Thus, an alternative explanation is that ED did not generate blends when letters were separated by 2.0 or 4.0 cm because he only processed visual information from one letter on a substantial number of trials.

8. Experiment 6: reading scrambled words

In an initial assessment of ED's single word reading an unusual type of reading error was observed on a number of occasions. ED repeatedly produced "visual" errors in which the letters were substantially re-ordered. These re-ordering errors were observed occasionally when shown real words but with greater frequency with non-word letter strings. For example, he responded "home" to hmoe. A similar phenomenon has been observed in previous simultanagnosic subjects reported by Coslett and Saffran (1991) and Robertson et al. (1997). For example, RM (Robertson et al., 1997) read WAS as "saw" and BDE as "bed". Experiment 6 was performed to systematically explore this phenomenon.

One possible interpretation of these data is that ED identified the constituent letters adequately but was unable to map the location of the letters. Spatial uncertainty in conjunction with top-down influences from the visual word form system would cause the letters to be re-arranged to form a familiar word. Similar arguments regarding the interaction of bottom-up and top-down influences in perception have been made by a number of investigators including Humphreys (1998) and Farah (2000).

This account predicts differential effects as a function of the type of letter string. ED would be expected to read familiar words well as the as top-down information regarding letter sequence would be available for these words and would be likely to be consistent with the letter string as presented. If letter combinations that could constitute a real word are available but mis-sequenced, one would expect the top-down influences to lead to a re-sequencing of the letters to generate a familiar word on at least some trials. In contrast, if letter strings are presented that could not be re-sequenced to generate a familiar word, there would be relatively little top-down information to support a re-sequencing of the letters with the result that the ED would be unlikely to report a word. Instead, like several previously reported simultanagnosic subjects (Baylis et al., 1994; Coslett & Saffran, 1991), he would be expected to name individual letters.

In contrast, if ED's reading errors reflect either frequent letter misidentification or an unconstrained bias to report a word when confronted with a letter string, one might expect ED to make a substantial number of errors reflecting letter misidentification to familiar words and to report familiar words when shown letter strings that could not be re-sequenced to generate familiar words. To test these predictions ED was asked to read 15 high frequency nouns as well as two sets of non-word letter strings derived from these nouns.

8.1. Methods

Stimuli included 15 four-letter words; the letter sequence was CVCV (e.g., lake) for 10 words and CVVC (e.g., boat) for 5 words. Two additional sets of non-words were generated from these stimuli. One type of stimulus included letter strings in which the letters were re-arranged to produce non-word letter strings. A second type of non-word letter string was generated from the real words except that the vowels were replaced by the consonants "d", "l", "p" or "k". Stimuli are presented in Appendix B.

Letter strings were printed in lower case letters ranging in height from approximately 8 to 15 mm on white cards and individually presented to ED for an unlimited time at a distance of approximately 50 cm. He was told that some letters strings were words whereas others were not and was asked to name the words or letters. The three sets of stimuli were presented in different testing sessions several weeks apart.

Responses were scored as correct, visual errors, or partial report. Visual errors were responses that included 50% or more of the letters in the target letter string. Visual errors were further divided into those in which the letters were mis-sequenced (e.g., *velo* read as "love"), letter substations (*droa* read as "door") and letter omission/addition (e.g., *tsea* read as "tea"). Partial report errors included responses in which one or two letters were reported.

8.2. Results

Results are presented in Table 3 and Appendix B. ED read 12 of the 15 words correctly; all errors involved letter substitution or omission/addition. With scrambled words ED produced a real

Table 3
Categories of response to written strings in Experiment 6

	Words ($n = 15$)	Scrambled words ($n = 15$)	Consonant strings ($n = 10$)
Correct	12	0	0
"Visual" errors	0	0	0
Letter re-sequencing	2	8	0
Letter substitution	0	3	0
Letter omission/addition	1	3	0
Partial report	0	1	10

word on 14/15 trials. Eight trials involved the re-sequencing of the letters in the array; for example, he responded "home" to mhoe and "boat" to btoa. Three errors involved a single letter substitution and three responses involved letter omission or addition. There was one partial report error. Finally, when shown consonant strings, ED never reported seeing a word. He reported one or two letters on all 10 trials. Unfortunately, responses to five stimuli are not available.

8.3. *Discussion*

Although these data must be interpreted cautiously because of the small numbers of observations, the major finding is that when shown letter strings that could be re-sequenced to create familiar words, ED often generated responses that involved a substantial re-ordering of letters in the array. These responses are distinct from the "lexicalization" errors commonly observed in subjects with acquired alexia in that they do not contain letter substitutions, additions or deletions. Furthermore, like previously reported simultanagnosic patients (Baylis et al., 1994; Coslett & Saffran, 1991), when shown consonant strings, ED typically named one or two of the consonants rather than a familiar word. Finally, ED was at least relatively good (80% correct) at reading familiar words.

Although ED did exhibit errors that appeared to reflect misidentification of individual letters both in reading and when shown letter pairs (Experiment 2), this is unlikely to be the sole explanation for his performance; misidentification of letters in conjunction with a tendency to lexicalize would be expected to lead to erroneous reports of real words but not the striking degree of re-ordering described above. Additionally, if ED frequently misidentified letters one might expect him to lexicalize consonant strings. We suggest that these data are consistent with the hypothesis that ED identifies letters relatively accuracy but is unable to code their spatial location.

The hypothesis that word form information may partially compensate for degraded perceptual information is, of course, not novel. Similar arguments have been advanced to explain the performance of normal subjects with brief stimulus presentation (e.g., McClelland & Mozer, 1986; Mozer, 1983; Shallice & McGill, 1977; Treisman & Souther, 1986) as well as subjects with neglect dyslexia (Arduino, Burani, & Vallar, 2003; Behrmann, Black, McKeff, & Barton, 2002). In the latter disorder, the perceptual disorder typically affects the left side of the letter array with the consequence that top-down influences typically give rise to substitutions, additions and deletions early in the letter string. As ED suffers from bihemispheric lesions, the entire letter array is compromised with the result that the substitutions, additions, deletions and re-ordering of the constituent letters involves the entire array. In this sense, ED is more similar to a patient reported by Saffran and Coslett (1996) with "attentional dyslexia" in the setting of the posterior variant of Alzheimer's Disease.

9. General discussion

ED exhibits at least relatively good pre-attentive or parallel visual search but is impaired in serial search. He not only fails to detect stimuli defined by a conjunction of visual features but also makes frequent errors that suggest that visual feature information has been miscombined. His deficit is apparent on tasks involving surface detail (e.g., "red T"; Experiment 1) as well as form ("Is there a T?"; Experiment 2). Illusory conjunctions are observed in which form elements shift from one object to another (Experiment 3). Errors are also observed in which elements of one perceptual unit appear to shift position resulting in the perception of an "object" that is not present in the array. Top-down influences from stored perceptual units appear to constrain his performance on tasks involving the detection of letters (Experiment 2), feature migration between letters (Experiment 3) and letter re-sequencing in non-word letter strings (Experiment 5). Finally, the number of illusory conjunctions was significantly decreased by increasing the distance between stimuli. In many of these respects, he is similar to simultanagnosic subjects reported by Humphreys et al. (2000) and Robertson and colleagues (e.g., Robertson, 2004; Robertson et al., 1997). It should be noted, however, that illusory conjunction errors have not been observed in all simultananosics to whom appropriate tests were administered (e.g., Coslett & Saffran, 1991).

How can these errors be explained? Following a number of investigators (e.g., Humphreys et al., 2000), we suggest that grouping procedures and other low-level visual routines (e.g., Ullman, 1984) operate pre-attentively to segregate visual feature information into local regions of coherence and, perhaps, candidate forms. Investigations in monkeys (e.g., Moran & Desimone, 1985) and man (Farah, 2000; Humphreys et al., 2000) have demonstrated that top-down effects influence processing in early visual cortices. In light of these pervasive and powerful effects, we assume that this pre-attentive, coarse parsing of the visual array is influenced by information from the object-recognition system and that this information serves to strengthen the associations between the visual feature elements that together correspond to familiar patterns or "objects". Thus, the recognition of an upper case "R" is facilitated by stored information that helps to maintain the spatial relations between the vertical, oblique and curved elements that comprise the letter. When confronted with a two-letter array containing RO, we assume that the constituent visual features (e.g., vertical segment, horizontal segment and curved elements) are activated. Visual attention, directed by subjects' expectations, goals and stored information about object form, is assumed to select a candidate region (or object), leading to the integration of visual feature information at the relevant location. The identification of both letters, then, would be expected to critically depend on the quality of the visual feature information, the ability to direct attention to the relevant location of the retinotopically organized visual feature maps, the precision of the co-registration of the feature information and the influence of top-down information from the object recognition system.

Although hypotheses regarding the nature of ED's impairment must be interpreted with caution given the strongly interactive nature of the visual system, one account of ED's perceptual deficit is that he suffers from a loss of precision in the registration of visual information (see also Robertson et al., 1997). Several lines of evidence support this assertion. First, ED was as likely to report seeing a "T" in an array containing only vertical and horizontal lines as he was when there was, in fact, a "T" in the array. This finding would be expected if he were unable to mark the precise location of the features. Furthermore, as previously noted, the fact that ED produced frequent illusory conjunctions on this task as well as on the form and surface ("red T") conjunction task for which the binding requirements would appear to be greater suggests that a limitation in the capacity to link information across multiple feature arrays is not the critical deficit. Finally, his tendency to produce blend errors in which features from one letter appear to migrate to a different letter is significantly influenced by the distance between the letters: he produces frequent blend errors with letters separated by 0.5 cm but rare blend errors on trials on which the letters are separated by 2.0 or 4.0 cm. ED's strikingly abnormal performance reading non-word letter strings (Experiment 6) is also consistent with the coarse coding account; in this task, ED's performance suggests that he identified letters at least relatively accurately but that the location of the constituent letters was not maintained; as a consequence, the letters, presumably under the influence of stored knowledge from the word recognition system, were recognized as familiar units. It should also be noted here that ED's report of words that appeared to be generated by re-sequencing non-word letter strings also argues strongly against the claim that his deficit is attributable to impaired input from object/word recognition systems; indeed, his performance on this task may be taken as evidence that stored knowledge has a disproportionate impact for ED, presumably because of the impairment in marking location of integrated visual feature information.

We acknowledge that the data from ED are also consistent with Feature Integration Theory (Treisman, 1998; Treisman & Gelade, 1980). In fact the coarse coding account and Feature Integration Theory are quite closely related. Indeed, as on Feature Integration Theory, the precision with which feature information is coded is influenced by visual attention, the coarse coding account may be viewed by some investigators as a variant of Feature Integration Theory. Although the coarse coding hypothesis and Feature Integration Theory generate very similar predictions, on at least some interpretations of Feature Integration Theory, they may differ in one respect. The former assumes that spatial information is imprecise but not absent whereas on the latter account information regarding the location of visual features is unavailable. Thus, as noted previously, the coarse coding account predicts an effect of distance on illusory conjunctions while Feature Integration Theory predicts that visual features would be "free-floating" with the consequence that distance between stimuli would not influence the incidence of illusory conjunctions. Data from Experiment 5 demonstrating a significant effect of distance between the letters on illusory conjunctions support the coarse coding account. It must be noted, however, that these data are not unambiguous; as ED reported two letters on fewer trials when the distance between the letters increased, one might argue that the reduction in illusory conjunctions in this condition is a reflection of his failure to "see" both letters when separated by 2 or more centimetres.

A comparison of the data from Experiments 3 and 6 is of interest with respect to the effects of stimulus type and task demands on ED's performance. Recall that in Experiment 3 ED produced a substantial number of illusory conjunctions when asked to name two letters. Responses in which letters were reported correctly but in the wrong position were rare. For example, ED reported both letters correctly but in the incorrect position (that is, QP in response to PQ) on only two trials; similarly, he correctly identified one letter but reported it to be in the wrong position (e.g., "CL" in response to LX) on only two trials. In contrast, when asked to name a letter string, ED appeared to re-sequence non-word letter strings to generate real words on numerous trials.

There may be several explanations for the discrepancy in ED's performance on these two tasks. One possibility is that stimuli in Experiment 6 were printed in lower case letters whereas the letters in Experiment 3 were presented in upper case. As previously noted, blend errors were uncommon with lower case letters. There is at least one other factor that should be considered, however. The fact that ED generated illusory conjunctions between letters in Experiment 3 but produced responses that appeared to reflect the re-ordering of letters when shown letter strings may be a function of ED's encoding and selection strategy. Support for this possibility comes from the report by Butler et al. (1991) who demonstrated that normal subjects exhibited either illusory conjunctions involving letter features (e.g., the oblique line of an "R") or letter mislocalizations depending on the nature of the task. Thus, subjects produced letter mislocalizations but few illusory conjunctions on a bar-probe task in which letter location was relevant. In contrast, subjects produced illusory conjunctions but no letter mislocalizations with the same stimuli on a letter identification task in which the stimuli differed by a single feature (e.g., R versus P).

We suggest that for both letter pairs and letter strings ED's errors reflected a miscombination of the elements that were relevant to the task at hand. That is, when identifying letter pairs, the line segments, arcs and circular elements that comprise the letters become the basic perceptual unit because they represent the elements that distinguish between letters. In contrast, when attempting to read words, letters constitute the basic perceptual unit. Thus, on our account ED's illusory conjunctions in letter identification and mis-sequencing of letters in word reading reflect the same underlying deficit, coarse coding of the visual information that is germane to the task at hand.

As indicated in Fig. 1, ED's lesion involved the parietal lobes and superior occipital lobes bilaterally. Although the extent of the lesions complicates the attempt to define the anatomic basis of his deficit in feature integration, a comparison of the lesion data from ED and other simultanagnosic subjects with bilateral lesions permits tentative conclusions regarding the anatomic basis of simultanagnosia with illusory conjunctions. We (Coslett & Chatterjee, 2003) recently reported lesion data from four simultanagnosic subjects. Two subjects, ED and IC (Pavese et al., 2002), exhibited deficits in visual attention with markedly impaired visual search and frequent illusory conjunctions. Their lesions overlapped in the superior occipital and occipito-parietal cortex. Two additional simultanagnosic subjects, BP (Coslett & Saffran, 1991) and JD, In preparation) exhibited bilateral inferior parietal lesions; neither of these subjects produced illusory conjunctions. We attributed their deficits to a pathologic restriction in the linking of representations computed in the dorsal and ventral visual pathways. The data from these four simultanagnosic subjects are thus consistent with the claim that the parieto-occipital and superior parietal cortex represents the anatomic basis for the deficits in visual attention and frequent illusory conjunctions. This finding appears to be consistent with anatomic data from RM, for whom high quality anatomic information is available (e.g., Friedman-Hill et al., 2003; Robertson et al., 1997); RM's lesion involves BA 19.

The account offered by Coslett and Chatterjee (2003) is also consistent with data from functional imaging studies. Corbetta, Shulman, Mizzin, and Peterson (1995) reported increased cerebral blood flow as indexed by PET scanning in the superior parietal cortex during a task in which subjects searched for a target defined by a conjunction of color and motion. More recently, Shafritz et al. (2002) demonstrated that visual feature location binding of the type demonstrated by ED involved the activation of bilateral superior parietal cortex as well as left cerebellum. Additionally, Piazza, Giacomini, Le Bihan, and Dehaene (2003) reported increases in bilateral intraparietal sulcal activation during a serial attention-requiring but not a pre-attentive parallel search task. Finally, Ashbridge, Walsh, and Cowely (1997) reported that TMS in the region of the posterior superior parietal lobe on the right was associated with a slowing of conjunction search without affecting feature search.

Appendix A

Letter pairs	Black/black	Black/black	Black/red	Lower case	Lower case
Non-blend pairs					
CL	+	+	+	+	+
XO	+	+	+	yo	yo
WS	+	+	+	+	+
EC	EX	+	+	+	es
OW	**QX**	+	ov	+	ou
VS	+	+	+	+	+
QI	+	+	**QP**	+	+
SE	SX	**SP**	+	+	+
Blend Pairs					
BF	**BB**	**BE**	**RE**	**BP**	+
LX	+	CL	+	+	+
MT	**MN**	**MX**	+	+	+
HF	**HE**	**HH**	+	+	+
IH	+	HP	+	**TH**	IB

Appendix A (*Continued*)

Letter pairs	Black/black	Black/black	Black/red	Lower case	Lower case
FL	**FE**	**EL**	+	+	+
RP	RS	CR	+	+	+
NL	**HN**	NP	+	hz	+
ZF	ZP	**ZX**	**ZE**	zp	pf
LT	+	**LE**	+	+	+
RO	**PQ**	**RQ**	RE	+	ib
KT	KR	+	VT	+	kl

Errors interpreted as "blends" are bold.

Appendix B

Stimulus	Response
Words	
home	home
make	Mayhem
seat	same
rose	rose
name	name
book	boot
date	date
lake	lake
more	more
love	love
menu	meet
boat	boot
road	road
feet	feet
pipe	pipe
Scrambled words	
mhoe	home
aekm	make
tsea	tea
orse	horse
nmae	name
ookb	book
edta	eat
alke	like
emor	more
velo	love
enum	numb
btoa	boat
droa	door
eetf	feet
peip	p
Consonant strings	
hlmk	m
mrkl	no data
sldt	d
rksl	ks
nkml	no data
bdlk	b
dltp	no data
lpkd	d
mprl	lp
lkvd	l
mknl	nm
bdpt	b
rpkd	no data
fplt	p
plpk	no data

References

Arduino, L. S., Burani, C., & Vallar, G. (2003). Reading aloud and lexical decision in neglect dyslexia patients: A dissociation. *Neuropsychologia*, *41*(8), 877–885.

Arguin, M., Cavanagh, P., & Joanette, Y. (1994). Visual feature integration with an attentional deficit. *Brain and Cognition*, *24*, 44–55.

Ashbridge, E., Walsh, V., & Cowely, A. (1997). Temporal aspects of visual search studied by transcranial magnetic stimulation. *Neuropsychologia*, *35*(8), 1121–1131.

Ashby, F. G., Prinzmetal, W., Ivry, R., & Maddox, T. (1996). A formal theory of illusory conjunctions. *Psychological Review*, *103*, 165–192.

Balint, R. (1909). Seelenlahhmung des "Schauens," optische Ataxie, raumliche Storung der Aufmerksamkeit. *Monatschr Psychiatrie Neurology*, *25*, 51–81.

Baylis, G. C., Driver, J., Baylis, L., & Rafal, R. (1994). Perception of letters and words in Balint's syndrome: Evidence for the unity of words. *Neuropsychologia*, *32*, 1273–1286.

Baylis, G. C., Driver, J., & McLeod, P. (1992). Movement and proximity constrain miscombinations of colour and form. *Perception*, *21*, 201–218.

Behrmann, M., Black, S. E., McKeff, T. J., & Barton, J. J. (2002). Oculaographic analysis of word reading in hemispatial neglect. *Physiology and Behavior*, *7*(4–5), 613–619.

Butler, B. E., et al. (1991). When do letter features migrate? A boundary condition for feature integration theory. *Perception Psychophysics*, *49*, 91–99.

Cohen, A., & Ivry, R. B. (1991). Density effects in conjunction search: Evidence for a coarse location mechanism of feature integration. *Journal of Experimental Psychology (Human Perception and Performance)*, *17*, 891–901.

Cohen, A., & Rafal, R. D. (1991). Attention and feature integration: Illusory conjunctions in a patient with a parietal lobe lesion. *Psychological Science*, *2*, 106–110.

Corbetta, M., Shulman, G. L., Mizzin, F. M., & Peterson, S. E. (1995). *Science*, *270*, 802–805.

Coslett, H. B., & Chatterjee, A. (2003). Balint's syndrome and related disorders. In T. E. Feinberg & M. J. Farah (Eds.), *Behavioral neuroscience and neuropsychology* (2nd ed.). New York: McGraw-Hill.

Coslett, H. B., & Saffran, E. (1991). Simultanagnosia: To see but not to see. *Brain*, *114*, 1523–1545.

Donk, M. (1999). Illusory conjunctions are an illusion: The effects of target-nontarget similarity on conjunction and feature errors. *Journal of Experimental Psychology (Human Perception and Performance)*, *25*, 1207–1233.

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

Farah, M. J. (2000). *The cognitive neuroscience of vision*. Oxford: Blackwell.

Farah, M. J., Brunn, J. L., Wong, A. B., Wallace, M. A., & Carpenter, P. A. (1990). Frames of reference for allocating attention to space: Evidence from the neglect syndrome. *Neuropsychologia*, *28*(4), 355–447.

Friedman-Hill, S. R., Robertson, R., Desimone, R., & Ungerleider, L. G. (2003). Posterior parietal cortex and the filtering of distractors. *Proceedings of the National Academy of Sciences*, *100*, 4263–4268.

Friedman-Hill, S. R., Robertson, L. C., & Triesman, A. (1995). Parietal contributions to visual feature binding: Evidence from a patient with bilateral lesions. *Science*, *269*, 853–855.

Gilchrist, I., Humphreys, G. W., & Riddoch, M. J. (1996). Grouping and extinction: Evidence for low-level modulation of selection. *Cognitive Neuropsychology*, *13*, 1223–1256.

Humphreys, G. W. (1998). Neural representation of objects in space: A dual coding account. *Philosophical Transactions of the Royal Society of London*, *353*, 1341–1351.

Humphreys, G. W., Cinel, C., Wolfe, J., Olson, A., & Klempen, N. (2000). Fractionating the binding process: Neuropsychological evidence distinguishing binding of form from binding of surface features. *Vision Research*, *40*, 1569–1596.

Husain, M., & Stein, J. (1988). Rezxo Balint and his most celebrated case. *Archives of Neurology*, *45*, 89–93.

Ivry, R. B., & Prinzmetal, W. (1991). Effect of feature similarity on illusory conjunctions. *Perception Psychophysics*, *49*, 105–116.

McClelland, J. J., & Mozer, M. C. (1986). Perceptual interactions in two word displays: Familiarity and similarity effects. *Journal of Experimental Psychology. Human Perception and Performance*, *12*, 18–35.

Moran, J. C., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, *229*, 782–784.

Mozer, M. C. (1983). Letter migration in word perception. *Journal of Experimental Psychology. Human Perception and Performance*, *9*, 531–546.

Navon, D. (1977). Forest before the trees: The precedence of global features in visual perception. *Cognitive Psychology*, *9*, 353–383.

Pavese, A., Coslett, H. B., Saffran, E., & Buxbaum, L. (2002). Limitations of attentional orienting: Effects of abrupt visual onsets and offsets on naming two objects in a patient with simultanagnosia. *Neuropsychologia*, *40*, 1097–1103.

Piazza, M., Giacomini, E., Le Bihan, D., & Dehaene, S. (2003). Single-trial classification of parallel pre-attentive and serial attentive processes using funtional magnetic resonance imaging. *Proceedings of Biological Sciences*, *270*(1521), 1237–1245.

Prinzmetal, W., Henderson, D., & Ivry, R. (1995). Loosening the constraints on illusory conjunctions: The role of exposure duration and attention. *JEP: HPP*, *21*, 1362–1375.

Prinzmetal, W., Ivry, R., Beck, D., & Shimizu, N. (2002). A measurement theory of illusory conjunctions. *Journal of Experimental Psychology. Human Perception and Performance*, *28*(2), 251–269.

Prinzmetal, W., & Keysar, B. (1989). A functional theory of illusory conjunctions and neon colors. *Journal of Experimental Psychology. General*, *118*, 165–190.

Prinzmetal, W., Presti, D. E., & Posner, M. I. (1986). Does attention affect visual feature integration? *JEP: HPP*, *12*, 361–369.

Rajaram, S. (1996). Perceptual effects on remembering: Recollective processes in picture recognition memory. *Journal of Experimental Psychology. Learning, Memory and Cognition*, *22*(2), 365–377.

Robertson, L. (2004). *Space, objects, minds, and brains*. New York: Psychology Press.

Robertson, L., Treisman, A., Friedman-Hill, S., & Grabowecky, M. (1997). The interaction of spatial and object pathways: Evidence from Balint's syndrome. *Journal of Cognitive Neuroscience*, *9*, 295–317.

Saffran, E. M., & Coslett, H. B. (1996). Attentional dyslexia in Alzheimer's Disease: A case study. *Cognitive Neuropsychology*, *13*, 205–228.

Sagi, D., & Julesz, B. (1985). What and where in vision. *Science*, *228*, 1217–1219.

Shafritz, K. M., Gore, J. C., & Marois, R. (2002). The role of the parietal cortex in visual feature binding. *Proceedings of National Academy of Sciences*, *99*, 10917–10922.

Shallice, T., & McGill, J. (1977). The origins of mix errors. *Attention and Performance*, *7*, 193–208.

Treisman, A. (1998). Feature binding, attention and object perception. *Philosophical Transactions of the Royal Society of London, Series B*, *353*, 1295–1306.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

Treisman, A. M., & Schmidt, H. (1982). Illusory conjunctions in the perceptions of objects. *Cognitive Psychology*, *14*, 107–141.

Treisman, A., & Souther, J. (1986). Illusory words: The roles of attention and of top-down constraints in conjoining letters to form words. *Journal of Experimental Psychology (Human Perception and Performance)*, *12*(1), 3–17.

Ullman, S. (1984). Visual routines. *Cognition*, *18*, 97–159.

Valenza, N., Murray, M. M., Ptak, R., & Vuilleumier, P. (2004). The space of senses: Impaired crossmodal interactions in a pateinet with Balint syndrome after bilateral parietal damage. *Neuropsychologia*, *42*(13), 1737–1748.

Verfaellie, M., Rapcsak, S. Z., & Heilman, K. M. (1990). Impaired shifting of attention in Balint's syndrome. *Brain and Cognition*, *12*, 195–204.

Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, *131*, 48–64.

Wolfe, J. M. (2003). Moving towards solutions to sme enduring controversies. *Trends in Cognition Sciences*, *7*(2), 70–76.