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Global perception in simultanagnosia is not as simple as a game of connect-the-dots

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ABSTRACT

Simultanagnosia is a neuropsychological disorder characterized by a restriction of visuospatial attention. In addition, patients are able to identify local elements of a scene, but not the global whole. This may be due to a failure to scan and assemble local elements into a global whole (i.e. connect-the-dots). We monitored the eye movements of a simultanagnosic patient while she identified local and global elements of hierarchical letters. Scanning each local element was not necessary, nor sufficient, for successful global level identification. Our results argue against a connect-the-dots strategy of global identification and suggest that residual global processing may be occurring.

1. Introduction

Simultanagnosia is a rare neuropsychological disorder that reflects in part a restriction of visuospatial attention. Classically a patient with simultanagnosia is said to be aware of only a single object at any one time (Moreaud, 2003; Rafal, 2003; Rizzo & Vecera, 2002). It typically occurs with bilateral lesions of the parieto-occipital junction, and is often a component of Bálint syndrome (Rizzo, 1993).

Some studies have shown that simultanagnosia can be associated with an abnormal direction of attention towards smaller, local, elements of a scene at the expense of larger global elements, a phenomenon called 'local capture' (Dalrymple, Kingstone, & Barton, 2007; Huberle & Karnath, 2006; Karnath, Ferber, Rorden, & Driver, 2000). This is reflected in the narrative of simultanagnosic patients describing visual scenes, which suggests a piecemeal approach and a failure to integrate the individual elements into a coherent whole (Dalrymple et al., 2007; Duncan et al., 2003; Humphreys & Price, 1994; Rafal, 2003). Local capture has been investigated experimentally with hierarchical stimuli (Dalrymple et al., 2007; Karnath et al., 2000; Rafal, 1997), such as large 'global' letters made up of several repetitions of smaller 'local' letters (Navon, 1977). Simultanagnosic patients identify local letters well, but are poor and inconsistent at identifying global letters, sometimes naming them successfully on one trial, only to fail on the next (Dalrymple et al., 2007; Huberle & Karnath, 2006; Karnath et al., 2000).

By monitoring the eye movements of simultanagnosics while they identified the local and global levels of hierarchical stimuli, Clavagnier and colleagues (2006) concluded that inconsistent global level identification in simultanagnosia is not due to an inability to disengage from the local elements of the stimulus, because the patients fixated multiple areas of the stimuli, rather than staying fixed on a single local letter. Patients made significantly more eye movements than control subjects and almost appear to trace the contour of the global letter with their eyes. If their inability to process the global level of these stimuli cannot be accounted for by an inability to disengage from local elements, what is an alternative explanation for their difficulties with this task?

Previously we tested a simultanagnosic patient (SL) while she identified the local and global levels of hierarchical stimuli (Dalrymple et al., 2007). SL's unsuccessful attempts at identifying the global level of hierarchical letters were often characterized by a close approximation of the global letter shape (e.g. reporting P when the global letter was a B). This suggests that SL's success or failure may depend on specific exploration of critical parts of a stimulus that distinguish the true letter from the mistakenly reported one. While healthy subjects can see all elements of the hierarchical stimulus at once, restricted visual attention may limit simultanagnosic patients to seeing only portions of the stimulus in the vicinity of their current fixation. Accordingly, their perception at a global level would require assembly and integration of

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the local elements processed in sequential fixations (i.e. "connecting-the-dots"). In support of this hypothetical assembly of global identities from local elements, simultanagnosic patients are better at naming the global form of hierarchical letters that are small and contain densely packed local elements (Dalrymple et al., 2007; Huberle & Karnath, 2006), conditions that place more neighbouring local elements within a spatially constricted attentional window. Furthermore, patients are better at identifying the global letter when using a finger to passively trace the global shape (Karnath et al., 2000), also suggesting the implementation of a 'connect-the-dots' strategy.

We monitored the eye movements of a simultanagnosic patient (SL) while she performed local and global identification tasks in separate trials to determine whether successful global letter identification requires thorough scanning and assembly of local elements (i.e. "connecting the dots"). If this hypothesis is correct, SL's incorrect global responses will be close shape approximations to the actual identity of the global letter. Furthermore, this hypothesis predicts that SL's unsuccessful global trials will be characterized by a failure to scan the critical region of the stimulus letter that distinguishes it from other possible letter identities.

2. Method

2.1. Participants

2.1.1. Patient SL: case report

Patient SL is a 49 year-old right-handed woman, with 12 years of education. She had idiopathic cerebral vasculitis resulting in bilateral parietal and lateral occipital infarcts (Fig. 1). She had been treated with cyclophosphamide and prednisone for her vasculitis, but had completed these 4 months prior to her testing. At the time of testing she was on carbamazepine for a single seizure suffered several months prior. She presented with left hemi-neglect, as assessed with the Sunnybrook Neglect Assessment Battery (Leibovitch et al., 1998), left inferior quadrantanopia, and Balint syndrome, with ocular motor apraxia, optic ataxia, and simultanagnosia, though her acuity was 20/25 in both eyes. Her optic ataxia was evident in that she often mis-reached for objects, and failed to orient her grasp correctly to the axes of objects such as pencils. Her simultanagnosia was evidenced through tests with four complex displays of visual scenes. For example, she could report elements of the Boston Cookie Theft picture (Goodglass & Kaplan, 1983), but was unable to make sense of the whole scene. She initially reported seeing only "a boy's face... eyes," without reporting the mother on the right side of the display or the second child in the scene, nor did she describe the action in the scene. Neuropsychological evaluation showed normal attention, language, and verbal memory functions. Her reading was in the borderline impaired range and she tended to guess words based on the first or last letters. She was successful at recognizing simple line drawings of objects and could correctly identify colours and simple shapes.

At the time of testing, several months after onset, SL no longer showed left hemi-neglect or quadrantanopia and had no defects in saccadic targeting and generation, as was confirmed by her rapid and accurate saccades during the calibration of the eye monitor. However she still showed optic ataxia when using the left hand to point to targets. This was a specific sensorimotor transformation for the contralateral hand, and therefore not a due to a general difficulty with perceptual localization (which would affect both hands). Patient SL has been discussed in previous reports (i.e. Dalrymple et al., 2007; Malcolm & Barton, 2007).

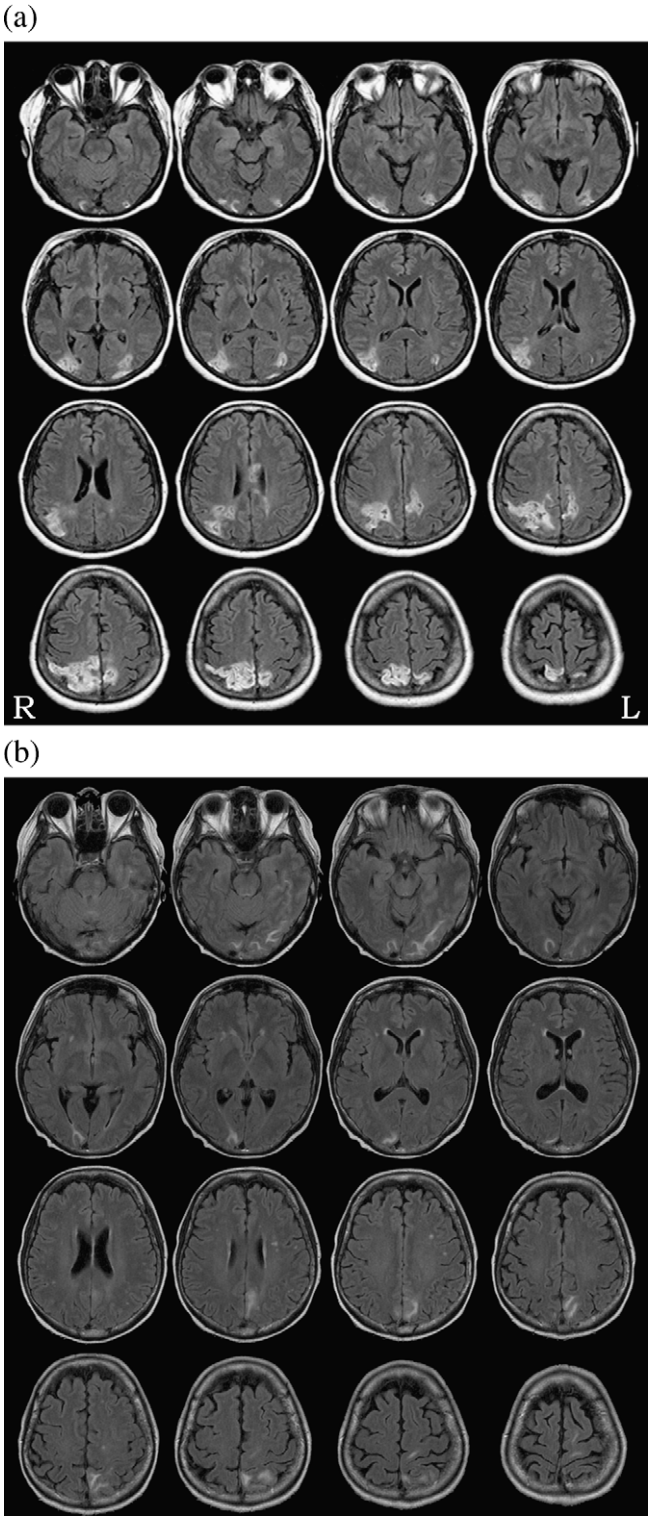

Fig. 1. Axial FLAIR sequences of MRI scans of (a) patient SL, and (b) patient ES. White areas indicate hyperintense signal in damaged brain regions. R = Right, L = Left side of the brain.

2.2. Control subjects

Healthy control participants ($N = 8$; five male) were volunteers from the community, who ranged in age from 40 to 57 years (mean = 51 years). All participants reported normal or corrected-to-normal vision and gave informed consent prior to participation

in the experiments, which were performed in accordance with the ethical guidelines of UBC.

2.3. Brain damaged control

2.3.1. Patient ES: case report

As an additional control, we tested another patient, ES, who had also suffered bilateral posterior occipitoparietal damage, but never had simultanagnosia. ES matched SL well in age, gender, the chronic phase at testing, and probable pathology, since she also has an underlying condition that is associated with vasculitis. She is a 47 year-old woman with systemic lupus erythematosis. She was tested several months after presenting with flashing lights and transient visual loss for 30 min, followed by headache. Her visual examination was normal, but MR imaging revealed bilateral occipital and parietal lesions consistent with either vasculitis or posterior leucoencephalopathy. Subsequently she had a seizure, and was treated with phenytoin for 9 months. At her most recent visit she was taking prednisone, chloroquine, and mycophenolate mofetil. Her visual acuity without correction at far was 20/20 in both eyes. Confrontation showed full visual fields. Fixation, pursuit and saccades were normal. There was no nystagmus, oculomotor apraxia or optic ataxia. There was no simultanagnosia as demonstrated by normal report on the Boston Cookie Theft picture.

3. Experiment

3.1. Stimuli and apparatus

Hierarchical letters (global upper-case letters made up of several repetitions of smaller, local upper-case letters) were presented on a 33×24.5 cm monitor corresponding to $36.5^\circ \times 27.5^\circ$ at the viewing distance of 50 cm. All letters were black uppercase and on a white background. All letters of the alphabet were eligible for use except local letters M, O, W, because their adjacent elements overlapped in dense global displays. Global and local letters were never the same. Stimuli were sampled with replacement (letters could recur within the same block) preventing subjects from deducing the identity of the letters based on which letters had been displayed. Letters were created in three different sizes and densities, for a total of nine different Size $\times$ Density combinations (Fig. 2; see also Dalrymple et al., 2007). Global letters averaged, $17.4^\circ \times 15.3^\circ$ for large stimuli, $8.9^\circ \times 7.0^\circ$ for medium, and $5.9^\circ \times 4.7^\circ$ for small. Inter-element spacing ranged from 3.3° for large/sparse stimuli to 0.06° for small/dense stimuli.

EyeLink II and 1000 systems detected saccades with an amplitude of at least 0.5° using an acceleration threshold of 9500 deg/s^2 and a velocity threshold of 30 deg/s. Fixations were defined as the epochs between successive saccades.

3.2. Procedure

For SL each block started with the experimenter stating that the target letter was Global or Local. On each trial the task was to fixate a central circle, which then disappeared and after 500 ms it was replaced by a target letter. SL named the target as quickly as possible. The experimenter keyed in the response (to avoid inaccurate reaching by SL) and this terminated the trial and triggered the next trial's fixation circle. The procedure was identical for Control subjects, except that they pressed a spacebar when the target was identified and entered their response on the keyboard. ES verbally reported her response, at which point the experimenter pressed the spacebar to terminate the trial and subsequently entered the response on the keyboard.

Trials were blocked by Size–Density configuration, and by task (Global or Local). Thus subjects performed nine blocks of Global target letters and nine blocks of Local target letters. Each block consisted of 11 trials. Patients SL and ES performed the Global before Local blocks. For Controls, the order was counterbalanced across participants. For all participants the trials within each block, and the blocks within a target level, were randomized.

4. Analysis

The data from one control was excluded from analysis because she did not complete all conditions. For all ANOVAs all of SL and ES's trials for each block were used; the average measures per

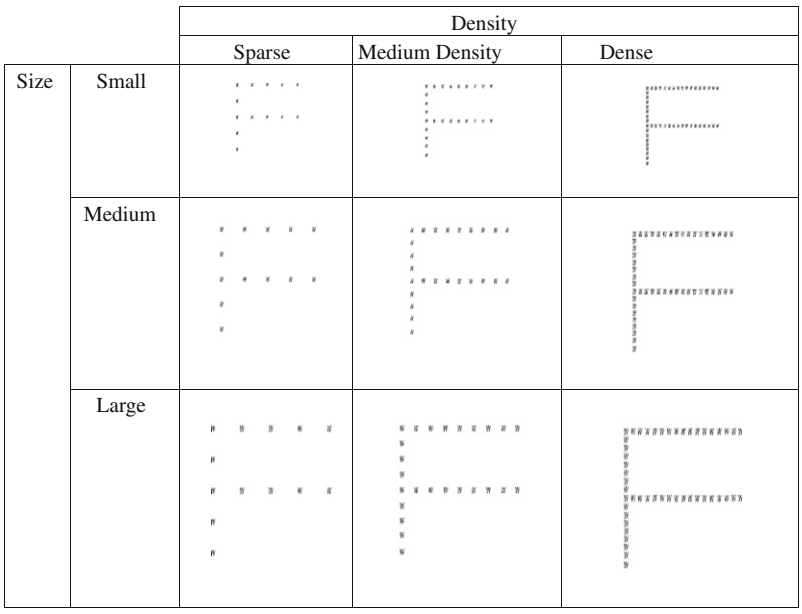

Fig. 2. Examples of the Navon hierarchical letters of each size and density used. Size refers to the dimensions of the global stimulus. Density refers to the degree to which the global letter is packed with local elements (more dense = more local elements)

block were used for each healthy control participant. All alpha levels were set to $p < 0.05$.

We analyzed the data set at three different levels:

4.1. Accuracy and basic eye movement measures

Basic performance on the Local and Global letter identification tasks was assessed, in terms of accuracy and the key scanning measures of number of fixations, fixation duration, and saccade amplitude.

4.2. Critical difference analysis

This analysis was designed to determine whether SL's incorrect Global reports were due to failures to scan the segments of the actual letters that made them distinct from her reported letter. This analysis determined whether, during unsuccessful trials, SL failed to fixate the part of a Global letter that made it distinct from other letters of the alphabet. For all Global trials that the patient identified unsuccessfully, we compared the shape of the actual Global letter to the shape of the letter that the patient reported. We then determined what part of the actual letter was 'Critically Different' from the reported letter. For example, if the actual letter was 'R', but the patient reported 'P', the area that is critically different between the two letters is the diagonal line of the 'R'. The Critical Difference between two letters can be the presence of a letter segment, such as the presence of the diagonal line on the letter 'R', the absence of a segment, such as the absence of a diagonal line on the letter 'P', or a combination of the presence and absence of various segments (i.e. Letters 'M' and 'N': 'M' can be distinguished from 'N' by the presence of a segment in the top right side of the 'M', and the absence of a segment on the bottom right of the 'M') (Fig. 3).

The shape and area of Global letters were defined by drawing a circle with a radius of 1° around each local letter. The patient's erroneous response letter on a given unsuccessful trial was overlaid on the actual letter that was presented on that trial. This determined the 'Critical Difference Area' between the two letters. Next, the patient's fixations on that trial were overlaid on the Critical Difference Area to determine what proportion of the fixations for that trial landed within this area.

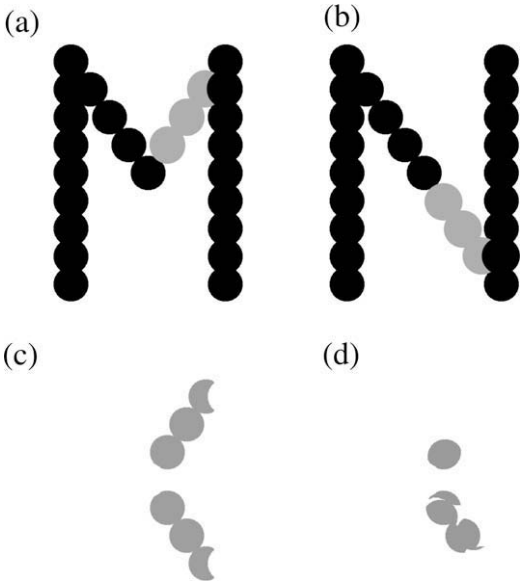

Fig. 3. Example of steps involved in determining fixation overlap with critical area: (a) identifying the actual letter viewed and tracing an area of 1° around each local element; (b) identifying the reported letter and tracing an area of 1° around each element; (c) identifying the critical area: the area of the actual letter and the reported letter that does not overlap; (d) determining the area of overlap between SL's fixations (defined by 1° around each fixation) and the critical area.

4.3. SL global task – successful vs. unsuccessful trials

We compared SL's eye movements on unsuccessful global trials to her eye movements during successful global trials to determine whether any other differences exist in her scanning technique that could account for her global processing deficit. While such comparisons have been made before in two patients with Balint syndrome (Clavagnier et al., 2006), Local and Global levels were identified simultaneously in the same trial in that prior report, and thus it was not possible to determine whether eye movements were being driven by processes involved in Local or in Global letter identification. In contrast, our patient performed Local and Global identification on separate trials. We also included new measures of scanning behaviour aimed at assessing where the patient's eye movements were distributed. This included the following:

(i) The amount of letter area[1] fixated, expressed as a proportion of the total letter area (the total proportion of the letter stimuli covered by each fixation, summed over all fixations and divided by the total amount of letter area, in pixels);
(ii) the average letter area covered per fixation;
(iii) the total proportion of the background covered by each fixation, summed over all fixations and divided by the total amount of background area, in pixels.

5. Results

5.1. Accuracy and basic eye movement measures

5.1.1. SL vs. Controls

5.1.1.1. Accuracy. We compared SL's Accuracy to that of Controls using a 4-way ANOVA with factors of Subject (Patient vs. Controls), Level (Global vs. Local), Density (Sparse, Medium Density, Dense), and Size (Small, Medium, Large). A significant effect of Subject, $F(1,4) = 11.74$, $p < 0.001$; Level, $F(1, 4) = 6.52$, $p = 0.011$; and Density, $F(2, 4) = 7.64$, $p < 0.001$. There was also a significant Subject by Level interaction, $F(1, 4) = 4.86$, $p = 0.028$; Subject by Density interaction, $F(2, 4) = 8.18$, $p < 0.001$; and Level by Density interaction, $F(2, 4) = 4.43$, $p = 0.013$. No other results were significant. To understand these interactions, Local and Global performance was analyzed with separate 3-way ANOVAs (see Fig. 4).

Local task: A 3-way ANOVA with factors of Subject, Density and Size revealed no significant main effects or interactions, indicating that SL did not differ from Controls in terms of Accuracy for naming the Local level of letters (Patient = 96% vs. Controls = 99%, $F(1, 4) = 1.44$, $p = 0.232$).

Global task: Controls were near-perfect at naming the Global letters, and significantly better than SL overall (Patient = 84% vs. Controls = 98%; $F(1, 4) = 10.57$, $p = 0.001$). There was a significant main effect of Density, $F(2, 4) = 7.70$, $p < 0.001$. Bonferroni Multiple Comparisons revealed that subjects were significantly worse at the Sparse letters (mean = 76%), compared to the Medium Density (mean = 94%) or Dense letters (mean = 99%). However, a significant Subject by Density interaction, $F(2, 4) = 6.89$, $p = 0.001$, indicates that this effect was driven by SL's accuracy pattern: while her accuracy varied with stimulus Density, $F(2, 4) = 11.50$, $p < 0.001$,

[1] All area measures were calculated by drawing a circle with radius of 1 degree of visual angle around each local letter of the stimulus and around each fixation.

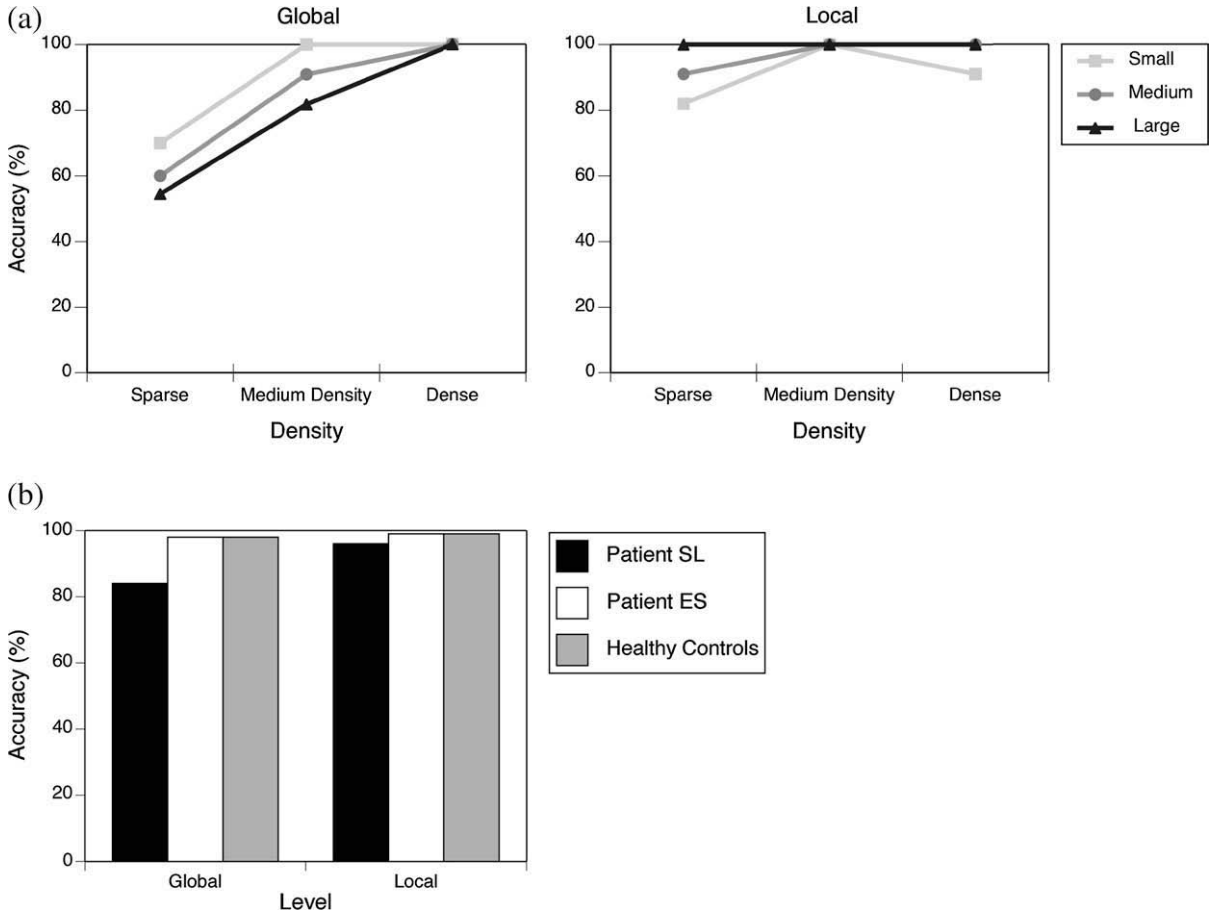

Fig. 4. (a) SL's accuracy (%) for naming global and local letters. (b) Overall accuracy for SL, ES, and healthy Controls, for identifying letters the global and local levels. Accuracy in (b) is collapsed over stimulus size and density because the performance of ES and healthy controls was at ceiling for all conditions.

Sparse = 61%, Medium Density = 91%, Dense = 100%, the accuracy of Control subjects did not, $F(2, 4) = 0.34$, $p = 0.710$.

5.2. Eye movements

Number of fixations, mean fixation duration, and mean saccade amplitude were analyzed with Subject, Level, Density and Size as factors.

5.3. Number of fixations

There were main effects of Subject, $F(1, 4) = 27.82$, $p < 0.001$, indicating that SL made significantly more fixations than Control subjects (13.63 vs. 3.80); Level, $F(1, 4) = 4.06$, $p = 0.045$, indicating that subjects made more fixations for Global than Local letters (11.99 vs. 7.58); and Density, $F(2, 4) = 3.21$, $p = 0.042$ with Bonferroni tests revealing that subjects made more fixations when identifying Sparse than Dense letters (13.63 vs. 7.23) with Medium Density (8.49) not differing from the two extremes. No other effects were significant.

5.4. Fixation duration

There were main effects of Subject, $F(1, 4) = 225.11$, $p < 0.001$, indicating that SL's durations were shorter than the fixations of Controls (457.00 vs. 264.60 ms); and Letter Size, $F(2, 4) = 4.25$, $p = 0.015$. Bonferroni tests revealed that durations were longer when identifying Small vs. Large letters (365.28 vs. 319.21 ms), with Medium letters (336.03 ms) not different from either Small or Large letters. No other effects were significant.

5.5. Saccade amplitude

There were main effects of Subject, $F(1, 4) = 262.30$, $p < 0.001$, indicating that SL's saccades were shorter than Controls (5.71° vs. 24.11°); and Level, $F(1, 4) = 4.64$, $p = 0.032$, indicating that saccades were larger overall for Global than Local letters (14.20° vs. 11.68°). No other effects were significant.

In summary, for both Local and Global targets, SL makes more fixations, of smaller duration and amplitude than Controls.

5.6. Brain damage control

In order to help disambiguate specific profiles of simultanagnosia from general effects of brain damage and related health problems, we tested one brain damaged control subject, ES. ES was chosen because she matched SL in terms of age, gender, and approximate lesion location, but ES was never simultanagnosic. This allows us to determine whether simultanagnosia itself is crucial to the behavioural effects observed in SL.

We compared ES to our healthy control group and to SL on measures of accuracy, number of fixations, fixation durations, and saccadic amplitude. We restricted our analyses to look at only at effects of Subject for each of the Global and Local tasks, respectively. Any main effects of Subject were followed up with a Bonferroni multiple comparisons test. Accuracy is presented in Fig. 4, while eye movement profiles are presented in Fig. 5.

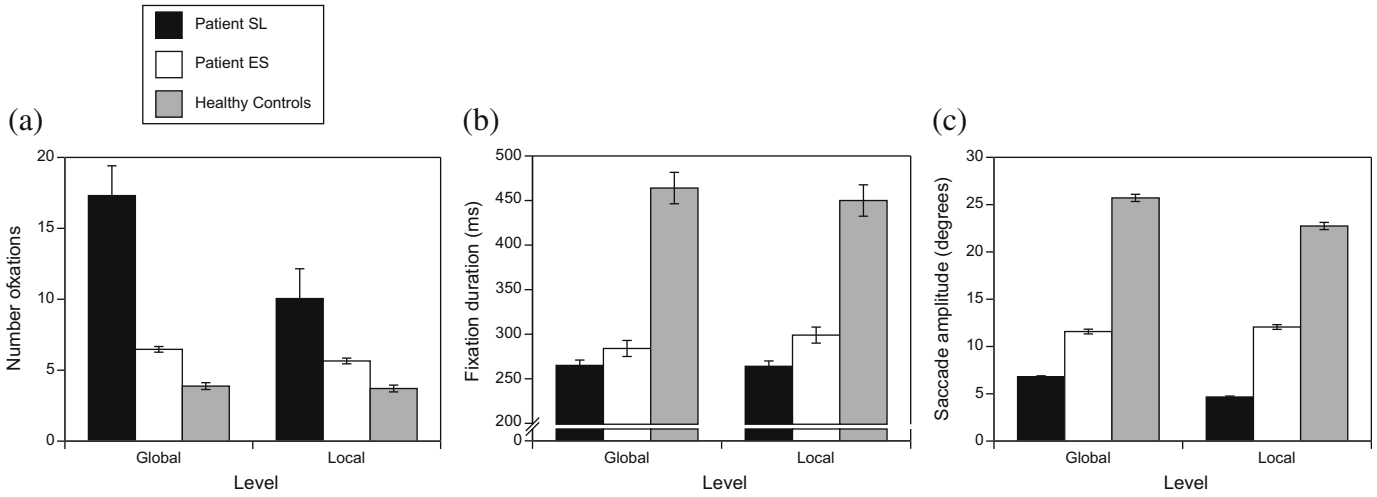

Fig. 5. Basic eye movement results for patients SL, ES, and healthy Control subjects for each of the global and local letter identification tasks: (a) mean number of fixations; (b) mean fixation duration; (c) mean saccade amplitude. Error bars represent standard error from the mean.

5.7. ES vs. controls vs. SL: global

5.7.1. Accuracy

We compared ES's accuracy to that of Controls and SL using a 1-way ANOVA with factors of Subject (ES vs. Controls vs. SL). There was a significant effect of Subject, $F(2, 255) = 9.70$, $p < 0.001$, indicating that SL's accuracy at the Global task was significantly worse than ES and Controls, who did not differ from each other (SL = 84%, ES = 98%, Controls = 98%).

5.7.2. Eye movements

There was a main effect of Subject for all eye movement measures, number of fixations $F(2, 255) = 12.75$, $p < 0.001$; fixation duration, $F(2, 255) = 93.08$, $p < 0.001$; saccade amplitude, $F(2, 255) = 107.89$, $p < 0.001$. SL made significantly more fixations than ES and Controls, who did not differ from each other (SL = 17.31, ES = 6.47, Controls = 3.88). In duration, Controls made significantly longer fixations than ES and SL, who did not differ from each other (SL = 265.09, ES = 284.04, Controls = 464.30 ms). SL had significantly shorter saccades than ES, who in turn had significantly shorter saccades than Controls (SL = 6.80°, ES = 11.58°, Controls = 25.51°).

5.8. ES vs. controls vs. SL: local

5.8.1. Accuracy

There was no significant effect of Subject, $F(2, 260) = 1.48$, $p = 0.229$, indicating that SL's accuracy at the Local task equivalent to that of ES and of Controls, who also did not differ from each other (SL = 96%, ES = 99%, Controls = 99%).

5.8.2. Eye movements

There was a main effect of Subject for all eye movement measures: number of fixations $F(2, 260) = 97.09$, $p < 0.001$; fixation duration, $F(2, 260) = 59.16$, $p < 0.001$; saccade amplitude, $F(2, 260) = 115.26$, $p < 0.001$. SL made significantly more fixations than ES, who made more fixations than Controls (SL = 10.05, ES = 5.65, Controls = 3.71). Controls made significantly longer fixations than ES and SL, who did not differ from each other (SL = 264.12, ES = 299.95, Controls = 449.70 ms). SL had significantly shorter saccades than ES, who had significantly shorter saccades than Controls (SL = 4.66°, ES = 12.06°, Controls = 22.74°).

In summary, ES had normal accuracy for both Global and Local letter identification. For eye movements on both tasks, ES made either similar or only slightly greater numbers of fixations than Controls, which were far fewer than those made by SL. However, the brevity of ES's fixations was more similar to SL than to Controls, and her saccades were smaller than those of Controls, though not as small as those of SL.

5.9. Critical difference analysis

SL's incorrect global responses are reported in Table 1. As predicted, SL's reports are close approximations of the actual global letter shape (e.g. reporting 'C' for the letter 'O'). To analyze whether her incorrect responses were due to a failure to scan the segments of the actual letters that made them distinct we designed and implemented our "Critical Difference" analysis. SL made errors on a total of 15 out of 96 Global trials. The overlap of the patient's fixations and the Critical Difference Area varied between 0% and 88%. Of note, she did fixate at least a portion of the Critical Difference Area on 87% of unsuccessful global trials.

5.10. SL global task – successful vs. unsuccessful trials

We performed 1-way ANOVAs with factor of Success (Successful vs. Unsuccessful) for each eye movement measure. SL made more fixations during Unsuccessful compared to Successful global trials (37.4 vs.13.59, $F(1, 95) = 8.52$, $p = 0.004$). However, SL's fixation durations and amplitudes did not vary with performance success.

SL made more fixations during Unsuccessful trials; where was she distributing these fixations? Analysis revealed that SL proportioned more of her fixations to the background during Unsuccessful than Successful global trials (0.063 vs. 0.030, $F(1, 95) = 17.99$, $p < 0.001$). There was no effect of letter area fixated and letter area encompassed per fixation. Thus, SL makes more fixations and scans more of the background during Unsuccessful compared to Successful Global trials.

6. Discussion

We tested the hypothesis that impaired perception of global forms in simultanagnosia results from a failure to adequately scan and then assemble local elements into a global whole. Our results confirm that SL has preserved perception of local elements and impaired global perception. In support of our hypothesis, SL's incor-

Table 1
Summary of SL's unsuccessful global trials and proportion of critical area fixated for each unsuccessful global trial (in order of viewing). Mean, high and low proportions are in **bold.**

Stimulus size	Stimulus density	Local letter	Global letter	Patient response	Proportion of critical area fixated
Medium	Medium	L	M	N	0.511
Large	Sparse	P	A	H	0.439
Large	Sparse	R	F	P	0.124
Large	Sparse	Q	A	H	0.159
Large	Sparse	Q	W	H	0.195
Large	Sparse	H	P	F	0.029
Small	Sparse	V	C	O	**0.000**
Small	Sparse	F	V	U	0.178
Small	Sparse	T	W	H	0.550
Large	Medium	F	Q	O	0.059
Large	Medium	F	C	O	0.000
Medium	Sparse	X	C	O	**0.875**
Medium	Sparse	D	S	B	0.109
Medium	Sparse	I	R	F	0.861
Medium	Sparse	H	N	H	0.239
				Mean	**0.289**

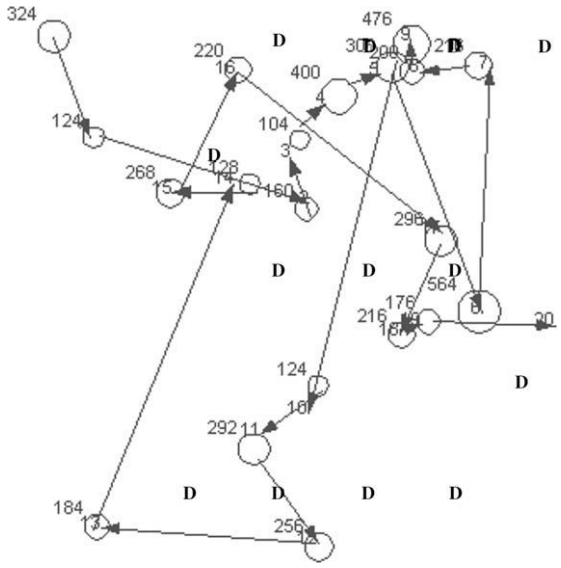

Fig. 6. Example of patient scan path for global trial. On this trial the patient incorrectly reported the global letter as a "B". Circles represent fixations. The size of circle represents the duration of the fixation, with larger circles representing longer fixations. Lines represent eye movements.

rect responses were often close letter-shape approximations of the correct letter, suggesting that part of her global-level problems may be the result of inadequate collection of local element data to differentiate similar letter forms.

Our "Critical Difference" analysis, however, did not support this hypothesis. This analysis examined whether SL was fixating the segments that distinguish the correct letter from her incorrect answer on unsuccessful global trials. SL scanned the critical difference area on all but two of her unsuccessful trials: for example, on one trial she reported that the letter 'F' was a letter 'P', despite scanning the open portion of the 'F' that would rule out the possibility that it was a 'P'. Conversely, a visual inspection of SL's trials indicated that there were no instances where she scanned the entire global form in order to correctly identify the global letter. Together, these findings indicate that fixating, or "connecting the dots" of the distinctive parts of the global shape, is neither necessary, nor sufficient, for SL to correctly discern their identity. These results have several implications.

First, SL's errors in identifying global letters despite fixating the portion of the letter that would invalidate the error could be due to a failure to process this information to a level of conscious awareness. Other research has shown that simultanagnosics can "look, but not see": stimuli disappear suddenly from their awareness despite steady fixation (Rizzo & Hurtig, 1987). Rizzo and Hurtig suggest that this abnormal disruption of visual awareness allows stimuli to be processed to a point where they can influence ocular motor movements, while not reaching a level of conscious processing. Thus, SL may be fixating the letter stimuli, but the information gathered during those fixations is not being processed to a level sufficient for identification of the global form.

Alternatively SL may acquire information where she is fixating, but may not correctly integrate it spatially with the information about other local elements. Rizzo and Robin (1990) have suggested that simultanagnosics may suffer from an inability to maintain continuous visuospatial attention across an array and that this could prevent multiple elements from being integrated so that spatial information is registered relative to each other. Similarly, Cooper and Humphreys (2000) have suggested that simultanagnosics have poor representations of the spatial relationship between elements such that, with no relative spatial information, they may even re-select the same object multiple times. This is consistent with SL's scanning patterns that show that she frequently revisits some elements, while failing to scan others (e.g. Fig. 6). Indeed, SL's increased fixation number may reflect persistent searching when a definitive (and correct) decision has not yet emerged, due to uncertainty on incorrect trials. The increased scanning of the empty background is of interest, and one interpretation of this result is that SL's failures are related to this excessive background scanning, perhaps due to getting 'lost' in empty space. However, SL fixated as much of the letter stimuli on unsuccessful as on successful global trials, so in principle she had ample opportunities to acquire local elements for global structure in both situations.

SL's successful performance on global trials is also informative. There are no instances where she scans all local elements. While it is possible that her occasional successes in global identification are due to successful assembly of the global shape from the local elements that she scans serially, her successful global letter identification could also be evidence of residual true global processing, rather than a feature-by-feature strategy. Other simultanagnosic patients have, like SL, been reported to struggle to name the global letters on some trials while successfully naming them on other trials (Clavagnier et al., 2006; Himmelbach, Erb, Klockgether, Moskau, & Karnath, 2008; Karnath et al., 2000; Shalev, Humphreys, & Mevorach, 2004; Shalev, Mevorach, & Humphreys, 2007). This behaviour has been correlated with fluctuations of brain activation in the posterior parietal cortex, the area affected in simultanagnosia (Himmelbach et al., 2008), suggesting a mechanism for preserved but unreliable global level perception in these patients.

In order to help disambiguate specific profiles of simultanagnosia from general effects of cerebral lesions and related health problems, we tested a second brain-damaged patient, ES. ES was age-matched, had bilateral occipitoparietal lesions, but was never simultanagnosic. Like SL, ES showed abnormal eye movements on our basic measures, making, in general, more fixations than healthy controls, fixations of shorter duration, and saccades of shorter amplitude, yet unlike SL, ES's performance was not impaired at either the global or local letter identification task. Therefore SL's impaired ability to report the global level of our hierarchical stimuli is likely a specific manifestation of her simultanagnosia, rather than a general result from bilateral posterior brain damage, or to her eye abnormal eye movements. Indeed our results ultimately show that aside from the amount of

background area scanned during global trials, SL's eye movements do not seem to predict her performance on this task.

We and others have shown that simultanagnosics are better at identifying global forms that are small and made up of densely packed local elements, yet are poor at identifying global forms that are large and made up of widely spaced local elements (Dalrymple et al., 2007; Huberle & Karnath, 2006). We replicated this finding, which suggests that forms that are easily grouped are available to the patient for conscious report. Other Gestalt rules, such as collinearity and closure, also predict patient performance (Cooper & Humphreys, 2000). The manipulations that promote global level perception in these patients are those that allow pre-attentive processing of the global shape (Cooper & Humphreys, 2000; Enns & Kingstone, 1995). Thus, it is possible that if a stimulus is pre-attentively packaged as a whole (e.g. small/dense letters), it will be explicitly available to the individual. The large/sparse letters, on the other hand, require attention to be grouped. Considering SL's limited attentional resources, this could make explicit report of the global form difficult.

With access to only a small portion of the scene at one time, increased inter-element spacing may also increase the demands on visual short-term memory (VSTM), suggesting another mechanism for SL's poor performance in these conditions. The capacity of visual short-term memory has been estimated to be limited to approximately 4 items (Luck & Vogel, 1997). Huberle and Karnath (2006) argue that if simultanagnosia is linked to a limitation of VSTM, the addition of more elements (and therefore VSTM load) would lead to impaired performance, the reverse of the improvement that is seen when patients view hierarchical letters made up of several, densely packed elements compared to a few, sparse elements. Using Bundesen's Theory of Visual Attention (TVA) Duncan et al. (2003) also suggested that VSTM capacity was not the primary deficit in simultanagnosia, instead suggesting a limitation of processing capacity. This is consistent with suggestions from others, who argue that simultanagnosia reflects deficits in sustained visual attention (Luria, 1959; Rizzo & Robin, 1990). Further research is necessary to clarify the role of VSTM in simultanagnosia.

7. Conclusions

Our results show that our simultanagnosic patient's failures of global level perception did not result from a failure to scan the parts of those letters that make them distinct from other, similar letters. Furthermore, scanning each individual element of the hierarchical letters was not necessary for successful global level perception. It is therefore unlikely that impaired global level perception in simultanagnosia is related to a failure of a strategic connect-the-dots pattern aimed at piecing together the identity of global letters. Rather, we found that unsuccessful global trials are characterized by excessive searching behaviour, reflected by increased eye fixations and greater coverage of background area. Beyond this, our patient's eye movements did not seem to predict her performance, suggesting that disrupted eye movements may not be the cause of her difficulties with the global letters, but rather the consequence of a breakdown in information processing.

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