Neuropsychologia 46 (2008) 2861–2864

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Note

Automatic statistical processing of visual properties in simultanagnosia

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ARTICLE INFO

Article history:
Received 27 July 2007
Received in revised form 15 May 2008
Accepted 16 May 2008
Available online 23 May 2008

Keywords:
Attention
Perception
Neuropsychology
Averaging

ABSTRACT

Previous research has suggested that, when operating in a distributed attention mode, the visual system automatically represents visual displays by their overall statistics, rather than their individual properties. Recent neuropsychological work shows partly preserved distributed attention in simultanagnosic patients, who are typically defined as only perceiving one object at a time. Here we assessed whether GK, a patient with simultanagnosia, shows averaging of stimulus properties when distributing his attention across a set of items. We manipulated different stimulus properties in two experiments: color shades and size. We found that, when GK was in a distributed mode of attention, he (incorrectly) identified the mean object from two classes of exemplars more than in a control condition, when only one exemplar class was present. Overall, this study suggests that automatic statistical processing of color and size is possible in simultanagnosia.

1. Introduction

How do we integrate information from complex visual environments in order to perceive a coherent representation of the visual world? One traditional view, exemplified by Feature Integration Theory (Treisman & Gelade, 1980), is that perception of a scene is generated from serial 'fixations' of attention, which are necessary in order to bind information at the attended locations. Although much work supports this view (e.g. Wolfe, 1998), other work suggests that relatively complex information can be derived in a spatially parallel manner. For example, participants can rapidly derive information about the gist of a scene (Biederman, 1972; Torralba, Oliva, Castelhano, & Henderson, 2006). To account for this apparent discrepancy, several investigations have recently argued that the visual system computes the statistical properties of scenes in parallel (Ariely, 2001; Chong & Treisman, 2003). Rapid statistical processing of visual scenes may be vital for our immediate impressions and ability to rapidly adapt to the environment.

Ariely (2001) provided important initial evidence for statistical processing. He compared performance when individual members of a display had to be identified relative to that when the mean of the display was reported. Observers performed well on the mean-discrimination task, indicating that quite precise statistical information is encoded when viewing a set of similar objects (see also Parkes, Lund, Angelucci, Solomon, & Morgan, 2001; Watamaniuk & Duchon, 1992). Constraints on statistical processing from visual displays were examined by Chong and Treisman (2003). Observers were unaffected by exposure duration or memory when judging the mean size of a set. One factor that does limit statistical processing, however, is the ability to distribute attention. Chong and Treisman (2005) found that extracting the mean from a set of items was disrupted by secondary tasks requiring focused attention (but not distributed attention). They propose that statistical properties are automatically available when attention is distributed across a visual scene.

Patients diagnosed with simultanagnosia typically have a very small attentional window, and are unable to perceive complex scenes (Kinsbourne & Warrington, 1962).[1] The clinical label, simultanagnosia, emphasizes an impairment in simultaneously encoding information from visual displays. One might imagine then that simultanagnosic patients would be extremely impaired at statistical processing in scenes. On the other hand, simultanagnosic patients are able to adopt a distributed mode of attention. For example, such patients can detect salient feature targets in a spatially parallel manner (e.g. Friedman-Hill, Robertson, & Treisman, 1995), and they make illusory conjunctions between multiple elements (Friedman-Hill et al., 1995; Cinel & Humphreys, 2006). In addition, although the patients show a local bias when presented with hierarchical forms, there is implicit processing of global forms (Karnath, Ferber, Rorden, & Driver, 2000; Shalev, Humphreys, &

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[1] Farah (1990) distinguished between ventral and dorsal simultanagnosia on the basis of the lesion site, though the functional nature of this distinction remains unclear (Duncan et al., 2003). Given his lesions, GK can be characterised as a dorsal simultanagnosic.

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doi:10.1016/j.neuropsychologia.2008.05.014

Mevorach, 2005). Recently, we presented evidence consistent with the argument for distributed processing in the patient featured here, GK (Demeyere & Humphreys, 2007). GK is unable to reliably count more than one or two visually presented items. Despite this, we showed that GK could estimate the number of stimuli at a greater than chance level. Moreover, while counting was improved by individuating the stimuli (e.g. giving them separate colors), estimating was improved by grouping the elements and disrupted by increasing their individuation, providing evidence that simultanagnosic patients are sensitive to different forms of information when in a distributed rather than a focused attention mode.

In the present note we examine whether a simultanagnosic patient can statistically process displays in a distributed manner. We presented GK with displays containing 4, 6 or 8 items. On critical trials, the initial display could contain two types of items (two different color shades in Experiment 1, two different sizes of the stimulus in Experiment 2). GK then received a single probe item and had to decide whether it was in the first display or not. When this probe item was new, it either fell at the extreme of the continuum on which the initial items varied, or in the middle of the continuum (e.g. the initial items would have values 2 and 4 along the continuum; novel probes had values 1, 3 or 5). If the two levels are processed in parallel, then novel probes falling in the middle of the continuum should be more difficult to reject compared to novel probes at the end of the continuum. In a control condition, only one of the critical feature values was present (one color in Experiment 1, one size in Experiment 2).

2. Experiment 1: statistical processing of color

2.1. Method

GK (66) suffered two strokes in 1986 affecting the right occipitoparietal, right temporoparietal, and left temporoparietal regions. GK shows symptoms characteristic of Balint's syndrome and severe simultanagnosia. A full case report can be found in Gilchrist, Humphreys, and Riddoch (1996).

The stimuli used were dots, with a radius of 0.98° visual angle. Each dot was colored in one of five different shades of green. The dots were randomly positioned on a grey background. In the results the shades are referred to by numbers 1 (darkest) to 5 (lightest). The colors were chosen based on values that GK could reliably discriminate between (color shades' RGB values from dark to light green: 51,102,0; 51,153,51; 51,204,51; 102,255,51; 204,251,51).

Each trial began with a centrally presented 2 s fixation cross, followed by a 3-s display of 4, 6 or 8 randomly positioned items. In the control condition, the displays consisted of dots with either shade value 2 or 4, in the experimental condition, values 2 and 4 were mixed. Recognition was probed with a single item (of any of the 5 values), centrally presented for or an unlimited duration. Responses were noted and reaction times measured by stopwatch (the degree of noise introduced by this technique is minimal in relation to GK's overall RTs (see Section 2.2).

The data were collected in 8 experimental and 8 control sessions. Each session consisted of 40 trials, with 8 trials per response category (shades 1–5).

2.2. Results

In order to assess GK's overall performance, taking into account both accuracy and reaction times (Fig. 1), we constructed a combined 'efficiency' measure by using RT correct/proportion correct as our dependent variable (see Townsend & Ashby, 1983). This is useful when error rates are relatively high, as here. A repeated measures ANOVA was conducted, with sessions treated as subjects, the shade manipulation as a within-subject factor and experimental versus control condition as a between-subject factor (Wojciulik & Kanwisher, 1998). To rule out the possibility that GK's performance was better in the control than the experimental condition on shade 3, because he found feature shade 3 difficult to discriminate relative to just one of the close feature-present shades, we considered only the single level item set which yielded the worst performance as a control condition.[2] In this instance, the trials where only level 4 was present in the initial display (see Fig. 1). We performed separate analyses for the present shade levels (2 and 4), and the novel shade levels (1,3 and 5). For levels 2 and 4, this revealed a significant effect of the experimental manipulation ($F(1,14) = 10.816$, $p = 0.005$, partial $\eta^2 = 0.436$), with overall performance being worse in the experimental than in the control condition. There was no effect of the shade level and no reliable interaction. For shade levels 1, 3 and 5, there was no reliable main effect of the experimental manipulation ($F(1,14) = 4.423$, $p = 0.054$, partial $\eta^2 = 0.240$). There was a significant effect of the shade level ($F(2,28) = 25.261$, $p < 0.001$, partial $\eta^2 = 0.643$) Importantly, there was a reliable interaction between the shade levels and the experimental manipulation ($F(2,28) = 12.456$, $p < 0.001$, partial $\eta^2 = 0.471$).

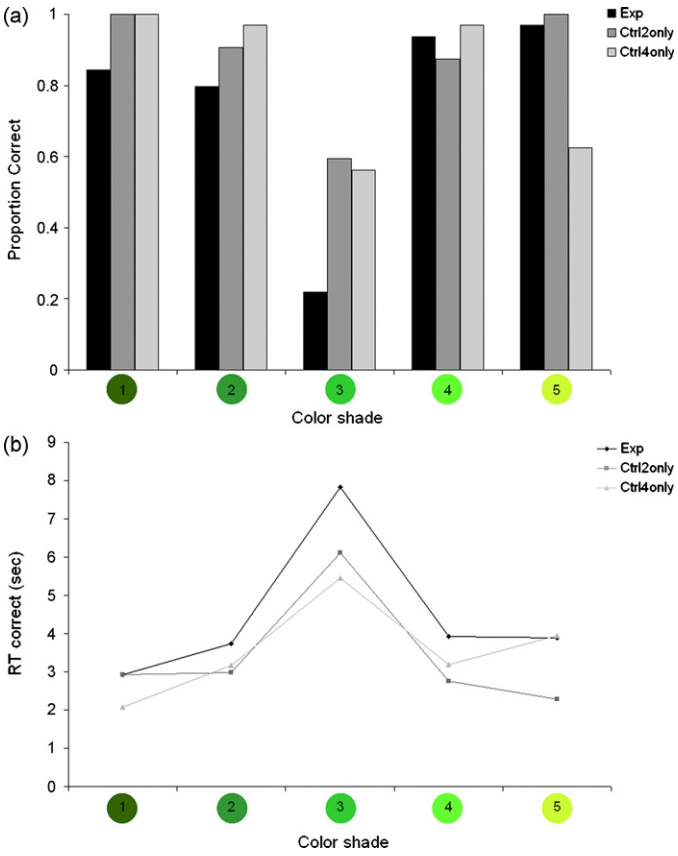

Fig. 1. Proportion correct (a) and mean reaction times (b) in judging the presence of the five different color shades in Experiment 1.

Independent t-tests further revealed a significant difference between the control and experimental condition on level 3 ($t(14) = 4.954$, $p < 0.001$), whereas there was no reliable difference on the closest extreme level 5 ($t(14) = 0.986$, $p = 0.353$).

2.3. Discussion

GK found it more difficult to correctly reject a novel item at the midpoint of the feature continuum, in both the experimental and control conditions—suggesting some sensitivity to the range

[2] This provides a more conservative test than pooling the data for the two control conditions (level 2 only and level 4 only). When analyzed with the pooled data, a similar pattern of results was present.

of stimuli across trials (items at level 3 of the continuum are in the middle of the range across trials). However, this effect was enhanced in the experimental condition—suggesting processing of both values. Rejection of the novel item with the middle value in the experimental condition was worse than rejection of the same item in the control, whereas no such difference was evident on the most difficult extreme level.

3. Experiment 2: size

In Experiment 2, we manipulated the size dimension, given that previous work done on statistical averaging used size as the feature dimension (Ariely, 2001; Chong & Treisman, 2003; Treisman & Chong, 2004; Chong & Treisman, 2005b), we can be confident that this is a dimension where averaging can operate.

3.1. Method

The method used was the same as in Experiment 1, except for the initial task, where GK was asked to estimate the number of items and the display stayed present until a response was made (to ensure distribution of attention—see Demeyere & Humphreys, 2007). The stimuli in the second experiment consisted of different sized black dots. The difference between the sizes of the dots was determined by GK's ability to discriminate between two adjacent sizes. The diameters of the different sizes were 0.65°, 1.15°, 1.96°, 3.11° and 4.74° visual angle, respectively. These sizes are referred to by values 1 (smallest) to 5 (largest).

The data were collected in 5 experimental and 5 control sessions. Each experimental session consisted of 75 trials, with 15 trials for each of the target sizes. Each control session consisted of 90 trials, with 18 trials for each of the target sizes. The order of the sessions was balanced and there was 1-week time between every session.

3.2. Results

GK's overall performance on the estimating task was significantly above chance ($\chi^2(1, N = 825) = 77.04$, $p < 0.001$). The mean reaction time for estimating the display was 10.6 s for correct and 12.4 s for incorrect estimations. The same analysis as for Experiment 1 was conducted (see Fig. 2 for an overview of his accuracy and RTs). Control trials where only level 4 was present yielded the worst performance and were used for the analysis. For the responses on levels 2 and 4, this revealed a significant effect of the size manipulation ($F(1,8) = 37.534$, $p < 0.001$, partial $\eta^2 = 0.824$) and a significant interaction between size and the experimental manipulation ($F(1,8) = 5.659$, $p = 0.045$, partial $\eta^2 = 0.414$), with performance on size level 4 worse in the experimental than in the control condition. There was no reliable effect of the experimental manipulation.

For the size levels 1, 3 and 5, there was only a reliable interaction between the size levels and the experimental manipulation ($F(2,16) = 12.294$, $p = 0.003$, partial $\eta^2 = 0.606$). Independent t-tests further revealed a significant difference in performance between the control and experimental condition on level 3 ($t(8) = 4.734$, $p = 0.008$), whereas there was no such difference on the closest extreme level 5 ($t(8) = 1.586$, $p = 0.153$).

This shows that GK was worse on the middle size in the experimental condition relative to the control condition, whereas this did not hold for the extreme level, closest to the control.

3.3. Discussion

These results were similar to Experiment 1: the mid-range stimulus was more difficult to discriminate for the experimental condition. One difference here was that GK's performance in the member identification task was also worse on the 'target present' size level 4 for the experimental condition relative to the control condition. This is likely to be due to his simultanagnosia. If GK's attention sometimes went to one item in the display (despite our attempts to have him distribute attention), then he might sometimes make errors in the experimental condition compared with the control, since the experimental condition has two types of stimuli whereas the control has one. Moreover, GK has an attentional bias to small stimuli (see Shalev et al., 2005). If this selection of a single stimulus took place, it would tend to be the small item (size 2).

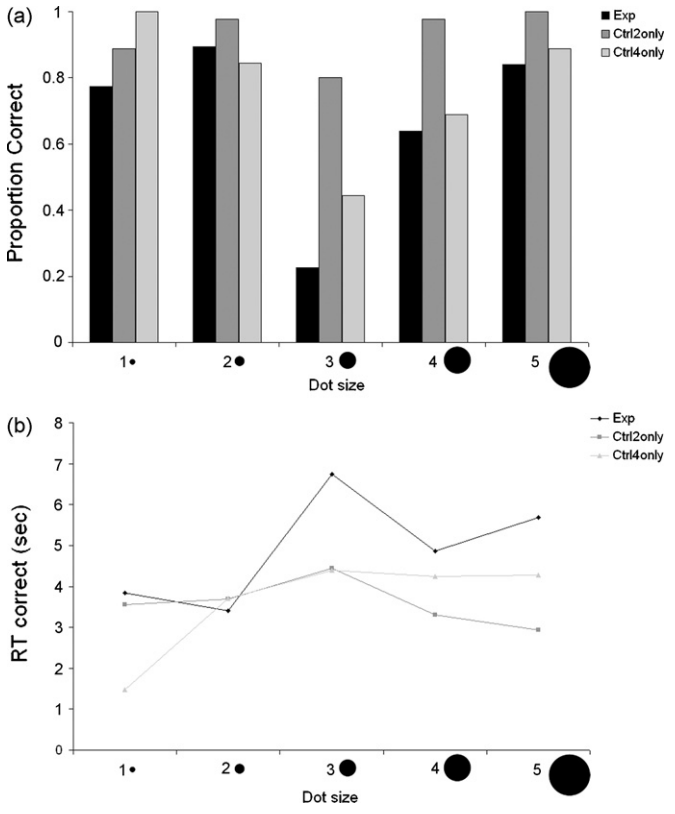

Fig. 2. Proportion correct (a) and mean RT correct (b) on the member-identification task in Experiment 2.

4. General discussion

Across two experiments we have demonstrated evidence for statistical processing of visual displays in a patient with dorsal simultanagnosia. In Experiment 1 (with stimuli varying in color) and Experiment 2 (stimuli varying in size) GK performed less efficiently when he had to reject a novel item drawn from the central range between two stimuli in a display. He also found it difficult to separate mid-range novel items even with control displays (with one type of item present). This last result demonstrates that GK had some sensitivity to the range of stimuli appearing across trials. Nevertheless, this effect was greatly magnified when the stimuli appeared simultaneously (in the experimental condition), providing evidence for parallel processing and statistical averaging taking place.

Huang, Treisman, and Pashler (2007) have recently found that normal participants reported two features from the same dimension (e.g. two colors) better with successive than with simultaneous presentations, whereas the same limitation did not hold for locations. They suggest that there is a perceptual limitation in coding multiple features from different dimensions. In our experiment, however, there seems to be no such competition, rather, statisti-

cal averaging of the features occurs, even though they are from a single dimension. This suggest that coding of multiple features along a dimension may not be a fundamental limitation in visual processing, though further work is needed.

The evidence for statistical processing here is interesting, given GK's severe simultanagnosia. Our results indicate that, despite poor explicit report, multiple items can be processed in parallel, with data being pooled across these stimuli. This fits with other evidence for parallel processing of visual displays in such patients, for example, the above change judgements on magnitude estimation tasks (see also Experiment 2 here) and the qualitative differences in the effects of visual variables on magnitude estimation and counting (Demeyere & Humphreys, 2007). We suggest that GK adopts a distributed mode of attention when required to estimate the number of items in display 1, and that, in this mode, he can process the elements in parallel and perform statistical averaging. An alternative view is that there is parallel processing with both distributed and focused attention, with early stages being sensitive to statistical averaging and supporting magnitude estimation. However, the information processed at these early stages may be coded implicitly and may not be available for conscious report unless focussed attention is passed across the elements. This process of serial scanning of elements, using focused attention, is impaired due to GK's bilateral parietal lesions. As a consequence, GK's forced choice responses are influenced by the information being computed, though he feels he is guessing. On this view, the dorsal parietal cortex is crucial for relaying information coded at earlier visual stages, but it is not the site of the averaging process itself. Whichever view is held however, the data suggest that statistical averaging is a basic visual process that can survive even after damage to posterior parietal cortex, and even when conscious appreciation of multi-items contexts is compromised.

Acknowledgments

This work was supported by grants from the Stroke Association, the Medical Research Council and the Biotechnology and Biological Sciences Research Council. Aspects of this study were presented to the Experimental Psychology Society (Cardiff, April 2007). Many thanks to GK for the time and effort put into these experiments.

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