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Research report

Density, connectedness and attentional capture in hierarchical patterns: Evidence from simultanagnosia

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ABSTRACT

We examined the effects of different grouping cues (item density, number and connectedness) on the ability of a patient with simultanagnosia (GK) to identify compound stimuli. In Experiment 1, the effects of density and connectedness on the recognition of global and local forms were examined. In Experiment 2, the spatial distance of local elements was manipulated by varying the size of the global forms and the number of local elements, to assess whether the distance between the local elements or their number determined the effects on global/local processing in disconnected patterns. The results showed that high item density and connectedness, each facilitates the grouping of local elements into global shapes, determined the explicit recognition of global stimuli in simultanagnosia. Moreover, in addition to any bias to attend to the local level, there was also evidence for attentional capture by stimuli at the global level. The data indicate that grouping processes still operate in simultanagnosia and can overcome biases to select at a local level. Any biases in selection can also be compounded by poor attentional disengagement.

1. Introduction

Simultanagnosia is a rare neuropsychological disorder caused by bilateral parieto-occipital brain damage which impairs the visual perception of several objects presented simultaneously whilst leaving relatively spared the visual perception of individual objects (Bálint, 1909; Holmes, 1918; Luria, 1959; Rafal, 1996). This disorder often occurs in the context of Bálint syndrome and is defined clinically by two main features: deficits in reporting two stimuli presented at the same time (e.g., Humphreys and Price, 1994) and difficulties in the description of complex scenes containing several objects (Humphreys and Price, 1994; Kinsbourne and Warrington, 1962; Luria, 1959).

In order to understand the underlying mechanisms in simultanagnosia, recent studies have examined the extent to which attentional and perceptual processing are preserved in patients (for a revision see Humphreys and Riddoch, 2006). There is now a considerable evidence that the aspects of perceptual organization (grouping and segmentation processes) can continue to operate even though the patients appear to be impaired at responding to multiple forms. For example, Luria (1959) classically reported that a patient would report a Star of David if two overlapping triangle had the same colour, but only reported the presence of a single triangle when the shapes had different colours. Humphreys and Riddoch (1993) showed that connecting elements together enabled patients to report whether the connected elements

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had the same or different colours, while Humphreys and Riddoch (2003) and Humphreys et al. (1994) observed that the presence of closure between visual elements affected which of two objects would be selected in a visual display (there was a bias to select the more closed of two stimuli). Other studies have indicated that collinearity, common shape, common closure and element familiarity can also affect visual selection (Gilchrist et al., 1996; Humphreys, 1998; Kumada and Humphreys, 2001; Shalev et al., 2007).

Although these results indicate that grouping processes may continue to operate in simultanagnosia, it remains the case that simultanagnosia patients are often impaired at perceiving global shapes when there are conflicting cues to guide attention to a more local level. In visual identification tasks, simultanagnosic patients can be affected by the presence of segmentation cues so that they report a part of an object as a whole stimulus (Riddoch and Humphreys, 2004). A striking example of this can occur when patients are presented with hierarchical compound letters, when they can be quite unaware of the identity of the global shape (e.g., see Karnath et al., 2000). Thaiss and De Bleser (1992) suggested that the impairment in the processing of global information in compound stimuli could reflect an artificially narrow spatial window of attention in the patients. However, other data contradict this. For example, several investigators have shown that there can be interference from global forms that cannot be explicitly identified (Karnath et al., 2000; Shalev et al., 2005), suggesting that there is implicit processing at a more global level. Huberle and Karnath (2006) have further argued that the ability to explicitly identify global compounds is modulated by grouping between the elements. They presented compound letters and varied the inter-element distances. Recognition of the global letter improved when the distance between the local elements was reduced. This result is similar to previous results with healthy participants showing better identification of global forms when the local elements are densely packed and better identification of the local level when the pattern is sparse (Martin, 1979; Lagasse, 1993; for a revision see Navon, 2003), though the effect is much exaggerated in the patients.

These data suggest that simultanagnosia cannot simply be explained in terms of patients having a limited spatial window of attention, though there may be an abnormal weighting in visual selection favouring local spatial regions. In addition, performance can also be affected by poor disengagement of attention once stimuli are selected. Humphreys et al. (1994) showed that simultanagnosic patients had more difficulty in identifying global compound stimuli when the local stimuli were closed rather than open forms, suggesting that the local closed forms tended to capture attention. Shalev et al. (2007) further showed that the ability to identify global forms was strongly affected by the familiarity of the local forms. In this study an English patient was able to identify English global letter forms made up of local Hebrew characters. However after training with the Hebrew letters there was a significant impairment in the ability to identify the global English forms. In this last case, attention seemed to be captured by the familiar local forms, preventing discrimination of the more global shapes.

In the present study we again examine the flexibility of stimulus processing in simultanagnosia, testing for a role of (i) different grouping processes (manipulated by varying the density of local elements and their connectedness) and (ii) attentional capture in generating the poor report of multiple elements. The starting point for the study was the report by Huberle and Karnath (2006) that global stimuli could be identified when the local elements were densely packed together. However, that study leaves open the question of whether performance is affected by the inter-element distance or by the total number of elements present. In two experiments we examined separately the effects of inter-element spacing and number of elements on the processing of global and local forms in a simultanagnosic patient and a group of healthy participants. In Experiment 1, we varied the number and density of the elements, and whether the elements were connected or not. In Experiment 2 we solely varied the density of the local elements and the size of the global patterns while keeping the number of items constant in the two main conditions. If inter-item spacing is critical, then the ability to report global forms should improve as the spacing between the local elements decreases. This is shown in both experiments. In addition, if connectedness operates to some degree independently of grouping based on the local density of elements (see Palmer, 1999, 2003; Palmer and Rock, 1994), then effects of connectedness should emerge even when the elements are too sparsely populated to generate grouping by local density.

On top of these tests of local grouping, we also assessed whether there could be a reversal of the 'standard' local advantage for simultanagnosic patients when there was strong local grouping. If attentional capture and impaired attentional disengagement also contribute to performance, then patients may be impaired at identifying local forms when grouping facilitates the selection of the global form. We show this result. Evidence for global capture provides a particular strong refutation of the proposal that there is a limited spatial window of attention. We discuss the implications of local grouping and global capture effects for understanding both perceptual report in simultanagnosia and for the nature of human perceptual organization.

2. Experiment 1: Manipulating density and connectedness on compound patterns

Experiment 1 examined the effects of element density and connectedness on the recognition of global and local forms in simultanagnosia. Density was manipulated in the manner of Huberle and Karnath (2006). We assessed if the density effects were overruled when grouping by connectedness was also present.

2.1. Method

2.1.1. Participants

A patient with simultanagnosia as well as six non-brain-damaged control participants was tested.

2.1.1.1. Patient GK. GK, a 67-year-old man, suffered two consecutive strokes in 1986 resulting in bilateral lesions affecting the right occipito-parietal, right temporo-parietal region and left temporo-parietal regions (see Humphreys et al., 2000, for a magnetic resonance imaging– MRI scan). As a result of the strokes, GK manifested Bálint's syndrome whose symptoms include optic ataxia (misreaching to visual targets), extinction and simultanagnosia. For example, GK had abnormal great difficulty in interpreting complex, multi-object scenes (such as the Boston Cookie Thief picture). He also showed poor report of two simultaneously presented objects relative to a presentation of single objects (Gilchrist et al., 1996; Humphreys et al., 2000). As well as being impaired with multi-element displays, GK also showed a lateral bias against item presented on his left side (Gilchrist et al., 1996), and he demonstrated visual neglect in bisection tasks. His ability to identify single objects and faces was relatively intact (Humphreys et al., 1993), though he had a tendency to identify a part as a whole stimulus (Riddoch and Humphreys, 2004). In addition, Shalev et al. (2005) noted that GK showed a poor explicit identification of global compound letters, tending to identify the local letters in such stimuli. However, these authors reported a reliable effect of implicit processing of global patterns when GK had to attend to the local stimuli. Data for the present paper were collected over a period between September and December, 2006. GK's performance remained stable during that period.

2.1.1.2. Controls. Six healthy age-matched volunteers (ages 63–75, mean age: 68.67, SD: 4.11) served as controls. All control participants had normal or corrected-to-normal vision. None had a history of neurological or visual disorders and all were right-handed.

2.1.2. *Stimuli and apparatus*

2.1.2.1. Patient GK. The stimuli were presented on a 17-inch colour computer display with a 75-Hz refresh rate and a resolution of 1600 × 1200 controlled by a microcomputer running E-Prime 1.1 software (Psychology Software Tools, 1996–2002). Viewing distance was about 60 cm.

2.1.2.2. Controls. The stimuli were presented on a 15-inch colour laptop display with a 60-Hz refresh rate and a screen resolution of 1024 × 768. Viewing distance was about 70 cm.

The stimuli consisted of large square and triangles made up of small squares and triangles. The dense global stimuli were made up of 24 local elements; the sparse global stimuli were composed of eight local elements. The local elements were printed in black and presented against a white background. Moreover, the connected stimuli were presented with grey lines joining local element together, 24 lines for dense and connected stimuli and eight lines for sparse and connected ones. The colour of the elements and the connecting lines was different (black and grey respectively) in order to differentiate between local components of the figures and perceptual grouping procedures. For the patient GK the size of the global shapes was 43 mm (about 4.11° of visual angle) vertically and horizontally. Each local shape measured 3 mm (about .29°) vertically and horizontally. Twelve different stimuli were presented in the experiment (see Fig. 1). In the case of controls, the size of the global patterns was 58 mm (about 4.74° visual angle) both vertically and horizontally. Local shapes measured 4 mm (about .33°) vertically and horizontally.

2.1.3. *Design and procedure*

A four-factor within subjects design was used with the following factors: attention condition (global-directed or local-directed), density (dense or sparse), connectedness (connected or disconnected) and consistency (consistent or inconsistent). In the globally directed condition, the subjects were instructed to attend selectively to the global letters while ignoring the local ones. In the locally directed condition, the subjects had to attend selectively to the local letters while ignoring the global ones. Dense global patterns were composed of many local elements; sparse global patterns were made up of few local elements. In the connected global patterns local elements were joined edge-to-edge by grey lines. If the global and local letters had the same identity, the stimulus was consistent; if the local and global letters had different identities, the stimulus was inconsistent.

Patient GK participated individually in two sessions with 192 experimental trials each. A session included two experimental blocks and two practice ones. Each experimental block consisted of 96 trials, whereas each practice block consisted of 24 trials. Each session lasted about 45 min. The second session was carried out a week later than the first one. Controls completed the experiment in a single session with two blocks of 192 experimental trials of both. There were 384 experimental trials in total.

Subjects were instructed to make their responses as quickly as possible while making as few errors as possible. Each trial started with the presentation of a cross-shape fixation mark at the centre of the screen; when the subject detected the fixation point and was ready to start the next trial, the experimenter pressed a mouse's key and, then, a visual stimulus was presented at the centre of the screen until response. The participant had to indicate the identity of the stimulus at the level to be attended (global or local) by pressing a numerical keyboard button (number 1 or 2) using the middle and index fingers of the dominant hand. The inter-trial interval was 1000 msec and it started when the subjects made their responses. The attention condition was blocked. The factors of density, connectedness and consistency of the local and global elements were randomised within blocks. The order of the blocks was counterbalanced across two sessions. In the first session, the local condition was presented first whereas in the second session the global condition was presented first.

The reaction times of GK were often prolonged and unstable, making response latency an unreliable index of performance.

2.2. **Results**

2.2.1. *Patient GK*

The main results are presented in Fig. 2. An overall assessment of the data was conducted using a log-linear analysis with four factors: attention (global *vs* local-directed), density

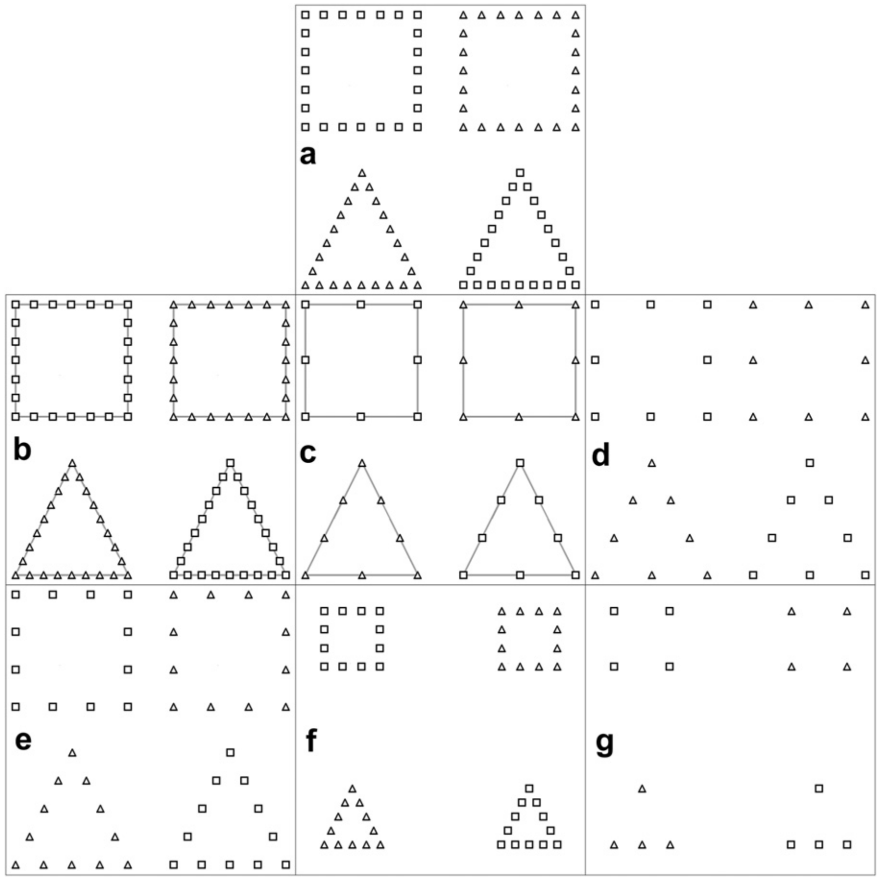

Fig. 1 – Stimuli used in the study. Panel a, dense and disconnected patterns presented in both Experiments 1 and 2. Panel b, dense and connected patterns. Panel c, sparse and connected ones patterns. Panel d, sparse and disconnected patterns (all from Experiment 1). Panels e (sparse and large stimuli), f (dense and small stimuli) and g (sparse and small stimuli) used in Experiment 2.

(dense or sparse), connectedness (connected *vs* disconnected) and consistency (consistent *vs* inconsistent). There was a significant two-way interaction between attention × consistency, $\chi^2(1) = 4.82$, $p = .028$, showing that, across the present conditions, there was reliable global-to-local interference on responses to local targets. In this condition, GK performed much better with consistent stimuli (96%) than with inconsistent stimuli (55%). When responding to global targets there was no overall difference between consistent and inconsistent figures (83% and 80% respectively).

One problem with the over-arching analysis is that the results are to some degree swamped by performance in the consistent condition, when it is difficult to judge whether responses are being made to the local or global form. When the results were analysed for just the inconsistent stimuli there was a significant three-way interaction between attention condition, density and connectedness, $\chi^2(1) = 4.27$, $p = .03$. When the patterns were disconnected and sparse there was a reliable advantage for local over global forms, $\chi^2(1) = 9.55$, $p < .01$. In contrast, in the other conditions (with disconnected but dense forms, and with both dense and sparse connected forms) a log-linear analysis revealed an advantage for global over local identification [$\chi^2(1) = 35.14$, $p < .001$] which did not interact with the pattern. This advantage for global over local forms held even with sparse elements when the local stimuli were connected [$\chi^2(1) = 11.02$, $p = .001$]. The opposite pattern of results was found in the local attention condition.

2.2.2. *Controls*

The results are presented in Fig. 2. The data on accuracy (percentages of correct responses) were analysed using an ANOVA involving four factors: attention condition × density × connectedness × consistency. There was a significant main effect of connectedness $F(1, 5) = 6, 81$, $p = .05$, indicating that accuracy was higher with disconnected (98.8%) relative to connected (97.6%) conditions. No other main effects or interactions were significant. Additionally, individual log-linear analyses were conducted using the design employed for GK, to directly compare with his performance. None of the analyses showed significant effects at an individual participant level. More specifically, no control participant showed an interaction of attention × consistency comparable to that seen in patient GK ($p > .71$). Similarly, no control participant showed a significant three-way interaction between attention condition, density and connectedness ($p > .88$) when the results were analysed for just the inconsistent stimuli. Finally, GK's responses in each condition were compared to controls using the modified *t*-test, which was specifically developed to compare an individual's score

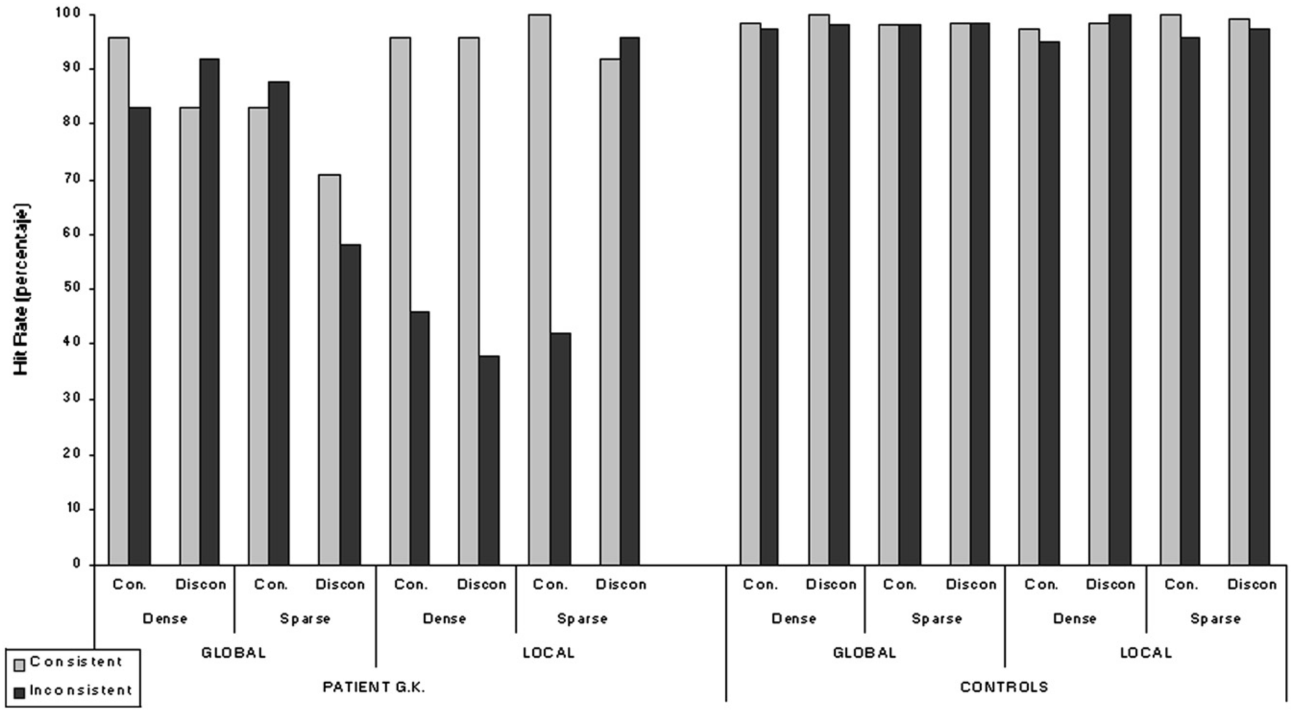

Fig. 2 – Average percentage of correct stimulus identification for patient GK and controls for each condition: attention, density, connectedness and consistency.

with a small control sample (Crawford and Garthwaite, 2002, 2006). Most of the comparisons reach significance ($p < .05$) showing a worse GK's performance. In contrast, GK and controls responded in a similar way to global stimuli when they were dense connected and consistent, $t(5) = -1.202$, $p = .283$, and also when they were dense disconnected and inconsistent, $t(5) = -1.659$, $p = .158$. GK and controls responded similarly to local dense consistent stimuli independently of their connectedness [connected: $t(5) = -.252$, $p = .811$; disconnected: $t(5) = -1.202$, $p = .283$] and also to local sparse stimuli when they were consistent and connected, $t(5) = .386$, $p = .716$, as well as inconsistent and disconnected, $t(5) = -.273$, $p = .796$.

2.3. Discussion

When GK was presented with disconnected, sparsely populated global shapes, a pattern of local dominance was apparent; GK was able to identify the local elements but had a difficulty in identifying global shapes. This replicates the previous pattern of data with GK and with other simultanagnosic patients (Karnath et al., 2000; Shalev et al., 2005, 2007). What is striking here is that exactly the opposite result emerged when the local elements grouped. When the local elements were densely packed and when they were connected, GK showed a global dominance effect and then found it difficult to identify local stimuli. On the other hand the results are consistent with GK showing poor attentional disengagement once a stimulus was selected. When there was strong local grouping, the global shape happened to be selected first. The result was global rather than local capture.

In addition to showing general effects of grouping, the present results also indicated that connectedness has a robust effect that held across separations where there appeared to be little grouping between unconnected elements. Effects of connectedness have been shown previously in simultanagnosia (Humphreys, 1998; Humphreys and Riddoch, 1993). In the present case, positive effects of connectedness occurred for GK even though the control participants showed a small decrease in performance with connected elements, probably because the connected displays were more complex. It is interesting that the positive effect for GK arose despite these results with control participants.

3. Experiment 2: Varying inter-element spacing and size of global patterns

In Experiment 2 we set out to assess if the spacing or number of elements was most critical to the grouping effects in Experiment 1 based on the density of the local elements in disconnected patterns. In Experiment 2 we used large or small global patterns composed of many or few elements. Examples of these patterns are presented in Fig. 1: (a) large and dense patterns, (e) large and sparse patterns, (f) small and dense patterns and (g) small and sparse patterns. The critical conditions were large sparse patterns and small dense patterns. These patterns had the same numbers of elements (12) but differed in their inter-element spacing. If the factor responsible for the improvement in the recognition of the global form is the distance between the local elements, then performance should be better for dense than sparse patterns independently of the number of elements (large or small dense global patterns composed of 24 or 12 local elements versus large patterns made up of 12 elements or small patterns composed of four elements). In contrast, if the number of local elements is the main determiner of global form recognition, then performance should be better for the large dense global patterns composed of 24 local elements (compared with all the other patterns). In addition, the use of different global sizes enabled us to assess the effects of stimulus size per se on GK's simultanagnosia.

3.1. Method

3.1.1. Participants

The patient with simultanagnosia, GK, and the same six non-brain-damaged control participants of Experiment 1 completed the present experiment.

3.1.2. Stimuli and apparatus

The apparatus was the same as that used in Experiment 1.There was a 2×2 design in which the size and density of the patterns was varied orthogonally (large or small, dense or sparse). The stimuli in the dense and large pattern condition were the same as those in dense and disconnected condition of Experiment 1 (global patterns made up of 24 local elements). The sparse and large stimuli had the same number of local elements (12) as the dense and small stimuli but different distance inter-elements and, consequently, different densities of local elements. Finally, the sparse and small patterns were made up of four local elements. Connective lines were not used in Experiment 2. In the large condition, global and local patterns had the same size as Experiment 1. In the small condition, global patterns measured 24 mm (about 2.3° of visual angle for GK and 2.5° for the controls) vertically and horizontally. Twelve different stimuli were presented in Experiment 2 (see Fig. 1).

3.1.3. Design and procedure

A four-factor within subjects design was used with the following factors: attention condition (global-directed or local-directed), density (dense or sparse), size (large or small) and consistency (consistent or inconsistent). The procedure and distribution of sessions, blocks and trials were the same as Experiment 1.

3.2. Results

3.2.1. Patient GK

The results are presented in Fig. 3. The data were analysed using a log-linear analysis with the following factors: attention (global *vs* local-directed), density (dense or sparse) size (large *vs* small) and consistency (consistent *vs* inconsistent). There was a significant three-way interaction between attention, density and consistency $\chi^2(1) = 6.14$, $p = .01$, indicating that dense global stimuli caused greater interference on the identification of the local form than sparse stimuli, independently of the sizes of the stimuli. This indicates that the short distance between the local elements and not the number of local elements was the main determiner of global form recognition. As in Experiment 1, a second analysis eliminating consistent stimuli was conducted and a two-way significant interaction between attention condition and density was found, $\chi^2(1) = 10.2$, $p = .001$, replicating the results of the previous analysis. With dense stimuli, there was an advantage for identifying inconsistent global forms over inconsistent local forms [$\chi^2(1) = 12.46$, $p < .001$]. With sparse stimuli there was an opposite advantage for identifying inconsistent local forms over inconsistent global forms [$\chi^2(1) = 11.22$, $p = .001$].

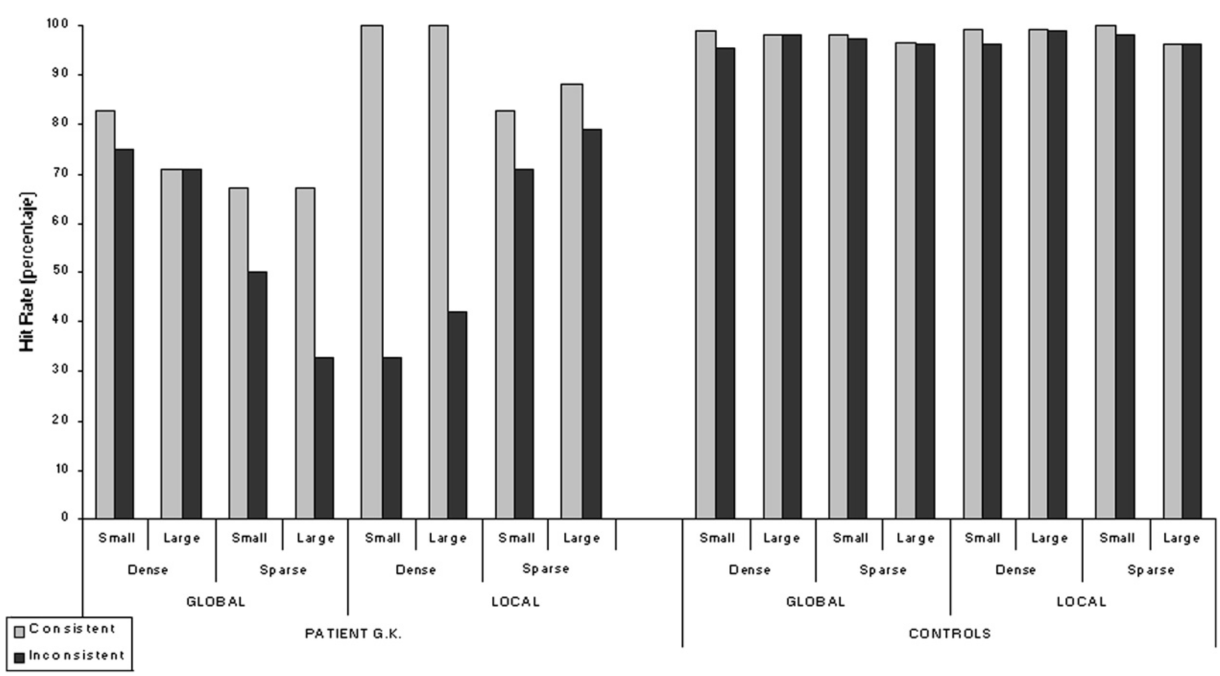

Fig. 3 – Average percentage of correct stimulus identification for patient GK and controls for each condition: attention, density, size and consistency.

3.2.2. Controls

The results are presented in Fig. 3. The data on accuracy (percentages of correct responses) were analysed using an ANOVA with four factors: attention condition, density, size and consistency. The analysis showed a significant main effect of consistency, $F(1, 5) = 12, 30$, $p = .01$, indicating that report was more accurate with consistent (98.3%) than inconsistent stimuli (96.9%) conditions. No other main effects or interactions were significant. In line with Experiment 1, individual log-linear analyses were conducted for all participants in order to directly compare patient's performance with controls in individual conditions. None of the analyses showed significant effects at an individual participant level demonstrating that the controls did not show the perceptual bias evident in GK. More specifically, no control participant showed a significant three-way interaction between attention condition, density and consistency comparable to that seen in patient GK ($p > .83$). Similarly, no control participant showed an interaction between attention and density ($p > .82$) when the results were analysed for just the inconsistent stimuli. Finally, GK's responses in each condition were compared to controls using the modified t-test, which was specifically developed to compare an individual's score with a small control sample (Crawford and Garthwaite, 2002, 2006). Most of the comparisons reach significance ($p < .05$) showing a worse GK's performance. In contrast, GK and controls responded in a similar way to local dense and consistent stimuli independently of global size [both large and small: $t(5) = .86$, $p = .716$].

3.3. Discussion

The effects of Experiment 2 were similar to those found in Experiment 1, and in both cases GK was strongly affected by the density of the local elements. When the elements were sparse, GK showed the local bias typical of patients with Bálint's syndrome, and he found it difficult to identify the global shape. In contrast, the results switched when the local elements were dense, when GK found it difficult to identify the local stimuli and now manifested a strong global bias. Note that GK's identification of the global form here indicates that his performance was not simply affected by abnormal crowding between local elements – but rather that it was only in this circumstance that he was able to attend to and identify the global shape. However, as a control to test for crowding effects, we presented GK with single lines from the global shapes when the local elements were dense and asked him to tell us the identity of the local shapes. He was able to do this (20/24). Thus GK was able to identify the local forms in the dense condition, but when the local forms made a competing global shape, he found it difficult to do other than attending to the global shape.

One other result in Experiment 2 is that there was no effect of the overall size of the global shape. This suggests that there is no direct relation between the size of a stimulus and simultanagnosia, as Bálint (1909) originally proposed.

4. General discussion

The present results confirm that patients with simultanagnosia remain able to process stimuli that they are unaware of, and so are influenced by grouping between the local elements making up global shapes. In both Experiments 1 and 2 patient GK showed a reliable local bias when presented with compound letters with sparse local elements, and his identification of the global forms was little better than chance. However, this strong local bias could be reversed when the local elements were dense and when the local elements were sparse but joined by connecting lines. With these 'grouped' stimuli, GK was able to identify the global form but then was at chance at identifying the local forms. This was not due to abnormal crowding given that GK could identify densely packed local forms when there was not a competing global shape available. The effects of connectedness overcome the effects of spacing out the local elements. There was no effect of the absolute size of the stimuli (Experiment 2). This result is consistent with that of Dalrymple et al. (2007) suggesting that inter-element spacing rather stimulus size per se affects perception of global pattern in simultanagnosia.

The present results are consistent with previous studies with simultanagnosic patients where it has been shown that short inter-element distance, improves the identification of global forms (Huberle and Karnath, 2006). However the present results go beyond those of Huberle and Karnath by disentangling, for the first time, the effects of inter-element distance from those of number of elements, and showing that the main determiner of the improvement in global form recognition is the short distance between the local elements and not their high number. The lack of an effect of absolute size also fits with the results reported by Shalev et al. (2005), who found that GK could be cued to attend to the local or global aspects of a compound letter if it was preceded by a small or large block letter. There is thus no inherent limitation in the spread of spatial attention. Shalev et al. did find, however, that GK's attention tended to fall back to the local elements when the interval between the block-letter cue and the compound letter increased. This indicates that, despite the ability to attend to a global level, the selection of patients such as GK tends to be biased to a local level. This may be because the posterior parietal cortex contains cells with relatively large receptive field, which play a part in driving attention across wide areas of space. With a lesion to that region, more ventral regions with smaller receptive fields may play a biasing role in selection (see Riddoch et al., 2008, for evidence).

It is interesting that, despite the local bias in visual selection, grouping continued to operate and influenced GK's performance. This suggests that grouping may operate to some degree independently of the processes that modulate visual selection, with factors such as local-item density and connectedness then determining which visual representations win any competition for selection. Given GK's posterior parietal lesions, we may speculate that these grouping processes are mediated by spared regions of ventral visual cortex.

One other result highlighted by the current study is that once GK selected the global form, he was impaired at identifying the local elements. This suggests that, as well as biases in selection in the first place, simultanagnosic patients can also have difficulties in disengaging attention, once stimuli are selected. This proposal is also supported by the results of the study of Dalrymple et al. (2007) who showed that simultanagnosic patients have difficulties in identifying the local elements of hierarchical face stimuli because of global capture. From the current results it is unclear whether the problem of disengaging attention when stimuli are selected overlaps with the bias towards local elements, or whether it is a distinct deficit present here due to the extent of GK's lesions – though Dalrymple et al.'s (2007) data suggest that the results are by no means unique to GK. Simultanagnosia may be characterised by a general problem in the disengagement of attention, in addition to perceptual biases towards local forms in the absence of strong inter-element grouping.

A final point concerns whether there are separate varieties of simultanagnosia. Farah (1990), for example, argued for the existence of a 'ventral' form of simultanagnosia distinct from 'dorsal' simultanagnosia, with these two disorders linked respectively to damage to left ventral occipital regions and bilateral posterior parietal cortex (as in patient GK here). Ventral simultanagnosia is associated with letter-by-letter reading and slow information processing (see Duncan et al., 2003). However, unlike dorsal simultanagnosics, ventral simultanagnosics show global awareness of their environments, they can show a normal ability to subitize a small number of objects (Humphreys, 1998) and, where tested, a global rather local advantage can arise in responding to hierarchical stimuli (Humphreys et al., 1985; Riddoch et al., 2008). In relation to this last pattern, GK generally falls functionally into the pattern of a local bias shown by other dorsal simultanagnosics (e.g., Huberle and Karnath, 2006). We conclude that the current pattern of data emerges in dorsal but not necessarily in ventral simultanagnosia, and indeed, given the differences in hierarchical perception in the different cases, it is far from clear that the two syndromes are functionally related.

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REFERENCES

Bálint R. Seelenlähmung des "Schauens" optische Ataxie, räumliche Störung der Aufmerksamkeit. *Monatsschrift für Psychiatrie und Neurologie*, 25: 51–181, 1909.

Crawford JR and Garthwaite PH. Investigation of the single case in neuropsychology: Confidence limits on the abnormality of test scores and test scores differences. *Neuropsychologia*, 40(8): 1196–1208, 2002.

Crawford JR and Garthwaite PH. Methods of testing for a deficit in single-case studies: Evaluation of statistical power by Monte Carlo simulation. *Cognitive Neuropsychology*, 23(6): 877–904, 2006.

Dalrymple KA, Kingstone A, and Barton JJS. Seeing trees OR seeing forests in simultanagnosia: Attentional capture can be local or global. *Neuropsychologia*, 45(4): 871–875, 2007.

Duncan J, Bundesen C, Olson A, Humphreys GW, Ward R, van Raamsdonk M, et al. Attentional functions in dorsal and ventral simultanagnosia. *Cognitive Neuropsychology*, 20(8): 675–702, 2003.

Farah MJ. *Visual Agnosia*. New York: Wiley, 1990.

Gilchrist I, Humphreys GW, and Riddoch MJ. Grouping and extinction: Evidence for low-level modulation of visual selection. *Cognitive Neuropsychology*, 13(8): 1223–1249, 1996.

Holmes G. Disturbances of visual orientation. *British Journal of Ophthalmology*, 2(9): 449–468, 1918.

Huberle E and Karnath HO. Global shape recognition is modulated by the spatial distance of local elements – Evidence from simultanagnosia. *Neuropsychologia*, 44(6): 905–911, 2006.

Humphreys GW. Neural representation of objects in space: A dual coding account. *Philosophical Transactions of the Royal Society*, B353(1373): 1341–1352, 1998.

Humphreys GW, Cinel C, Wolfe J, Olson A, and Klempen N. Fractionating the binding process: Neuropsychological evidence distinguishing binding of form from binding of surface features. *Vision Research*, 40(10–12): 1569–1596, 2000.

Humphreys GW, Donelly N, and Riddoch J. Expression is computed separately from facial identity, and it is computed separately for moving and static faces: Neuropsychological evidence. *Neuropsychologia*, 31(2): 173–181, 1993.

Humphreys GW and Price CJ. Visual feature discrimination in simultanagnosia: A study of two cases. *Cognitive Neuropsychology*, 11(4): 393–434, 1994.

Humphreys GW and Riddoch MJ. Interactions between object and space systems revealed through neuropsychology. In Meyers DE and Kornblum S (Eds), *Attention and Performance XIV*. Cambridge, MA: MIT Press, 1993: 143–162.

Humphreys GW and Riddoch MJ. From vision to action, and action to vision: A convergent route approach to vision, action and attention. In Irwin D (Ed), The Psychology of Learning and Motivation, vol. 42. New York: Academic Press, 2003.

Humphreys GW and Riddoch MJ. Features, objects, action: The cognitive neuropsychology of visual object processing, 1984–2004. *Cognitive Neuropsychology*, 23(1): 156–183, 2006.

Humphreys GW, Riddoch MJ, and Quinlan PT. Interactive processes in perceptual organization: Evidence from visual agnosia. In Posner MI and Marin OSM (Eds), *Attention & Performance XI*. Hillsdale, NJ: Erlbaum, 1985.

Humphreys GW, Romani C, Olson A, Riddoch MJ, and Duncan J. Nonspatial extinction following lesions of the parietal lobe in humans. *Nature*, 372(6504): 357–359, 1994.

Karnath HO, Ferber S, Rorden C, and Driver J. The fate of global information in dorsal simultanagnosia. *Neurocase*, 6(4): 295–306, 2000.

Kinsbourne M and Warrington EK. A disorder of simultaneous form perception. *Brain*, 85(3): 461–486, 1962.

Kumada T and Humphreys GW. Lexical recovery from extinction: Interactions between visual form and stored knowledge modulate visual selection. *Cognitive Neuropsychology*, 18(5): 465–478, 2001.

Lagasse LL. Effects of good form and spatial frequency on global precedence. *Perception and Psychophysics*, 53(1): 89–105, 1993.

Luria AR. Disorders of "simultaneous perception" in a case of bilateral occipitoparietal brain injury. *Brain*, 82(3): 437–449, 1959.

Martin M. Local and global processing: The role of sparsity. *Memory and Cognition*, 7(6): 476–484, 1979.

Navon D. What does a compound letter tell the psychologist's mind? *Acta Psychologica*, 114(3): 273–309, 2003.

Palmer SE. *Vision Science: Photons to Phenomenology*. Cambridge, MA: Bradford Books/MIT Press, 1999.

Palmer SE. Perceptual organization and grouping. In Kimchi R, Behrman M, and Olson CR (Eds), *Perceptual Organization in Vision*. London: LEA, 2003: 3–43.
Palmer SE and Rock I. Rethinking perceptual organization: The role of uniform connectedness. *Psychonomic Bulletin and Review*, 1(1): 21–55, 1994.
Rafal R. Balint's syndrome. In Feinberg TE and Farah MJ (Eds), *Behavioural Neurology and Neuropsychology*. New York: McGraw-Hill, 1996.
Riddoch MJ and Humphreys GW. Object identification in simultanagnosia: when wholes are not the sum of their parts. *Cognitive Neuropsychology*, 21(2–4): 423–441, 2004.
Riddoch MJ, Humphreys GW, Akthar N, Bracewell RM, and Schofield AJ. A tale of two agnosias: Distinctions between form and integrative agnosia. *Cognitive Neuropsychology*, 25(1): 56–92, 2008.
Shalev L, Humphreys GW, and Mevorach C. Global processing of compound letters in a patient with Balint's syndrome. *Cognitive Neuropsychology*, 22(6): 737–751, 2005.
Shalev L, Mevorach C, and Humphreys GW. Local capture in Balint's syndrome: Effects of grouping and item familiarity. *Cognitive Neuropsychology*, 24(1): 115–127, 2007.
Thaiss L and De Bleser R. Visual agnosia: A case of reduced attentional "spotlights". *Cortex*, 28(4): 601–621, 1992.