



Explicit and implicit perception of illusory contours in unilateral spatial neglect: behavioural and anatomical correlates of preattentive grouping mechanisms

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Abstract

Studies of hemispatial neglect suggest that some perceptual processes still operate on contralesional stimuli independent from spatial attention or awareness. Here we examined whether preattentive processing in extrastriate areas may group unconnected elements inducing illusory contours despite neglect. While it has been debated whether illusory contours arise from preattentive grouping or higher cognitive processes, neurophysiological studies show that neurones in secondary visual cortex (V2) can code for illusory contours. Twelve patients with right hemisphere damage and left neglect were tested for implicit and explicit detection of illusory contours using, respectively: (1) a bisection task where patients were not explicitly required to attend to lateral elements and judged the midpoint of Kanizsa illusory stimuli, as well as other physically connected or unconnected stimuli of the same length; (2) a matching task where patients had to overtly attend to lateral elements and made same/different judgements on pairs of illusory stimuli with identical or different inducers on the right or left side. In some patients, bisection judgements were consistently similar on Kanizsa stimuli with illusory contours and connected stimuli with real contours but different on unconnected gap figures, regardless of their length, suggesting implicit grouping of inducing elements prior to processing stages where a spatial attentional bias arose. Their lesions centred on the inferior parietal cortex or thalamus. Other patients did not show a systematic bisection pattern and had lesions extending posteriorly in the lateral occipital cortex. However, both groups of patients failed to detect left-side inducers in explicit matching judgements, even though errors often revealed unconscious processing, and they showed similar neglect severity on other standard tests. These findings suggest that grouping by illusory contours can occur preattentively and influence bisection independently from the ability to detect contralateral inducers explicitly, severity of inattention, and other forms of unconscious processing. Implicit grouping may depend on the sparing of lateral occipital areas involved in figure-ground segmentation at early stages of visual processing. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Hemispatial neglect is a common disorder after unilateral brain damage in which patients usually fail to perceive and orient to stimuli in the space contralateral to their lesion [28,42,48]. Neglect reflects an impairment

in directing attention toward sensory information from the contralesional side and follows damage to a variety of cortical and subcortical sites within a distributed network subserving the spatial allocation of attention, particularly the posterior parietal cortex, frontal cortex, and thalamus in the right hemisphere [28,42]. However, some perceptual mechanisms may still operate on visual information independently from spatial attention and presumably rely on earlier stages of processing in extrastriate visual areas. Thus, segmentation and grouping processes may automatically extract figure edges

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from ground and organize separate stimuli or locations into a single candidate object representation prior to the level where attentional mechanisms select sensory information for conscious awareness [11,48]. Several recent studies showed that such automatic perceptual processing can occur normally in patients with neglect despite their contralesional spatial inattention, influencing the region of space which eventually becomes attended or neglected [12,18,44,62], and proceeding sometimes even in the absence of conscious detection [4,9,37,61]. The present study used Kanizsa-type illusory figures [31] to examine whether grouping effects can indeed arise preattentively in spatial neglect as a function of the integrity of specific areas in the visual cortex.

Kanizsa figures provide interesting stimuli for this purpose, since they consist of inducing elements that are spatially unconnected but group together to yield the percept of a single bright surface bound by illusory contours, in the absence of real physical luminance gradients (see [35,46] for reviews). Furthermore, neurophysiological studies in the monkey demonstrated that neurones in the primary and secondary visual cortex respond to illusory contours as well as to real contours of identical orientation [45,59], with Kanizsa-type contours eliciting responses from V2 but not V1 neurones, and contours from offset-gratings eliciting responses both in V1 and V2 [22,59]. However, it has been disputed whether the subjective perception of illusory contours arise from lower-level grouping and filling-in processes that work at early stages of vision [7,10,35] or from higher-level cognitive mechanisms that depend on attentive search and recognition [19–21,52,53]. In support of automatic preattentive processes, two recent studies in patients with hemispatial neglect showed that bilateral inducers in a Kanizsa figure can be effectively grouped together to generate a single visual object despite contralesional inattention [41,60]. Mattingley et al. [41] found that left extinction in a right parietal-damaged patient decreased when bilateral simultaneous stimuli were part of an illusory figure surface. Similarly, we [60] reported that bisection judgements in three patients with right hemisphere damage could be influenced by illusory grouping of Kanizsa-type figures even without explicit detection of the left-side inducers. All patients in these two studies had relatively anterior or subcortical brain damage, sparing the posterior extrastriate visual cortex.

By contrast, several other studies have reported that the ability to perceive object closure and illusory contours is often impaired after posterior lesions in the right hemisphere [25,27,32,63]. This raises the possibility that automatic preattentive grouping of Kanizsa figures in spatial neglect might be seen only in cases with a relative sparing of extrastriate visual areas.

The aim of our study was therefore fourfold: (1) to extend previous findings that bilateral elements inducing illusory contours can group preattentively in spite of hemispatial neglect; (2) to determine to what extent evidence of preserved grouping can dissociate from the ability to direct attention to the same contralesional inducing features when explicitly required by the task; (3) to determine to what extent such residual grouping is independent of the severity of spatial neglect, or instead whether it correlates with residual capabilities of attention; (4) to establish whether particular brain areas in the visual cortex must be intact to subservise preattentive detection and grouping of illusory contours.

2. Methods

2.1. Patients

We studied 12 consecutive right-handed patients (eight males, four females, mean age 66.7 years old) who had a first single stroke in the right hemisphere (mean 10.7 weeks post-stroke onset) and clinical signs of left visuospatial neglect. The presence and severity of neglect was assessed by standard tests such as letter cancellation, line cancellation, line bisection, drawing, and reading (Table 1). None of the patients had other major cognitive impairment besides neglect and related visuospatial disabilities, and all were clinically alert and cooperative. Seven patients had a contralesional visual field defect (hemianopia in four, quadranopia in three) and five intact visual fields on both sides. Other clinical characteristics are shown in Table 1. Only patients with a strictly unilateral and focal brain lesion were included, as evidenced from CT (three cases) or MRI (nine cases). A computerized template system [16] was used to reconstruct the extent of brain lesions in three dimensional space and measure their volume in each case. Involvement of specific cortical areas was further analysed using a standard anatomical atlas [6]. All patients were given the clinical neglect tests and the two experimental tasks during a single session of ~45 min, interspersed with short informal breaks. Some data for three patients (BAF, LAO, ROU) were reported previously [60].

2.2. Experimental tasks

The stimuli were similar to those used in a previous study [60] and are shown in Fig. 2. All were printed in black on a white sheet of paper (29 × 21cm) and presented sequentially in free vision, on a table desk, aligned with the patient's trunk midline. Illusory figures were bars (120 mm long) and rectangles (60 mm long) with subjective contours of Kanizsa type and lateral

Table 1
Clinical characteristics of the patients

Patient	Sex	Age	Lesion	Left hemiparesis		Visual fields	Line bisection ^b	Line cancellation ^c	Letter cancellation ^d
				Volume (cm ³)	Etiology				
MAT	m	64	F,P,AIC, APVW	130	infarct	15	intact	16+9	28+17
VIA	m	64	F,P,IC,APVW	84	infarct	4	intact	0+0	28+8
BAF	m	74	P	19	infarct	5	intact	16+2	28+20
GAR	f	72	F,P,IC,APVW	86	infarct	28	inf quadranopia	16+5	28+15
ROU	m	68	T,O,TH	15	infarct	4	sup quadranopia	8+0	24+1
LAO	m	64	T,O,TH	10	infarct	3	sup quadranopia	16+0	28+19
MOB	f	72	P,O	57	haemorrhage	4	intact	16+5	28+20
STF	m	72	F,P,T,PIC, PPVW	133	infarct	6	haemianopia	7+0	28+17
GYA	m	51	P,O,PPVW	57	haemorrhage	7	haemianopia	11+0	15+11
GIA	f	73	F,T,P,IC,PVW	165	infarct	8	haemianopia	1+0	28+19
GRY	f	66	F,P,T,IC,PVW	135	infarct	20	haemianopia	16+4	27+14
KRM	m	60	F,P,PVW	60	infarct	24	intact	9+0	28+14

^a F = frontal, P = parietal, T = temporal, O = occipital, TH = thalamus, A/P IC = anterior/posterior internal capsule, A/P PVW = anterior/posterior periventricular white matter.

^b Line bisection: 6 lines, 220 mm.

^c Line cancellation: 16 R-side+16 L-side targets.

^d Letter cancellation: 28 R-side+28 L-side targets. L = left; R = right.

inducers that could be identical (Fig. 2a) or different (Fig. 2b) on their right and left sides. The same figures were used in the two following experimental conditions.

2.2.1. Bisection task

This task was used to test for implicit detection of grouping by illusory contours when attention to the

lateral inducing elements is not explicitly required. Patients were asked to judge the length of the stimuli and mark their midpoint by drawing a small dot at their centre. Bisection judgements for Kanizsa-type illusory bars and rectangles (Fig. 2a,b) were compared to those for three other types of stimuli at each of the same two lengths (120 and 60 mm): standard horizontal

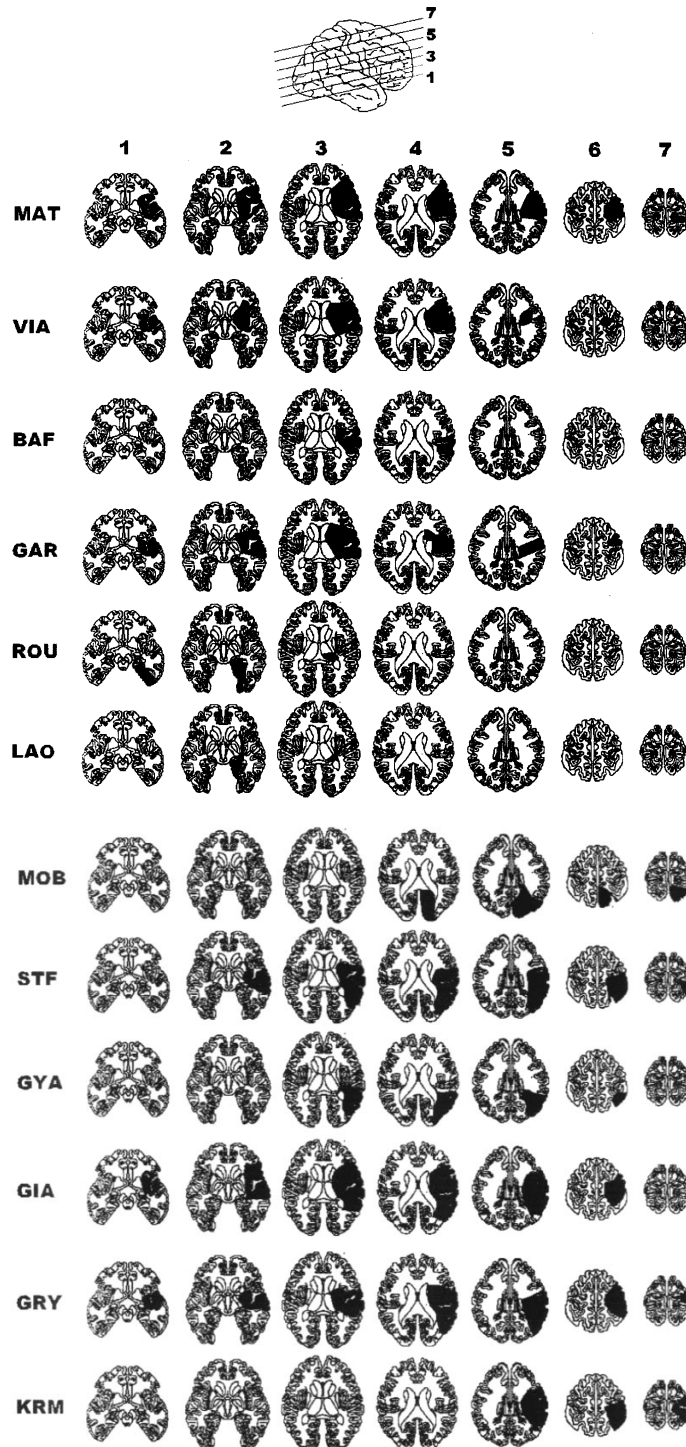


Fig. 1. Reconstruction of the brain lesions in each patient.

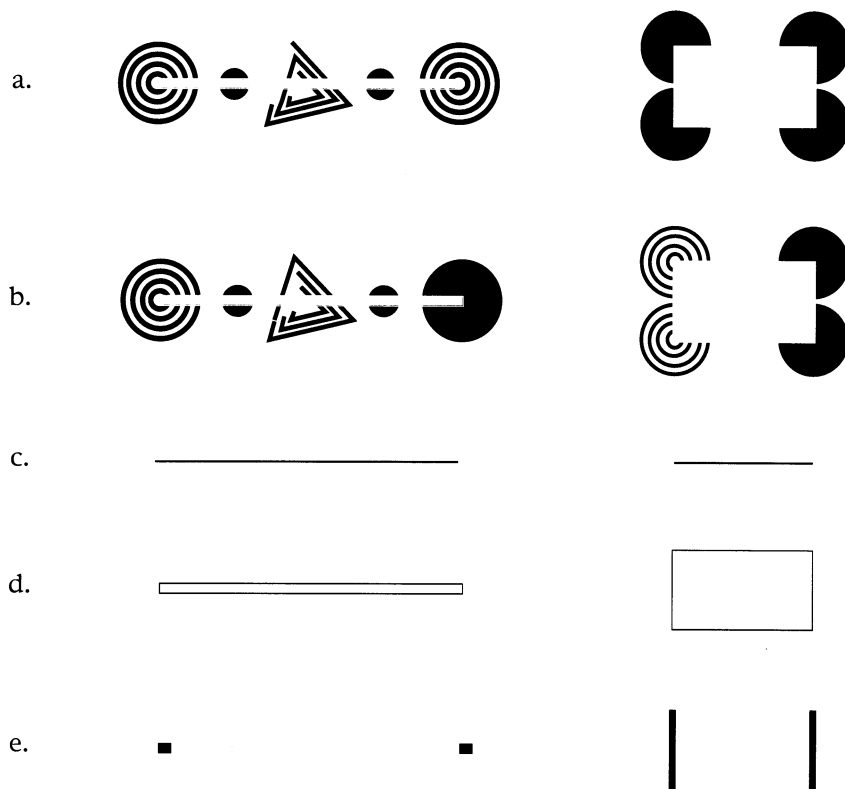


Fig. 2. Illustration of the stimuli used in experiments 1 and 2.

lines, 1 mm thick (Fig. 2c); bars and rectangles delimited by real contours (Fig. 1d); and gap figures delimited by two vertical lines having a comparable height and horizontal extent, but producing no subjective grouping and filling-in (Fig. 1e). Stimuli were shown one at the time, with eight trials for each stimulus type at each length, and alternated in a pseudo-random order. This first task was split into two equal blocks (32 trials each), respectively given before and after the second task.

2.2.2. Matching task

This task was given to examine the patients' ability to direct their attention to and explicitly report the inducing features on the contralesional (left) side of illusory figures. Patients were asked to make same-different judgements for pairs of Kanizsa-type figures that were presented one above the other. The figures were either the same on both sides (a third of trials) or differ by their left or right inducers (a third of trials each), e.g. see pairs of stimuli in Fig. 2a,b, right-side or left-side panel, respectively. In the case of 'different' judgements, the patients were further asked to describe and point to the differences. Pairs of long (120 mm) and short (60 mm) figures were shown in two separate blocks of 12 trials each (with four similar, four right-different, and four left-different pairs in a pseudo-random order at each length).

3. Results

3.1. Bisection task

Percentages of deviation from the true midpoint were measured for each stimulus type and length as the mean error (in mm) divided by the total stimulus length (120 or 60 mm), with positive values denoting rightward errors and negative values denoting leftward errors. Table 2 shows the mean percentages of deviation in all patients and conditions. A $4 \times 2 \times 2$ ANOVA was performed on data collapsed across all patients using stimulus type (Kanizsa, real contour figures, lines, gap figures), stimulus length (120 vs. 60 mm), and block (first vs. second) as factors. Rightward deviation in bisection judgements did not differ between blocks ($F(1,766) = 0.43$, $P = 0.5$) but was greater for longer than shorter stimuli (mean 14.1% vs. 7.3%; $F(1,766) = 163$, $P < 0.0001$), as typically found in spatial neglect (e.g. [26]). Most critically, there was a significant effect of stimulus type ($F(3,764) = 10.6$, $P < 0.0001$). Post-hoc comparisons showed that bisection judgements for the gap stimuli significantly differed from the three other stimuli condition ($P \leq 0.05$ for each pairwise comparison, Scheffe test), while bisection judgements for illusory Kanizsa figures were similar to the physically connected stimuli, i.e. lines ($P = 0.9$) and real contours figures ($P = 0.3$; see Fig. 3). Other comparisons were

Table 2
Results in the bisection task^a

Patient	Kanizsa figures				Real contours				Lines				Gap figures			
	Long (120 mm)		Short (60 mm)		Long (120 mm)		Short (60 mm)		Long (120 mm)		Short (60 mm)		Long (120 mm)		Short (60 mm)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
MAT	2	0.6	1.5	1.1	2.7	1.4	2.5	2.2	1.7	0.7	1.2	0.7	4.8	0.6	4.7	0.7
VIA	9.4	4.5	3.7	2.2	12.3	1.8	3.9	3.4	6.6	2.7	5.3	1.8	3.7	1.8	1.8	1.4
BAF	15	8.3	7.7	5.9	16.6	3.6	5.1	4.6	17.5	6.3	14.8	3.1	-7.5	7.4	-7.1	5.2
GAR	13.2	3.3	11	1.7	21.7	5	8.3	9.1	18.9	5.3	12.2	3.5	13.5	1.7	3.8	4.6
ROU	8	2.7	4.9	9	11.1	8.8	-5.1	2.4	12.6	7.1	-7.5	3.4	-1.8	3.8	-10.3	2.2
LAO	31.5	1.3	6.6	3.5	25.2	7.9	3.4	3.6	24.2	8.5	11.2	10	10.3	4.6	0	5.6
MOB	23.9	2	17.8	3.1	15.9	0.8	18.5	4	19.6	1.9	21.5	5	24.7	3.5	19.1	5.6
STF	17.1	9.6	6.2	2.4	7.6	4.3	2.8	2	11.5	3.7	8.8	8.9	16.7	7.5	6.2	2
GYA	11.8	10	-5.3	2.5	10.3	5.3	-4.5	1.8	16.6	5.1	0.2	5	8.5	6.4	-2.3	4.3
GIA	13.9	10.6	5.1	3	12	3.8	3	1.7	7	0.9	3.2	1.1	9.9	2.9	3	2.8
GRY	12.2	3.7	7.1	1.9	12.6	1.9	-0.8	5.1	18.6	5.9	8.4	3.9	21.7	5.6	4	10.1
KRM	13.6	8.4	13.1	9.3	16.6	6	9.4	5.6	13.7	6	8.1	7.4	13.5	5	12	5.9

^a Percentage of rightward deviation.

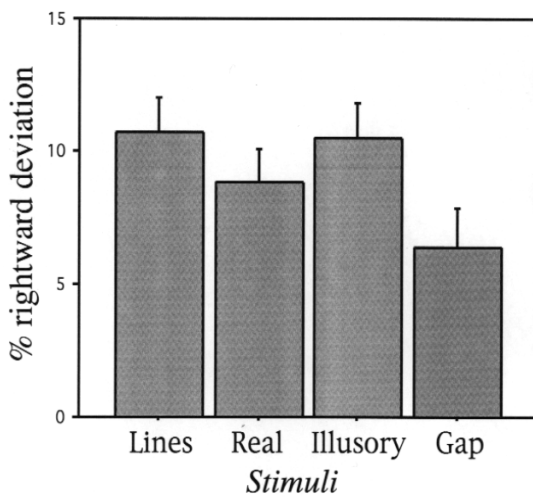


Fig. 3. Percent of rightward deviation in bisection judgements for each stimulus type across all patients (mean \pm S.E.).

not significant. This suggests that the spatially unconnected features in Kanizsa figures were effectively grouped together and treated as a single object for midpoint judgements, unlike the non-illusory gap figures, which generally appeared to force a more deliberate orienting of attention toward the left-sided features. A separate analysis restricted to Kanizsa figures showed again an effect of length (long vs. short; $F(1,190) = 40$, $P < 0.001$) but no significant effect of symmetry of the inducing features (same vs. different; $F(1,190) = 0.01$) and no interaction ($F(1,188) = 0.17$).

3.2. Matching task

Patients accurately reported all differences in inducing features on the right side of pairs of Kanizsa figures and made no false alarms on pairs with the same features on both sides. In contrast, they usually failed to detect differences in features on the left side of the

figures (mean 70% missed; see Table 3). There was no significant differences in miss rate between long and short stimuli (mean $3.0/4 \pm$ S.D. 1.6 and $2.6/4 \pm$ S.D. 1.7, respectively; paired t -test, $t(11) = 1.2$, $P = 0.26$). Thus, even though illusory figures appeared to be implicitly treated as single objects for bisection judgements, patients had generally marked difficulties in attending to the contralesional inducing elements.

However, somewhat unexpected to us, several patients repeatedly reported non-existing differences on the right side of Kanizsa figures while the features actually differed on the left side but were neglected (Table 3). These 'pseudo-differences' were typically subtle, and clearly irrelevant compared to the obvious real differences on the neglected side. For instance, the patients often volunteered that the right-side features had a slightly bigger or smaller size, 'larger stripes', or 'a different blackness'. None reported the correct difference transposed from the left to the right side. Remarkably, these pseudo-differences were reported on 25% of the left-different pairs overall (mean $2.0 \pm$ S.D. 1.6, out of eight trials), but none of the pairs that were identical on both sides (a disproportion highly above chance, $\chi^2(1) = 27.4$, $P < 0.0001$). Pseudo-differences were similarly reported for both long and short stimuli (paired t -test, $t(11) = 1.2$, $P = 0.28$). This suggests that, although they were not available for conscious perception and explicit report, left-side features were still processed unconsciously in such a way that they could induce misidentification errors in matching judgements.

3.3. Individual differences

Inspection of individual data in the bisection task revealed that only a subset of the patients clearly showed the pattern found to be significant at the whole group level, with a systematic difference in bisection judgements between Kanizsa figures and gap stimuli

Table 3
Detection of differences in the lateral inducing features of Kanizsa figures

Patient	Nb of real differences missed on the left side		Nb of pseudo-differences reported on the right side	
	Long (120 mm)	Short (60 mm)	Long (120 mm)	Short (60 mm)
MAT	3	2	0	1
VIA	1	1	0	0
BAF	4	2	2	2
GAR	4	3	1	1
ROU	4	3	2	1
LAO	4	3	0	0
MOB	0	0	0	0
STF	4	4	2	1
GYA	4	4	2	0
GIA	0	3	2	0
GRY	4	3	1	1
RM	4	3	2	3

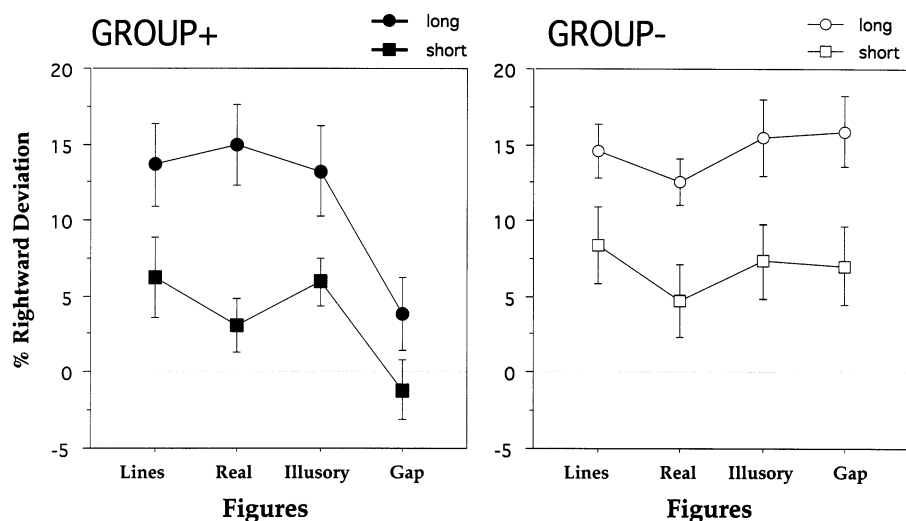


Fig. 4. Mean percent of rightward deviation (\pm S.E.) in bisection judgements for each stimulus type in patients who showed (group +) and patients who did not show (group -) a distinct pattern of performance for illusory Kanizsa and non-illusory gap figures. Note that apparently equal performance across stimulus types in Group - mainly reflects the absence of a systematic pattern in averaged data, unlike the more consistent pattern in Group +.

but no difference between Kanizsa figures and other stimuli with connected contours. If such a pattern of bisection performance reflects an effect of implicit grouping of Kanizsa figures during bisection, these differences between the patients could result from a different degree of residual processing for illusory contours in individual cases; alternatively, individual differences might reflect a different residual ability to direct attention in contralesional space, hence to process contralesional elements to some extent for a proportion of trials or certain stimulus types. To explore further the source of this variability, we separated the patients into two subgroups, based on whether or not their performance on Kanizsa figures was consistent with an influence of grouping by illusory contours during bisection. Separate two-way ANOVAs were performed on individual data in order to determine significant effects of the different stimuli on bisection judgements in each patient, using stimulus type and length as independent factors. The two subgroups were distinguished using strictly operational criteria based on (1) individual ANOVAs of bisection performance revealing a significant main effect of stimulus type, and (2) post-hoc tests indicating that bisection of Kanizsa stimuli differed from gap stimuli but not from connected stimuli.

Among the 12 patients, six of them (BAF, GAR, LAO, MAT, ROU and VIA) showed a significant main effect of stimulus type ($F(3,60) \geq 4.8$, $P < 0.05$ in each subject, Bonferroni-corrected for multiple comparisons), whereas six other patients (GIA, GRY, GYA, KRM, MOB and STF) demonstrated no significant effect of stimulus type ($F(3,60) \leq 2.7$, $P > 0.05$ in each subject). Pairwise post-hoc tests indicated that in all six patients of the former subgroup (group +), the bisection

judgements made on illusory and other complete stimuli (lines and real contours) were always significantly different from those made on unconnected gap figures (post-hoc Fischer's least statistical difference, $P < 0.05$ in each case), whereas judgements for illusory figures were always similar to those for other complete stimuli, and all other comparisons between stimuli were non-significant in these patients (except for a greater deviation on lines than real contour figures in BAF, and conversely greater deviation on real contour figures than lines in MAT). Thus, bisection judgements by patients in group + were generally consistent with illusory figures being treated like other complete objects (lines or real contour) but not like unconnected gap stimuli (Fig. 4a). In all cases except one (MAT), rightward deviation was always the smallest for gap stimuli, while it was the greatest in patient MAT. By contrast, the remaining six patients (group -) showed no systematic pattern, in keeping with the absence of a significant main effect of stimulus type in individual ANOVAs; the average bisection deviations in this subgroup were similar across the different stimuli (see Fig. 4b). Consistent with the results obtained for the whole group, the main effect of length was significant in all individual patients ($F(1,62) \geq 12$, $P < 0.05$ Bonferroni-corrected) except for one in group + (MAT) and two in group - (KRM and MOB). Length effects interacted with stimulus type in only one patient in each group (VIA and MOB, $F(1,60) = 6.2$ and 6.7 , respectively, $P < 0.05$ Bonferroni-corrected). The typical effect of greater bisection errors for longer stimuli [26] was reliably found only for real contour and Kanizsa figures in VIA (not for lines nor gaps), while it was found only for Kanizsa and gap figures in MOB (not

for lines and real contour stimuli). Length effects were otherwise independent from stimulus type in all other ten patients, and since these effects are usual in neglect and not of direct relevance to the present issue, they were not examined further here.

Based on the above individual patterns of results, we postulated that group + and group – might represent distinct patients in whom implicit effects of grouping by illusory contours appeared to occur and influence bisection (group +), or did not appear to do so (group –). We then sought to determine whether specific behavioural and/or anatomical factors might account for this difference. As there was also a substantial variability between patients in the degree of neglect for left-sided features in the matching task (see Table 3), differences in bisection performance might be related to a residual ability to attend to both sides of the stimuli on some trials. On the other hand, if the influence of illusory grouping arises from residual preattentive processing, this should occur regardless of the severity of neglect and errors in the matching task, where detection of bilateral elements is explicitly required.

3.4. Behavioural correlates

There was no evidence for a difference in the degree of contralesional visual inattention or impaired spatial exploration between patients in Group + and those in Group –. Importantly, patients in the two groups did not differ in their difficulty to detect the left-side features of illusory figures in the matching task (mean \pm S.D. 5.7 ± 2.0 missed vs. 5.5 ± 3.2 missed in group + vs. group –, respectively; $t(10) = 0.12$, $P = 0.91$). Neither did they differ in the number of ‘pseudo-differences’ reported on the right side of stimuli instead of real differences neglected on the left side (mean \pm S.D. 1.7 ± 1.6 errors vs. 2.3 ± 1.6 errors; $t(10) = 0.77$, $P = 0.46$). Conversely, the patients were separated after median-split into those who missed left elements on many trials in the matching task ($\geq 88\%$, $n = 7$) and those who correctly reported them in at least a few trials ($\leq 25\%$, $n = 5$), and their mean bisection errors were then submitted to a repeated ANOVA using matching performance (group with many vs. few misses) as well as stimulus type (all four figure categories) and length (short vs. long) as factors. This showed no main effect of matching performance ($F(1,22) = 1.9$, $P = 0.17$), and critically, the significant effects of stimulus type ($F(3,69) = 3.9$, $P = 0.012$) and stimulus length ($F(1,22) = 8.6$, $P = 0.008$) did not interact with matching performance ($F(3,69) = 0.2$, $P = 0.86$ and $F(1,22) = 1.9$, $P = 0.17$, respectively). The mean percent of rightward error on bisecting Kanizsa figures was 10.1 in patients who made few misses in the matching task and 10.7 in those who made many misses, whereas it was 5.7 and 6.8 on bisecting gap

figures, respectively. Other interactions were also non-significant. Overall, this indicates that distinct effects in bisection for illusory Kanizsa figures and non-illusory gap stimuli cannot be explained by different capabilities to detect lateral elements on both sides.

In addition, we directly tested whether bisection judgements (in particular for Kanizsa figures) were influenced by the ability to attend to contralesional elements in the matching task. Across all 12 patients, there was no significant correlation between their rate of left misses in the matching task and deviation from midpoint in the bisection task for Kanizsa stimuli (Spearman rank test, $\rho = -0.04$, $P = 0.88$) or for gap stimuli ($\rho = 0.02$, $P = 0.95$). Neither did the mean difference in bisection between these two types of stimuli correlate with rate of left misses ($\rho = 0.04$, $P = 0.88$). Moreover, midpoint judgements made on Kanizsa stimuli were significantly correlated with those made on lines and complete stimuli in group + (Spearman rank test, $\rho \geq 0.94$, $P \leq 0.03$ in both cases) but not in group – ($\rho \leq 0.77$, $P \geq 0.09$), whereas the correlation between Kanizsa and gap stimuli was not significant in group + ($\rho = 0.42$, $P = 0.34$) but close to significance in group – ($\rho = 0.83$, $P = 0.06$). This provides additional support to the hypothesis that Kanizsa stimuli were implicitly treated more like other connected objects by patients in the former group, but more like unconnected gap stimuli by patients in the latter group.

Furthermore, patients in group + and group – exhibited a similar severity of left spatial neglect in a number of other clinical measures (see Table 1), such as the magnitude of rightward deviation on a line bisection test (mean \pm S.D. 38 ± 23 mm vs. 40 ± 15 mm; $t(10) = 0.60$, $P = 0.56$), the total number of omissions (14.6 ± 9 vs. 11.5 ± 8 ; $t(10) = 0.65$, $P = 0.53$) or left-right asymmetry of omissions (9.3 ± 6 vs. 8.5 ± 4 ; $t(10) = 0.29$, $P = 0.77$) in a line cancellation test, as well as the total number (40.7 ± 9 vs. 41.5 ± 8 ; $t(10) = 0.17$, $P = 0.87$) or left-right asymmetry of omissions (14 ± 6 vs. 9.8 ± 4 ; $t(10) = 1.43$, $P = 0.18$) in a letter cancellation test. Time post-stroke onset (mean 9.8 ± 9 weeks vs. 11.5 ± 8 weeks, group + vs. group –, respectively; $t(10) = 0.32$, $P = 0.77$) and age (mean 67.7 ± 2 vs. 65.7 ± 3 ; $t(10) = 0.5$, $P = 0.62$) were also similar. Visual field defects were more common in patients of group –, with four of them having hemianopia but none of the patients in group + (Fisher’s exact test, $P = 0.030$), and in particular, the lower visual field was intact in five out of six cases in group +. However, a contralesional field defect alone cannot provide an entirely satisfactory account for a difference in illusory figure grouping since visual fields were intact in two and three patients in group – and group +, respectively.

3.5. Anatomical correlates

Volume of brain lesions tended to be smaller in patients in group+ than those in group– but not significantly so (mean \pm S.D. 57.5 ± 49 cc vs. 101.52 ± 48 cc, group+ vs. group–, respectively; $t(10) = 0.154$, $P = 0.15$). However, the two groups showed a clearly different topographical distribution of cortical damage. The average overlapping images obtained from the lesion location in each patient and reconstructed using a three-dimensional computerized template system [16] are shown in Fig. 5. Patients in group+ had damage overlapping mainly in the inferior posterior parietal lobe (Brodmann's area 40), while posterior lateral occipital areas were always spared. Two patients (LAO and ROU) had an infarct in the posterior cerebral artery territory including the posterolateral thalamus. Patients in group– had damage involving not only the inferior parietal cortex, but also extending more caudally in the lateral occipital lobe (Brodmann's areas 18–19).

4. Discussion

This study provides a number of important findings which suggest that: (1) grouping by illusory contours can occur implicitly without requiring spatial attention

and is indeed independent from the severity of unilateral neglect; (2) such grouping involves specific processes that are distinct from other forms of implicit processing that can occur outside conscious awareness; (3) effective preattentive grouping by illusory contours may depend on the integrity of secondary visual areas in the lateral occipital cortex.

In spite of hemispatial neglect, patients could make bisection judgements on Kanizsa illusory figures that closely paralleled their bisection of physically connected stimuli of the same length, but differed from the bisection of unconnected gap figures which did not yield a single illusory surface completion. Illusory figures were thus generally treated like complete objects, but unlike other unconnected gap stimuli, suggesting that grouping processes involved in the formation of illusory contours could still influence size judgement and bisection to some extent independently of spatial neglect. This pattern held true for the patients taken as a whole group but most particularly in some of them (group+), and it was observed even though the patients were often unable to attend to and detect the left-side inducing elements of Kanizsa figures when this was explicitly required, as evidenced by their performance in the matching task. Thus, while some processing seemed to operate on bilateral elements in illusory figures and influence performance when indirectly assessed during bisection, the ability to orient attention to the contra-

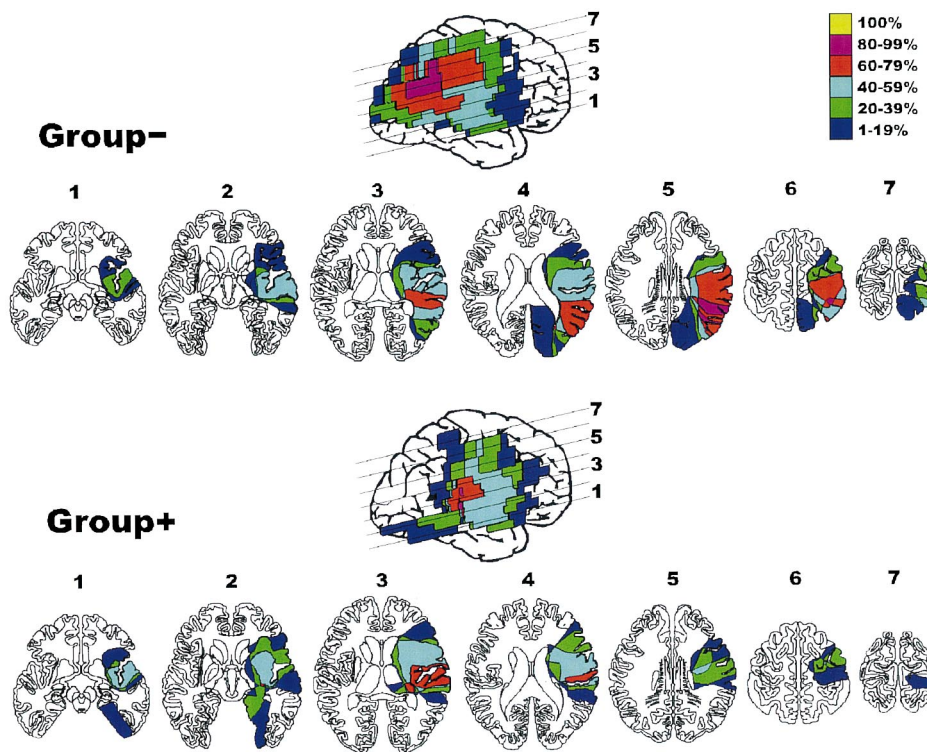


Fig. 5. Average overlapping lesion location in patients who showed (group+) and those who did not show (group–) evidence of implicit grouping on the bisection of illusory Kanizsa figures.

sional inducers and explicitly report them was severely defective. These findings imply that the spatially distant elements in illusory figures were somehow grouped together by the visual system before being bisected and eventually neglected. In other words, visual mechanisms that presumably operate at an early stage of processing could segment contralesional visual information in the scene and extract illusory contours to generate a unitized 'gestalt' object, prior to the stage where attention is allocated to segmented objects and where an abnormal spatial bias may eventually arise in patients with neglect. These findings are consistent with recent observations in neglect patients [41,60] and normal subjects [7], which suggest that the detection of illusory contours involves automatic processes of grouping and independent of attention [10,23,24,35,45,49] rather than attentive processes based on cognitive interpretation, object knowledge, or memory [5,20,21,52,53].

More generally, these results converge with other evidence in neglect patients, demonstrating that substantial residual processing may take place for contralesional stimuli without attention [4,37] and thus determine appropriate object segmentation even when the patients fail to orient overtly to these stimuli or remain unaware of them [11,12,48]. Implicit processing of visual information that is neglected at a later attentional stage and unavailable to explicit conscious perception has been found for figure-ground segregation based on luminance contrast [39], shape symmetry [12] or elongation axis [13], as well as in instances of object-centred neglect [2,3,17,38] and geometric size illusions induced by neglected stimuli [40,51]. Similarly, in normal subjects, it has been shown that perceptual grouping of visual features according to gestalt properties may occur automatically without attention and influence responses in a line-length judgement task even when the features inducing grouping are not consciously perceived [43]. Taken together, such observations indicate that the visual system is capable of processing and organizing sensory information to some extent preattentively in order to extract candidate objects in space, to which attention can then be directed for conscious processing.

In addition to the above, our study extends previous observations of preattentive processing in spatial neglect in a number of ways. We were able to distinguish two groups of patients who, respectively, showed a consistent pattern of bisection performance suggesting implicit grouping by illusory contours (group +) or did not show any consistent pattern (group -). Bisection judgements for Kanizsa stimuli correlated with those made on other complete stimuli in group +, but with those made on gap stimuli in group -, consistent with the hypothesis that these figures might be treated as single segmented objects in the former but not in the latter patients. The two groups differed in the topo-

graphical distribution of brain damage, but did not differ in several clinical measures such as neglect severity and stroke recency, nor in their capacity to explicitly direct attention to and report left-sided features in Kanizsa figures in the matching task. This suggests that implicit effects in bisection cannot be simply attributed to a difference in the severity of neglect or a residual ability to process both sides of the stimuli explicitly. Many previous studies showing evidence of unconscious or preattentive processing in neglect have assumed that this must necessarily reflect residual effects of specific neural mechanisms that arise independently of spatial neglect and would remain unchanged with the degree of contralesional inattention, but this has never been directly tested. Moreover, since individual neglect patients may considerably vary in their lesion location and behavioural presentation [28,34,38], it is plausible that not all cases would show the same extent of residual implicit processing and preserved influences of preattentive object segmentation processes [8,11]. A different degree of residual processing could result from qualitatively distinct impairments after particular lesions [11]. However, this could also simply reflect a pervasive effect from individual differences in the abnormal spatial bias of visual processing and a subsequent non-specific degradation in the quality of visual representations [4,8,14]. Thus, Farah et al. [14] argued that dissociations observed between implicit and explicit measures of perception in neglect do not necessarily demonstrate the existence of distinct processes but might stem from an unilaterally impoverished input to the visual system, still sufficient to affect performance in implicit tasks but inadequate to sustain the normal neural representation necessary for explicit tasks. Importantly, here we found that differences in implicit grouping between our group + and group - patients independent of contralesional neglect, which reinforces the idea that grouping effects reflect the operation of specific processes that are not dependent on spatial attention, but automatically engaged at preattentive stages of vision.

Furthermore, our patients demonstrated another form of implicit processing in the matching task whereby they often noticed irrelevant 'pseudo-differences' in the right-side features of illusory figures while neglecting in fact more obvious differences in the left-side features. By contrast, they never committed such errors when the left-side features were identical. Similar observations were previously reported in other neglect patients [4,9,37]. This finding indirectly confirms that left features can be processed by the visual system outside conscious awareness, hence capable of biasing matching judgements, as well as eventually determining appropriate detection and grouping of illusory contours. Remarkably, the lack of implicit grouping effects in group - compared to group + patients was not

associated with less propensity to report such erroneous pseudo-differences and thus cannot be explained by a general non-specific difference in the degree of residual (preattentive or unconscious) processing. To our knowledge, this is the first report of a dissociation between two forms of implicit processing for the same stimuli in hemispatial neglect. Unconscious processing of left elements in 'pseudo-differences' might rely on the detection of contrast differences by very early visual processes (e.g. in primary cortex) and be preserved in both group + and group – patients, even when there is damage to extrastriate areas in the occipital lobe (possibly mediating implicit processes of higher level such as segmentation and grouping) as in group – patients.

Indeed, a different distribution of lesion location was the most distinguishing feature between patients who showed some evidence consistent with residual preattentive detection and grouping of illusory contours (group +) and others who did not (group –). Group + patients had lesions overlapping in the inferior posterior parietal cortex or subcortical damage in the thalamus, two regions previously found to be the most common in association with hemispatial neglect [28,58], whereas more posterior areas in the occipital cortex were spared. In contrast, group – patients had lesions that always extended posteriorly in the lateral occipital cortex, including at least the anterior portion of Brodmann's areas 18–19. These occipital areas might contain the human homologue of V2 neurones found in monkeys, coding for interpolated edges and presumably subserving the perception of illusory contours [45,56,59]. In support of this, recent functional neuroimaging studies [15,29] suggest that the perception of Kanizsa-type illusory contours is associated with a specific activation in the posterior lateral extrastriate cortex (Brodmann's area 18), particularly in the vicinity of the lateral lunate sulcus [15] and predominantly in the right hemisphere [29]. Activity in the lateral occipital gyrus seems also associated with higher-order features of visual images such as long-range structure, pattern symmetry, or texture regularities [57], suggesting that this area may play a privileged role in figure-ground segmentation processes. Such a specialization of the superior lateral occipital cortex appears consistent with the perception of illusory contours being better in the lower than the upper visual hemifields [54] and preferentially mediated by the magnocellular rather than the parvocellular visual pathways [36,54], which project more to the superior and inferior portions of V2–V3, respectively [25,30]. Indeed, lower visual field defects were less common in our group + than group – patients. More efficient mechanisms for the detection of illusory contours and interpolation of edges across gaps in the lower visual field might result from a more frequent occurrence of surface occlusion there and a greater need for appropriate segmentation on the ground plane [47,54].

Finally, our results may allow to reconcile the finding of preserved grouping by illusory contours in right parietal-damaged patients with neglect [41,60] with neuropsychological studies showing impaired perception of figural closure and illusory contours after posterior damage in the right hemisphere [27,32,63], and other evidence of a right hemisphere specialization for the detection of subjective contours in normal subjects [1,25]. Implicit preattentive processing that afford the detection and grouping of bilateral features in illusory Kanizsa figures despite neglect might occur only in some cases with relative sparing of extrastriate areas in the lateral occipital cortex. We also note that lesions in superior lateral occipital cortex can impair the perception of stereo-depth [27,50]. Therefore, our results suggesting a role of these areas in the detection of illusory contours also provide support to theories that have assumed a close interaction between perceptual mechanisms encoding surface segmentation and completion, on the one hand, and depth position, on the other hand [5,23,27,33,63].

One potential limitation of this study is that illusory and non-illusory gap stimuli were not matched in terms of low-level physical properties, and differences in bisection judgements might have been partly related to factors other than implicit grouping. However, such effects of physical differences would likely result in bisection biases being generally less rightward with highly contrasted contralesional elements in Kanizsa figures as compared to the gap stimuli [55], as well as a greater correlation with the severity of neglect, both of which are opposite to the observed results. Also, while physical effects would possibly explain some difference in bisection between stimulus types, they would not explain differences between patients independent of neglect and a selective relation of performance to lesion location. In summary, the present findings provide support to recent hypotheses that preattentive mechanisms of segmentation and grouping may continue to operate on visual stimuli despite hemispatial neglect after parietal damage [12,18,44,61,62], and presumably rely on processing in earlier extrastriate cortical areas. To our knowledge, this study is the first to delineate distinct anatomical correlates of these two (preattentive and attentive) sides of perception in neglect.

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