Research report

Attention as the 'glue' for object integration in parietal extinction

Markus Conci [a,], Julia Groß [a], Ingo Keller [b,c], Hermann J. Müller [a,d] and Kathrin Finke [a,e]*

[a] *Department of Psychology, Ludwig-Maximilians-University, Munich, Germany*
[b] *Schön Clinic Bad Aibling, Germany*
[c] *Department of Neuropsychology, Medical Park Bad Feilnbach, Germany*
[d] *Department of Psychological Sciences, Birkbeck, University of London, UK*
[e] *Hans-Berger Department of Neurology, University Hospital Jena, Germany*

ARTICLE INFO

ABSTRACT

Patients with unilateral, parietal brain damage frequently show visual extinction, which manifests in a failure to identify contralesional stimuli when presented simultaneously with other, ipsilesional stimuli (but full awareness for single stimulus presentations). Extinction reflects an impairment of spatial selective attention, leaving basic preattentive processing unaffected. For instance, access to bilaterally grouped objects is usually spared in extinction, suggesting that grouping occurs at a stage preceding (in the patients: abnormally biased) spatial-attentional selection. Here, we reinvestigated this notion by comparing (largely between participants, but also within a single-case participant) conditions with objects that varied in their dominant direction of grouping: from the attended to the non-attended hemifield (data from Conci et al., 2009) versus from the non-attended to the attended hemifield (new data). We observe complete absence of extinction when shape completion extended from the attended hemifield. By contrast, extinction was not diminished when object groupings propagate from the unattended hemifield. Moreover, we found the individual severity of the attentional impairment (assessed by a standard "inattention" test) to be directly related to the degree of completion in the unattended hemifield. This pattern indicates that grouping can overcome visual extinction only when object integration departs from the attended visual field, implying, contrary to many previous accounts, that attention is crucial for grouping to be initiated.

1. Introduction

A key property of the human visual system is its ability to effectively organize the complex input from the ambient array. In fact, visual processing appears to operate fairly effortlessly in structuring our natural environment, achieving a coherent representation of the external world in a seemingly automatic manner. Yet, whether the integration of

* *Corresponding author.* Allgemeine und Experimentelle Psychologie, Department Psychologie, Ludwig-Maximilians-Universität, Leopoldstr. 13, D-80802 München, Germany.
E-mail address: conci@psy.lmu.de (M. Conci).

fragmented parts into coherent wholes (objects) arises from high-level cognitive functions that depend on attention or from low-level automatic, that is, "preattentive" processes has remained a controversial issue. Influential theories of vision suggest that only a subset of primitive features is encoded preattentively, whereas integrated objects become available only later, requiring the engagement of selective attention (Treisman & Gelade, 1980). By contrast, opposing views hold that attention is, in essence, object-based, with the representation of complete-objects arising preattentively — that is, prior to the engagement of attention (Driver & Baylis, 1998; Humphreys, 2016; Scholl, 2001, for reviews).

An effective means for testing whether object integration does, or does not, require attention is provided by the assessment of brain-damaged patients with a selective impairment of attentional functioning. For instance, discrete lesions predominantly located in the right inferior parietal lobe are known to produce visual hemispatial neglect and associated symptoms of visual extinction (Karnath, Milner, & Vallar, 2002; Kerkhoff, 2001). Neglect patients show a profound loss of perceptual awareness of stimuli in the contralesional field, often despite generally preserved low-level visual processing (Driver & Vuilleumier, 2002, for review). Extinction is a specific deficit frequently observed in residual, or mild, neglect: patients are capable of detecting single stimuli, but tend to miss contralesional stimuli if these are presented together with ipsilesional stimuli. Importantly, extinction and neglect do not only, or simply, reflect deficits in spatial orienting. Rather, they are thought to arise from a competitive disadvantage for selection from the contralesional field due to disrupted processes of selective attention (Baylis, Driver, & Rafal, 1993; Finke et al., 2012; Humphreys, Romani, Olson, Riddoch, & Duncan, 1994; Ptak & Schnider, 2005; Ward & Goodrich, 1996). In this view, extinction results from a pathological, competitive bias against the contralesional hemifield (Desimone & Duncan, 1995). Accordingly, the lack of attention to stimuli on the contralesional side is a relative, rather than an absolute, deficit, with fewer attentional resources allocated to the contralesional, as compared to the ipsilesional, hemifield (Bays, Singh-Curry, Gorgoraptis, Driver, & Husain, 2010; Gögler, Finke, Keller, Müller, & Conci, 2016).

Despite their extinction behavior, these patients display preserved access to complete objects (Driver, 1995, for review). Intact processing has, for instance, been reported in a variety of studies that presented stimulus fragments that had to be grouped across the two hemifields to form a complete object for explicit report (Brooks, Wong, & Robertson, 2005; Driver, Baylis, & Rafal, 1992; Gilchrist, Humphreys, & Riddoch, 1996; Marshall & Halligan, 1994; Pavlovskaya, Sagi, Soroker, & Ring, 1997; Ro & Rafal, 1996; Robertson, Eglin, & Knight, 2003; Vuilleumier & Landis, 1998; Vuilleumier, Valenza, & Landis, 2001; Ward, Goodrich, & Driver, 1994). The typical finding in these studies is that extinction patients show preserved access to the grouped, integrated object, with completed objects being available inspite of the attention bias. These results thus suggest that grouping precedes attentional engagement (see also Shomstein, Kimchi, Hammer, & Behrmann, 2010), supporting object-based views of attention.

Particularly strong evidence for intact complete-object representations despite extinction was reported in studies

that presented Kanizsa figures, which give rise to the perception of illusory figures (see Fig. 1A, panel ii; Kanizsa, 1955). These experiments (Conci, Böbel, Matthias, Keller, Müller, & Finke, 2009; Mattingley, Davis, & Driver, 1997) presented parietal extinction patients with a sequence of displays that consisted of four circles arranged to form a square, centered around fixation. On each trial, quarter-segments were briefly removed from the circles, either from the left, the right, or both sides (or not at all), and the task was to tell the sides of the offsets (see Fig. 1A for an example trial and Fig. 1B for examples of possible target offsets). When segments were arranged such that no bilateral grouping was supported (Fig. 1A, panel i), the patients showed a severe deficit in reporting offsets on the left. However, this typical extinction behavior effectively disappeared when bilateral segments could be grouped to form a complete Kanizsa square, linking the stimuli across the two hemifields (Fig. 1A, panel ii), in which case detection of bilateral offsets was comparable to unilateral offsets. This pattern of results was taken to indicate that the formation of integrated (illusory) objects is preserved despite severe attention deficits, that is: integration occurs preattentively (see also Vuilleumier & Landis, 1998; Vuilleumier et al., 2001).

A reduction of extinction was not only observable for complete Kanizsa squares, but also for configurations that elicited just partial, less conspicuous, groupings (Conci et al., 2009; see Fig. 2B for example stimuli). For instance, extinction was reduced (to a similar extent as with the Kanizsa square) when bilateral segments supported grouping by means of surface filling-in to form a partial shape. Extinction was also reduced (albeit to a smaller extent) when bilateral segments could be grouped by collinear contours without corresponding surface portions. It thus appears that extinction varies systematically with the degree to which grouping processes effectively integrate fragmented parts into coherent wholes (Fig. 4C), with gradual contributions from contour and surface completion mechanisms (Grossberg & Mingolla, 1985). A comparable gradual variation has also been reported in visual search studies with healthy observers, which presented Kanizsa figures: search efficiency varied systematically with the amount of contour and surface information in candidate target objects (Conci, Gramann, Müller, & Elliott, 2006; Conci, Müller, & Elliott, 2007; Nie, Maurer, Müller, & Conci, 2016; Töllner, Conci, & Müller, 2015; Wiegand et al., 2015).

Given that extinction patients show the same qualitative pattern as normal subjects with Kanizsa-type object configurations, we consider these stimuli to be ideally suited for examining how grouping processes operate in general. In this regard, the combined evidence with extinction patients and normal subjects supports recurrent models of grouping (Roelfsema, Lamme, Spekreijse, & Bosch, 2002; Stanley & Rubin, 2003), which assume that fragments are first linked to represent coherent surfaces, followed by the interpolation of the precise bounding contours. Importantly, however, the evidence reviewed supports the view that both mechanisms of surface and contour grouping are available prior to the allocation of attention.

The fact that partial shape information can reduce extinction suggests that object integration propagates automatically from the available segments to form a grouped region. That is, grouping may be triggered both by information
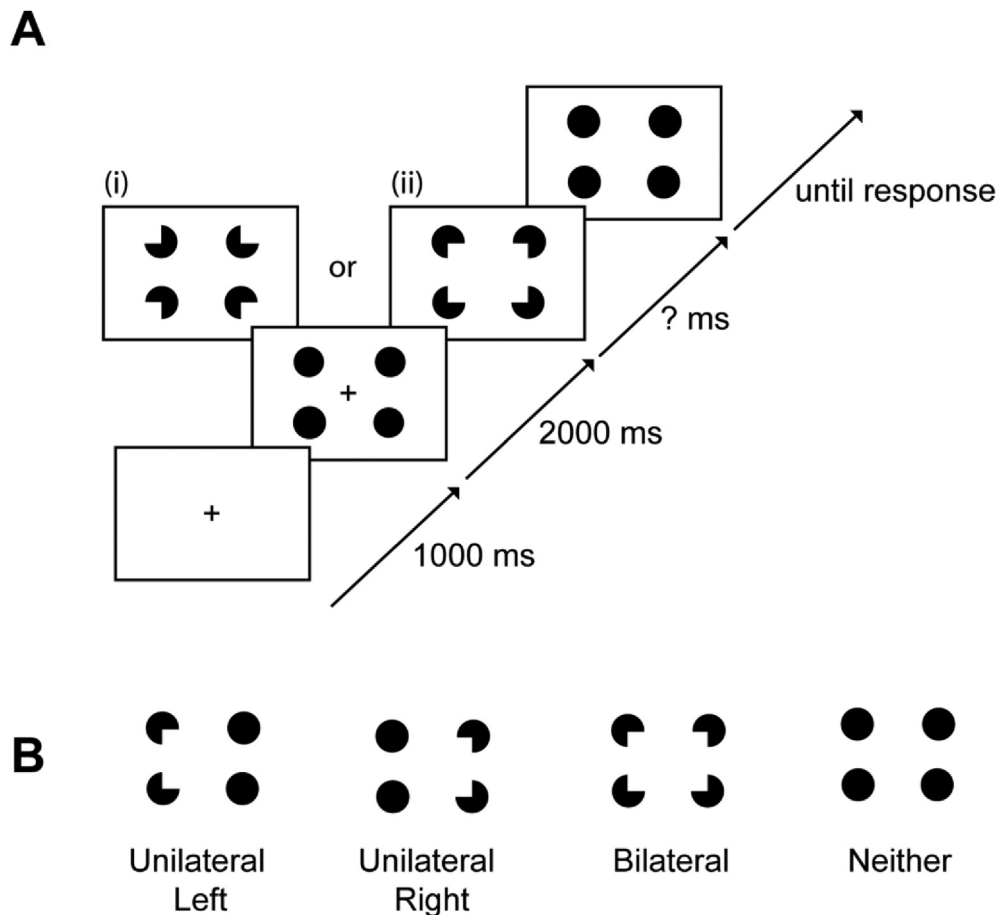
Fig. 1 — Example trial sequence and stimulus types. (A) Each trial started with the presentation of a fixation cross, followed by a premask display of four placeholder circles. Next, quarter-segments were removed from the circles for a short period (as specified individually in a pretest). Finally, a postmask was presented until response. In the example sequence, bilateral segments were removed, yielding either a configuration without (i), or with (ii) a centrally grouped shape. (B) Example stimulus types with quarter-segments removed either at unilateral left, unilateral right, bilateral, or neither side(s). The task was to indicate the sides at which quarter-segments were removed (left, right, both, or none).

present in the attended and by information in the unattended hemifield. Our previous study (Conci et al., 2009) invariably presented identical 'square-like' segments in the ipsilesional (right) visual field, arranged such that an illusory square could potentially emerge. Groupings would propagate into the contralesional (left) visual field (see Fig. 2B) — that is, the prevailing direction of grouping for these stimulus arrangements was from the attended into the neglected hemifield. In principle, however, *preattentive* grouping processes should equally operate when initiated by stimulus fragments in the contralesional hemifield, that is, they should also propagate from the left to the right.

In the current study, we tested the influence of attention on object integration in parietal extinction by systematically comparing variations in the direction of perceptual grouping, either from the left to the right (Fig. 2A) or from the right to the left (Fig. 2B; as tested in Conci et al., 2009). In the critical condition, which permitted attention and object completion to be dissociated, extinction patients were presented with (partial) Kanizsa square groupings that extended from the contralesional field. Thus, with the primary to-be-grouped

elements presented in the neglected field, successful object completion would require propagation from the impaired to the attended visual field.

To our knowledge, all prior studies that examined object integration in extinction patients usually reported a performance advantage for bilaterally grouped displays, which either resulted from equated/symmetric (or, in some cases from unequal/asymmetric) grouping cues between the two display halves (e.g., Mattingley et al., 1997; Vuilleumier & Landis, 1998; Vuilleumier et al., 2001; Ward et al., 1994). Of note, however, none of these studies explicitly tested the effects of grouping direction. Hence, one cannot tell from their results whether grouping operated symmetrically from both sides or asymmetrically from one (the attended) towards the other (the neglected) side. Given that the latter cannot be ruled out, one can also not tell from their results whether grouping is truly automatic, that is, whether object integration can emerge from parts of the visual field that effectively lack attention. The left-to-right manipulation introduced in the present study, with patients exhibiting extinction behavior, was designed to decide this issue.
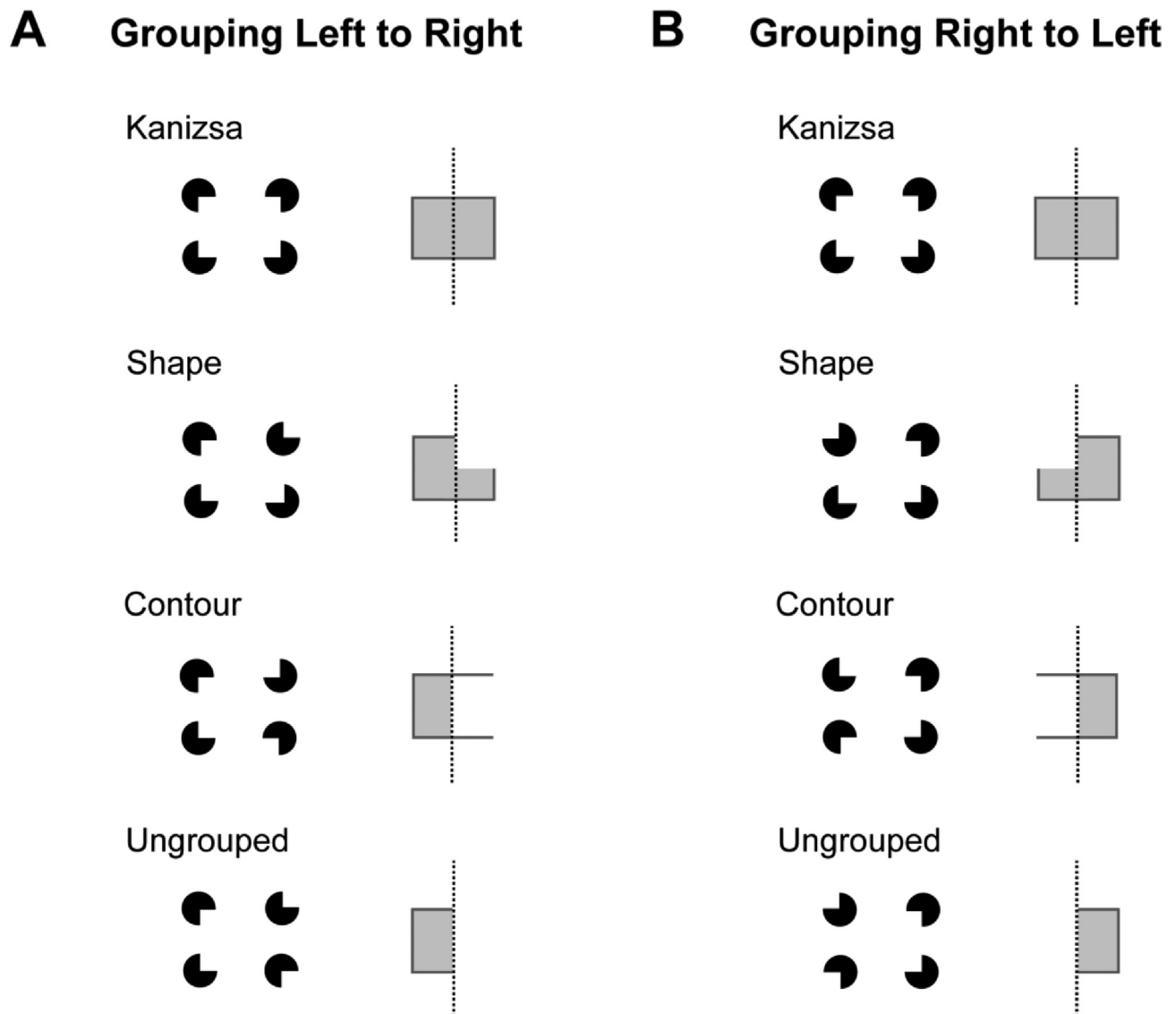
A Grouping Left to Right

Kanizsa

Shape

Contour

Ungrouped

B Grouping Right to Left

Kanizsa

Shape

Contour

Ungrouped

Fig. 2 — Examples of right- and leftward object groupings. Stimulus configurations with groupings extending from the left, neglected hemifield to the right, attended hemifield (A), or from right to left (B, as tested previously in Conci et al., 2009). Each grouping depicts a local arrangement of inducers together with the representation of the global object, illustrating the respective contour and surface stimulation (in dark and light gray, respectively) with relation to the (dashed) vertical midline. Four types of grouping were employed: For Kanizsa stimuli, a complete global square was induced. By contrast, Shape stimuli presented a partial global grouping that consisted of incomplete bilateral surface and contour groupings. Contour stimuli consisted of bilateral illusory contours without corresponding surface portions. Finally, Ungrouped configurations did not exhibit any bilateral contour- or surface-based groupings.

2. Materials and methods

2.1. Subjects

Our sample consisted of twelve right-handed patients (seven male; mean age: 61.0 years, SD: 14.1, range 33–76 years) who were recruited from the Neurological Clinic Bad Aibling, Germany. Eleven of these patients suffered from a stroke and one from a contusion in the right hemisphere. Inclusion criteria for participation were clinical signs of visual hemi-neglect according to (i) prior neurological examination and (ii)

reports of the patients' neuropsychological therapists, plus (iii) impaired performance on a minimum of two out of the following five neglect subtests of the (standardized battery of the) Behavioral Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987): cancellation, visual search, line bisection, figure copying, and representational drawing. BIT sum scores were computed in order to estimate the individual degree of unilateral inattention. Based on these scores, neglect was severe to moderate in 4 (BIT score < 100), mild in 7 patients (BIT score > 100), and only residual in 1 patient (who scored above the BIT neglect diagnosis cutoff of 129) at the time of testing
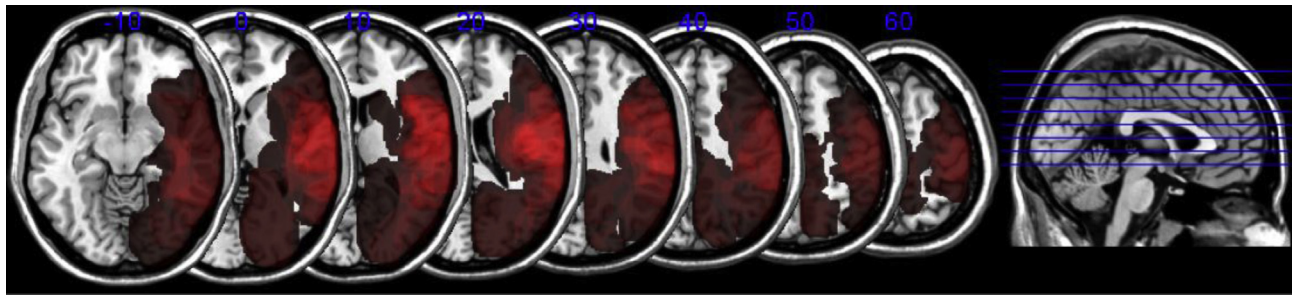
Fig. 3 – Lesion reconstructions. Lesion location overlap for all 12 tested extinction patients reconstructed for 8 transversal slices (left) and their positions in sagittal orientation (right). Numbers above each slice depict the z-score in Talairach coordinates. Higher lesion overlap is shown in light red, lower overlap in dark red.

(Table 1). Patients were tested within 6–26 weeks post injury. One patient (F.F.) received medical treatment for high blood pressure, and another patient (R.O.) suffered from diabetes mellitus type II. All patients had normal intelligence quotient (IQ) values and normal or corrected-to-normal visual acuity. Visual perimetry was performed in all patients, indicating left hemianopia in six individuals (see Table 1). In two patients, the visual field defect was incomplete, with residual visual function in a small upper-left region in patient E. K. and a large upper-left and a small lower-left region in patient F. F. However, it should be noted that measuring visual field deficits by means of automated perimetry often makes it difficult to disentangle symptoms associated with the hemianopia from

deficits that actually result from visual neglect (Müller-Oehring et al., 2003; Parton, Malhotra, & Husain, 2004). We therefore explicitly tested whether these patients would be able to see and report the unilateral stimuli presented within the central region of the screen (which extended 2.5° of visual angle into the left and right hemifields; see details below). This was the case in all of these six patients. For instance, the mean overall accuracy of unilateral left target detections was 89% (range: 72%–97%), with comparable levels of performance for the six patients with hemianopia (89%) and the six without hemianopia (88%). Lesion locations were identified by means of perfusion computer tomography (CT), which was recorded 1–26 weeks prior to testing. As depicted in Fig. 3, lesions were
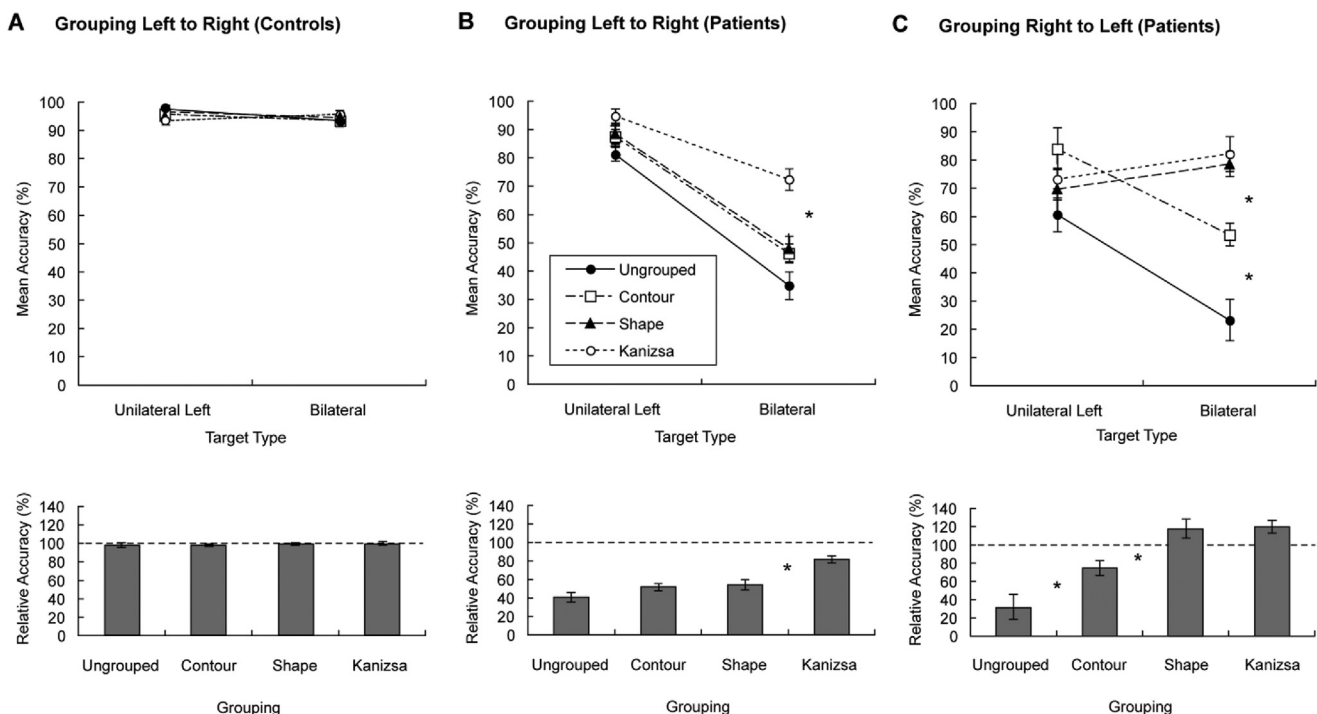

Fig. 4 – Behavioral performance. Results for rightward (A, B) and leftward (C) grouping displays in a control group (A) and in two groups of extinction patients (B, C). The upper panels depict the mean percentage (and associated within-subject standard errors) of correct target detections as a function of target type (unilateral left or bilateral), separately for the four different object types (Ungrouped, Contour, Shape, and Kanizsa). The lower panels show the corresponding relative accuracy values (and their associated within-subject standard errors) for the different types of bilateral object groupings (a value of 100% would correspond to unilateral-left baseline performance). Significant differences of pairwise comparisons across relative accuracies are indicated by an asterisk. Results from panel C were adapted from Conci et al. (2009).

Table 1 − Subject Details. Clinical and demographic data of patients and corresponding group averages for patients and controls. *Extrapolated value (on the basis of three available BIT-subtests).

	Sex	Hand	Age	Injury type	VF deficit	IQ score	BIT Score	TSI (weeks)	Presentation time (msec)
Patients									
Y.Z.	f	r	33	MCA	H	101	114	11	500
M.B.	m	r	48	TBI; C	−	104	121	23	50
F.F.	m	r	62	MCA	H	112	92	10	1400
H.F.	m	r	73	MCA	H	104	68	14	2200
D.K.	m	r	76	MCI	−	112	101	10	600
E.S.	f	r	41	MCA	H	130	100	8	300
G.H.	m	r	73	MCA	−	118	128	10	25
E.K.	f	r	73	MCA	H	101	44	22	1500
M.R.	f	r	66	MCA	−	107	126*	26	50
E.S.	f	r	71	MCA	−	112	138	7	200
P.S.	m	r	54	MCA	H	93	67	6	700
R.O.	m	r	62	MCA	−	118	106	9	50
Group average									
Patients	7f, 5m	12r	61.0	−	−	109.3	100.4	13.0	631.2
Controls	7f, 5m	10r, 2l	65.1	−	−	127.6	−	−	23.3

Abbreviations: VF − Visual Field; IQ − intelligence quotient; BIT − behavioral inattention test; TSI − time since injury; m − male; f − female; r − right; l − left; MCA − right medial cerebral artery infarction; TBI − traumatic brain injury; C − rightward contusion; H − left hemianopia.

confined to the right hemisphere and clustered in inferior-parietal and/or temporo-parietal areas. Of note, one patient with a contusion of the right hemisphere subsequent to traumatic brain injury (M.B.) might additionally have suffered from a contrecoup injury, which often is not clearly visible in the CT scans (though such injuries are not very frequent after parietal lesions; see Ruan, Khalil, & King, 1994). In one of the analyses reported, the results from the group of 12 patients tested in the current study were compared to those obtained from a different group of seven extinction patients who had taken part in a previous study (Conci et al., 2009).

An additional, age-matched healthy control group of twelve subjects (ten right-handed; four male; mean age: 65.1 years, SD: 5.9, range 57−72 years) was tested. All subjects had normal or corrected-to-normal vision. None of them reported any history of neurological or psychiatric disease. Controls did not differ significantly from the patient group with respects to age, t(22) = .92, p = .36, and the gender distribution was identical.

The experimental procedure of the experiment was approved by the local ethics committee (Department of Psychology, LMU Munich), and informed consent according to the Declaration of Helsinki II was obtained from all participants. Demographic and clinical data of all patients and corresponding means for patients and controls are summarized in Table 1. Our sample size was based on previous work in this area. Of note, the final sample of neglect/extinction patients was larger than the samples in the majority of the neuropsychological studies on perceptual grouping cited in this article.

2.2. Apparatus and Stimuli

All experimental procedures were essentially comparable to those in our previous study (Conci et al., 2009). The experiment was programmed using Matlab routines and Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Stimuli were presented on a 17-inch monitor (1024 × 768 pixel screen resolution, 70-Hz refresh rate). Observers viewed the monitor from

a distance of 57 cm, with head position maintained by the use of a head and chin rest. To control for eye movements, a light-sensitive web-camera was used, with maintenance of fixation monitored by the experimenter. In case of a loss of central fixation, the experimenter verbally instructed the observer to refixate at the screen center. It should be noted that neglect/extinction patients often show a tendency to shift their eye gaze overtly towards the unimpaired, attended hemifield, and this control procedure was intended to minimize these types of eye movements. The experiment was conducted in a sound-attenuated and dimly lit room.

Stimulus configurations were composed of four gray circles (3.81 cd/m2) with a diameter of 1.6° of visual angle, presented on a black background (.01 cd/m2). Each stimulus configuration of circles was arranged in rectangular form subtending 2.1° × 3.4° of visual angle. The distance of each circle from the central fixation cross (.6° × .6°) was 2° of visual angle on a diagonal. There were four different types of target display: Unilateral Left displays presented the two circles left of fixation with quarter-segments removed from the circles. For Unilateral Right displays, quarter-segments from the circles right of fixation were removed. In Bilateral displays, all four circles were presented with quarter-segments removed. Finally, on catch trials ('Neither'), four full circles were presented (to provide a measure for guessing). Examples of all four types of target display are presented in Fig. 1B.

Different types of object groupings were generated in bilateral stimuli by systematically varying the orientations of the quarter-segments. While in our previous study (Conci et al., 2009), the predominant direction of grouping was from right to left (Fig. 2B), here groupings extended from the unattended hemifield, i.e., from left to right (Fig. 2A). Ungrouped configurations were arranged such that no bilateral groupings were induced, that is, there was no connection of the pacmen by means of grouping across the left and right hemifields. For the Kanizsa figure configuration, the segmented circles were arranged such that a complete illusory square was elicited by

means of inward-facing quarter-segments. The Contour configuration presented the quarter-segments such that illusory contours were induced (without corresponding surface portions), extending across the horizontal borders rightwards. In the Contour configuration, two horizontal illusory contours extended across the top and bottom border of the figure, respectively. Finally, for the Shape configuration, the quarter-segments were arranged to form an illusory contour extending horizontally with corresponding (partial) surface portions (either extending along the top or bottom horizontal border of the figure). That is, the Shape configuration depicted an illusory contour plus a corresponding partial surface that would connect the lateral segments of the figure. In Fig. 2A, examples of all four types of local stimulus arrangement (left panels) are always presented together with illustrations of corresponding grouped objects (right panels). For unilateral target displays, the spatial arrangement of the circles with removed quarter-segments corresponded to the spatial arrangement in the bilateral target displays.

2.3. Procedure and Design

Each trial started with the presentation of a central fixation cross, shown for 1000 msec. The subsequent premask display presented four circles in rectangular arrangement around fixation for 2000 msec. Next, the target display was presented with quarter-segments removed from the circles on either the left or the right side, both sides, or neither side (relative to fixation). The duration of the removal was based on results of individually performed pretests (see below). Finally, a post-mask of complete circles reappeared until the observer responded verbally, indicating which segments were removed in the display (left, right, both, or none). The experimenter recorded the responses via keyboard. Each trial was separated from the next by an inter-trial-interval of 1000 msec. Fig. 1A shows an example of a trial sequence.

At the beginning of the experiment, each observer completed a pretest to determine the individual target display duration at which unilateral left trials could be detected with an accuracy of ~85% correct responses. The sequence of displays in the pretest was similar to the experiment itself, except that only ungrouped stimulus configurations were presented. Stimulus duration was determined by means of an adaptive staircase procedure. The starting duration was 200 msec and was adjusted individually by the experimenter according to the level of correct responses until the performance criterion (~85% correct unilateral left detections) was reached. The pretest consisted of 20 randomized trials overall (with 10, 5, 3, and 2 trials presenting unilateral left, unilateral right, bilateral, and catch target displays, respectively), where the (10) trials with unilateral left targets were used to determine the presentation duration of the target display. This procedure was identical to our previous study (Conci et al., 2009), as well as being comparable to that used in a previous, related study (Mattingley et al., 1997). The mean presentation durations derived from the pretests were 23 msec for the controls (range 20–35 msec) as compared to 635 msec for the patient group (see Table 1 for individual presentation times), showing a large increase of the required presentation duration for the patients, t(22) = 2.97, p < .008.

The experiment proper consisted of 144 experimental trials, presented in four blocks of 36 trials each, with a break after each block. Each block presented one type of object configuration (Kanizsa, Shape, Contour, or Ungrouped) and consisted of 8 unilateral left, 8 unilateral right, 16 bilateral, and 4 catch trials that were presented in randomized order. Thus, in each block, there were an equal number of right- and left-hemifield targets, so as to avoid any strategic biases that might influence the pattern of responses. Blocks were administered in random order on an observer-by-observer basis. In summary, the experiment varied two factors, object type (Kanizsa, Shape, Contour, Ungrouped) and target (Unilateral Left, Unilateral Right, Bilateral, Neither) – comparable to previous, related studies (Conci et al., 2009; Mattingley et al., 1997).

2.4. Single-case analysis

We additionally tested a single patient, Y.Z., for both rightward and leftward (Conci et al., 2009) grouping variants of the experiment in order to directly compare the effects of grouping direction within a single subject (see also Caramazza, 1986, for a discussion of the single-case methodology). The experimental sessions with right- and leftward groupings were presented on separate days, and presentation times were adjusted individually at the beginning of each testing session (500 msec and 300 msec for right- and leftward groupings, respectively).

Patient Y.Z. is female, right-handed, and 33 years old at time of testing. Subsequent to an infarction of the medial cerebral artery, which resulted in right-hemisphere parietal brain damage (Fig. 6A), she showed clear signs of left-sided visual hemi-neglect and extinction behavior (BIT score of 114, cut-off: 129).
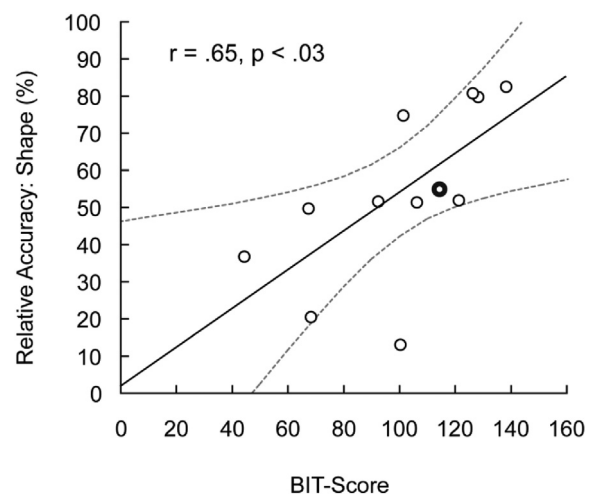

Fig. 5 – **Correlation between extinction and bilateral grouping performance. The graph plots a significant relationship between neglect severity (as measured by the overall score in the Behavioral Inattention Test, BIT) and the degree of extinction in shape configurations that extend from the unattended left hemifield to the right hemifield. Patient Y. Z. is depicted in bold. The dashed gray line denotes the 95% confidence interval.**
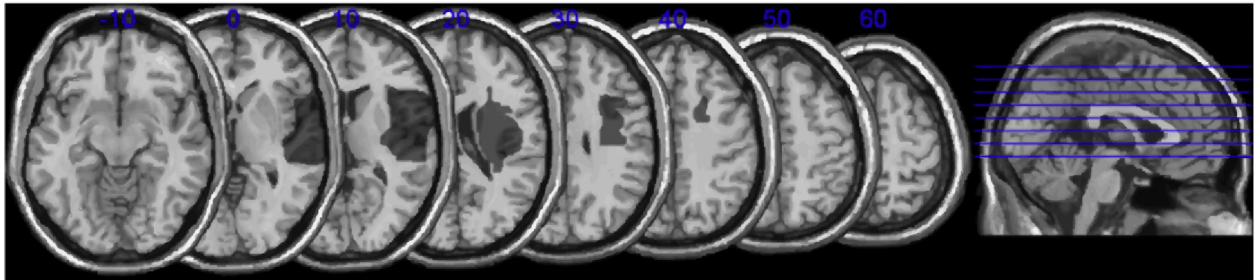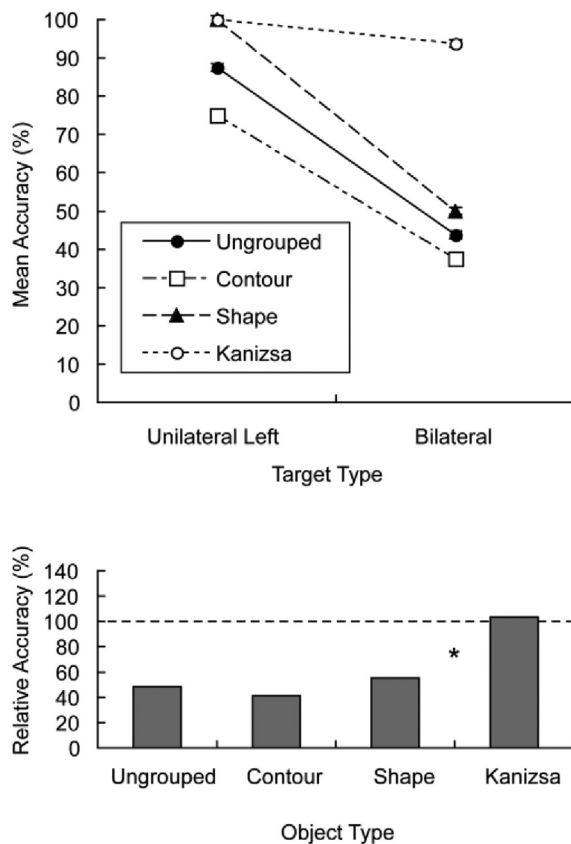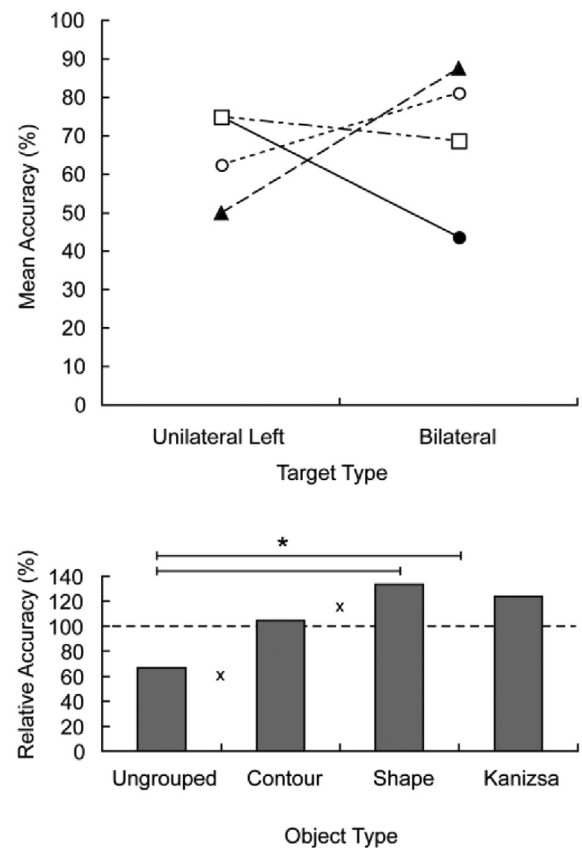
A Reconstructed Brain Lesions (Patient Y.Z.)

B Grouping Left to Right (Patient Y.Z.)

C Grouping Right to Left (Patient Y.Z.)

Fig. 6 — Lesion reconstruction and behavioral performance in patient Y. Z. (A) Brain lesions from patient Y. Z. reconstructed for 8 transversal slices (left, with z-score in Talairach coordinates) and their positions in sagittal orientation (right). Panels (B) and (C) depict Y. Z.'s results for right- and leftward grouping displays, respectively. Upper panels show mean percentages of correct target detections as a function of target type (unilateral left or bilateral), separately for the four different object types (Ungrouped, Contour, Shape or Kanizsa). The lower panels depict corresponding relative accuracy values for the various types of bilateral object groupings (were 100% would correspond to the unilateral left baseline performance). Significant [marginal] differences of pairwise comparisons across relative accuracies are indicated by an asterisk [symbol X].

2.5.   Statistical tests

Statistical tests were conducted on the relative accuracy scores, a measure that quantifies correct target detections in bilateral configurations relative to unilateral left displays. Additional tests were also performed for corresponding percent-correct measures (see Supplement). Mixed-design ANOVAs were computed with the between-subjects factor group and the within-subject factor(s) object type (as well as target type for the analyses presented in the Supplement). Additional repeated-measures ANOVAs with the factor object type were used to examine the relative accuracies for the single-case patient. Post-hoc comparisons were performed using t-tests (two-tailed). In addition, Pearson's correlation coefficients were computed to relate the individual BIT neglect score to the relative accuracy measure. The significance level was set at $p = .05$ for all statistical tests reported.

We additionally report the Bayes factors (BF_{10}) estimated by comparable Bayesian statistics for all ANOVAs and for the correlation analysis using JASP (JASP Team, 2017). The Bayes factor provides the ratio with which the alternative hypothesis is favored over the null hypothesis (i.e., larger BFs argue in favor of the alternative hypothesis, with values above 3 denoting 'substantial evidence' in favor of the alternative hypothesis; by contrast, values less than 1 support the null hypothesis; see Dienes, 2011).

3.   Results

Results showed that performance for unilateral right target presentations was high for both patients and controls (95% correct detections in both groups), with comparable levels of performance in both patients and controls and for the various types of grouping (all $ps > .46$, all $BF_{10} < .3$). In addition, all participants were highly accurate in identifying catch trials (that presented no offsets, i.e., when no quarter segments were removed from the circles; 99% correct detections of catch trials), again without any significant differences between groups and object types (all $ps > .14$, all $BF_{10} < .7$). This shows that observers were able to perform the task, without any indication of guessing responses.

3.1.   Detection performance in patients and controls

The aim of the present study was to investigate — in a group of parietal extinction patients — whether attention influences perceptual grouping. Our main analyses therefore focused on the comparison of trials that presented targets within the contralesional (left) hemifield, since extinction would usually occur for left-sided targets under conditions of bilateral stimulation. Consequently, correct target detections were compared for unilateral left (baseline) and bilateral displays (Fig. 4, upper panels). To quantify and statistically analyze the change in detection performance, a measure of relative accuracy was computed, quantifying target detections in bilateral configurations relative to unilateral left displays (Fig. 4, bottom panels). The relative accuracy denotes the individual performance of correct target detections (in %), where 100% denotes performance in the unilateral-left baseline condition.

Accordingly, values > 100% indicate better performance and values < 100% a decrease in performance for target detections in bilateral, relative to unilateral left, displays. As can be seen from the supplementary section, analogous analyses of the raw accuracy data (from which the relative scores were computed) yielded comparable results to the analyses of relative accuracy data presented below.

First, relative accuracy was examined by means of a mixed-design analysis of variance (ANOVA), with the between-subjects factor group (patients, controls) and the within-subject factor object type (Kanizsa, Shape, Contour, Ungrouped). There was a main effect of group, $F(1,22) = 47.3$, $p < .001$, $\eta^2 = .68$, $BF_{10} = 18941.4$: while (relative to the 100% unilateral-left baseline) there was no difference in performance (98%) for bilateral displays in the control group, there was a performance decrease (to 57%) in the patient group, overall indicative of extinction behavior. In addition, a significant main effect of object type was obtained, $F(3,66) = 9.8$, $p < .001$, $\eta^2 = .31$, $BF_{10} = 120.2$, indicating that performance varied for the different stimulus configurations. Importantly, the interaction was also significant, $F(3,66) = 8.1$, $p < .001$, $\eta^2 = .27$, $BF_{10} = 196.9$. Performance remained effectively constant for the control group, with relative scores of 98%, 98%, 99%, 100% for the ungrouped, contour, shape, and Kanizsa stimulus configurations, respectively (see Fig. 4A), ts(11) < 1, $p > .36$. This contrasts with a clear drop in performance (relative to the 100% baseline) in the patient group (see Fig. 4B): patients displayed reduced bilateral target detections with the ungrouped (40%), contour (52%), and shape (55%) configurations relative to the Kanizsa square configuration (82%), ts(11) > 3.8, $p < .004$. In other words, control group observers were equally effective in detecting targets on the left, irrespective of the display layout and object grouping. The patient group, by contrast, exhibited clear signs of extinction for the ungrouped and partially grouped objects, with spared access to bilateral segments *only* for the complete-object Kanizsa figure.

3.2.   Effects of grouping direction

In a subsequent step, we compared the data obtained in the present study on groupings that departed from the impaired hemifield directly with data on groupings that departed from the preserved hemifield (see Fig. 2 for example stimulus configurations). The latter data stem from a different group of patients tested in our previous study (Conci et al., 2009). The relative accuracies were analyzed for the different directions of grouping, comparing groupings that departed from the impaired hemifield (left to right) with our previously reported data on groupings that extended from the attended visual field (right to left). For this comparison, a mixed-design ANOVA was performed with the between-subjects factor completion direction (leftward, rightward) and the within-subject factor object type (Kanizsa, Shape, Contour, Ungrouped). This analysis revealed main effects of completion direction, $F(1,17) = 7.8$, $p < .02$, $\eta^2 = .32$, $BF_{10} = 2.4$, and object type, $F(3,51) = 24.6$, $p < .001$, $\eta^2 = .59$, $BF_{10} = 112821.6$, illustrating that performance varied overall between left- and rightward completion and between object types. Importantly, the interaction term was also significant, $F(3,51) = 6.9$, $p < .001$, $\eta^2 = .29$, $BF_{10} = 41.2$. As described above (see Fig. 4B), extinction was not reduced when

partial (shape and contour) groupings extended rightwards, that is, from the impaired into the good hemifield. By contrast, as reported in Conci et al. (2009; see Fig. 4C), groupings that emerged from the right, attended hemifield into the impaired hemifield depicted a graded reduction of extinction, that is, there was a monotonic recovery from extinction from un-grouped (31%) through contour (74%) to shape (117%) and Kanizsa (120%) configurations, ts(6) > 2.9, ps < .03 (except for the comparison between shape and Kanizsa configurations, $p = .67$). This pattern of results indicates that grouping reduced extinction effectively *only* when attention was available to initiate completion. However, importantly, grouping did not reduce extinction when insufficient attention was available for object completion processes to operate.

A potential alternative explanation to account for differences in the efficiency of leftward and rightward grouping might relate to the variability between the two patient groups tested. For instance, detection of unilateral left targets appears to be somewhat more accurate in the patient sample with rightward groupings (Fig. 4B) than in sample with left-ward groupings (Fig. 4C), and this subtle difference in baseline performance might account for the observed variations in the efficiency of grouping. To address this point, a second analysis was performed on a subsample of patients who were pre-sented with rightward groupings. For this subsample, seven patients were selected who exhibited similarly low accuracy scores in detecting unilateral left targets, making the levels of performance effectively comparable between the two patient groups (presented with left- and, respectively, rightward groupings), t(12) = 1.5, $p = .2$. Next, a mixed ANOVA was per-formed with the factors grouping direction and object type on the relative accuracy scores (as above). This analysis revealed the same pattern of results as described above: most impor-tantly, the grouping direction by object type interaction was again significant, F(3,36) = 5.6, $p < .001$, $BF_{10} = 15.4$, mirroring the pattern as described for the entire sample of 12 patients. Subsequent post-hoc comparisons in the subsample of pa-tients with rightward groupings again revealed that only the Kanizsa configuration differed from all other object types (all p's < .05), while there were no differences between ungrouped and partially grouped objects (all p's > .5). This outcome makes it very unlikely that differences in grouping efficiency arise from possible variations in baseline performance.

3.3. Influence of neglect severity on perceptual grouping

In an additional analysis, we used the current data for left-ward groupings (Fig. 2A) to examine the influence of individ-ual neglect severity on perceptual grouping departing from the contralesional side. The results revealed individual neglect severity (as assessed by the conventional Behavioral Inattention Test, BIT, Wilson et al., 1987) to be related to the degree of extinction evidenced in shape configurations, r = .65, $p < .03$, $BF_{10} = 3.8$ (Fig. 5). We did not find a comparable, significant correlation in an additional analysis on the Kanizsa configurations, where grouping could originate from both sides and extinction could, thus, be effectively remedied by the presented groupings, r = .21, $p = .53$, $BF_{10} = .4$. Thus, the degree to which shape completion was initiated in the con-tralesional, unattended hemifield — supporting detection of

left-sided object-part targets — was directly related to the degree of left-sided inattention.

3.4. Single-case analysis

We also compared leftward and rightward directions of grouping in a single, representative patient, Y.Z., who dis-played clear signs of left-sided extinction after right-hemisphere parietal brain damage (Fig. 6A; overall BIT score: 114; cut-off value: 129). The results for unilateral left and bilateral targets are presented in Fig. 6 (upper panels), together with the corresponding relative accuracy scores (lower panels). The relative accuracy score for this particular patient was computed by quantifying target detections in bilateral config-urations (correct/incorrect responses in a given, single trial) relative to Y.Z.'s average of target detections in unilateral left displays. For groupings that originated from the contrale-sional, neglected (left) field (Fig. 6B), an ANOVA with the factor object type (Kanizsa, Shape, Contour, Ungrouped) was per-formed on the individual relative accuracy. This analysis revealed a significant main effect, F(3,45) = 4.5, $p < .007$, $\eta^2 = .23$, $BF_{10} = 16.7$. Compared to the 100% unilateral-left baseline, there was no extinction in the Kanizsa condition (103%), but extinction was evident for all other partial groupings (between 41% and 55%). Post-hoc comparisons confirmed that the Kanizsa square permitted better performance than all other configurations, ps < .02, without any further differences among the shape, contour, and ungrouped configurations, all ps > .54.

Next, a comparable ANOVA on groupings that extend from the attended (right) hemifield (Fig. 6C) also revealed a signifi-cant main effect of object type, F(3,45) = 3.6, $p < .02$, $\eta^2 = .19$, $BF_{10} = 3.9$ — providing evidence of extinction in the ungrouped condition (67%), and a gradual improvement of the relative accuracy from contour (105%) to shape/Kanizsa (133% and 125%, respectively) configurations. Post-hoc comparisons revealed a significant reduction of extinction for shape and Kanizsa relative to ungrouped configurations, ps < .03, along with an 'intermediate' level of performance for contour completions. Specifically, the contour configuration engen-dered marginally better performance than the ungrouped condition, $p = .08$, and marginally worse performance than shape configurations, $p = .09$, while there was no difference between shape and Kanizsa stimuli, $p = .58$. This pattern is indicative of a graded increase in performance with an in-crease of the grouping strength in the objects presented.

Taken together, this pattern reveals a dissociation in Y.Z., with preserved grouping for objects extending from right to left, but no effects of grouping for objects extending from left to right. Thus, Y.Z. can use grouping operations to effectively reduce extinction when completion extends from the unim-paired hemifield, but there is no comparable benefit when grouping originates in the contralesional, neglected field. This outcome mirrors the pattern of effects observed for the overall sample of extinction patients described above.

4. Discussion

In this study, we addressed a long-standing controversy in the literature on whether or not attention is needed to integrate

visual fragments into coherent wholes. Prime evidence to decide this question derives from extinction patients, who display a strong bias in allocating attention towards the ipsilesional (right) hemifield. Despite this competitive disadvantage, several previous studies documented spared access to bilateral objects when these could be grouped into a uniform region that extends across the two hemifields (Driver, 1995; Gillebert & Humphreys, 2015, for reviews). These findings have been taken as strong support for the notion that attention operates on the basis of complete-object representations (Driver & Baylis, 1998), arguing against the idea that attention is required to integrate parts of a scene into coherent objects (Treisman & Gelade, 1980).

However, to our knowledge, previous studies with extinction patients have never investigated any directional spreading of grouping cues between the unimpaired and impaired hemifields. This leaves the possibility that grouping (rather than operating preattentively) proceeds in 'incremental' fashion, gradually integrating parts into a complete-object representation concurrent with the spreading of attention (Roelfsema, 2006). On this view, grouping in extinction patients would extend from the attended to the neglected hemifield, thereby connecting otherwise ungrouped image fragments, for instance, by neuronal activity spreading across the region of a grouped object. Critically, 'incremental grouping' presupposes that attention is intricately involved in the binding of image fragments: grouping proceeds along with the spreading of attention to fragments in the neglected hemifield.

To test these alternative predictions of preattentive versus attentive (incremental) grouping, our study systematically compared the direction of grouping, either from the attended to the neglected hemifield (leftward direction; data based on Conci et al., 2009), or from the neglected to the attended hemifield (rightward direction; new data). The results from two groups of extinction patients and from an additional single case both revealed a critical dissociation: object groupings attenuated, or largely eliminated, extinction behavior when groupings departed from the attended hemifield. That is, extinction patients were able to detect bilateral stimulus arrangements when attention was available to initiate grouping (Conci et al., 2009). By contrast, when groupings departed from the unattended hemifield, no reduction of extinction was observed for partial (surface and contour) groupings, with performance being comparable to the ungrouped baseline condition. Moreover, clinical measures of neglect were found to be related to the degree of extinction in partial (shape) groupings (Fig. 5). This suggests that the greater attention bias towards the right hemifield and, thus, the less the attentional capacity devoted to the left side, the less likely it is that an integrated object representation is formed. This relationship between syndrome severity and grouping success thus suggests that attention is in fact required to build complete-object representations (see also Gögler et al., 2016; Naughtin, Mattingley, & Dux, 2016).

Together, this pattern of results lends support to the view that attention is needed to integrate fragments into coherent wholes. Our findings challenge conceptions according to which preattentive processing suffices to render complete objects (Driver & Baylis, 1998; Scholl, 2001); instead, they support the view that attention may act as a "glue" enabling object binding (Treisman & Gelade, 1980). Hitherto, a crucial

role of attention for grouping has been reported in only few studies that either presented near-threshold stimulus configurations in a masked-priming paradigm (Schwarzkopf & Rees, 2011) or that presented groupings under conditions of inattentional blindness (Mack, Tang, Tuma, Kahn, & Rock, 1992). Given this, additional work might be helpful to substantiate the notion that object integration requires attention to be – at least partially – engaged on the stimulus.

A potential framework for explaining the current results may be derived from reverse-hierarchy theory (Hochstein & Ahissar, 2002). On this view, visual input is initially transmitted in parallel to high levels of processing. This feedforward sweep of information would correspond to automatic, preattentive processing, whereas recurrent feedback from higher to lower areas in the visual hierarchy corresponds to the engagement of selective attention. Thus, within this framework, individual 'pacmen' inducers would be processed automatically in a feedforward sweep. Completion of a Kanizsa square would subsequently be initiated by selection mechanisms in parietal cortex (with extinction patients exhibiting an abnormal selection bias towards the unimpaired hemifield). Subsequent to parietal activation, feedback connections would trigger (i) region segmentation processes (possibly in lateral occipital cortex) to render an object's surface, and (ii) processes of illusory contour interpolation (in areas V2 and V1) to determine the boundaries of the illusory square (Murray & Herrmann, 2013, for a review; Roelfsema et al., 2002; Stanley & Rubin, 2003). In this framework, perceptual grouping is established via recurrent feedback that leads to a spreading of neuronal activity as initiated by parietal selection mechanisms – with a crucial role of the "attentional glue" to integrate fragments into coherent wholes.

Acknowledgments

Author contributions

MC, KF, and HJM designed the experiment. JG and IK conducted the experiment. MC analyzed the data. MC, KF, and HJM wrote the paper.

Competing interests

The authors declare that they have no competing interests.

Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.cortex.2017.12.024.

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Supplementary Information

Conci, M., Groß, J., Keller, I., Müller, H. J., & Finke, K. Attention as the 'glue' for object integration in parietal extinction.

Additional analyses on the raw accuracy data

The results as described in the main manuscript are based on *relative accuracy scores*, that is, a single measure that quantifies correct target detections in bilateral configurations relative to unilateral left displays. To complement these analyses of the relative accuracy scores, this supplement presents corresponding analyses of the *raw* (i.e., non-relative) *accuracy scores* (see also Figure 4, upper panels).

Detection performance in patients and controls. In a first step, a mixed-design analysis of variance (ANOVA) was performed on mean accuracies, with the between-subjects factor group (patients, controls) and the within-subject factors object type (Kanizsa, Shape, Contour, Ungrouped) and target type (unilateral left, bilateral). This analysis revealed significant main effects of group, $F(1,22) = 56.4$, $p < .001$, $\eta^2 = .99$, $BF_{10} = 9386.4$, object type, $F(3,66) = 11.4$, $p < .001$, $\eta^2 = .34$, $BF_{10} = 1.3$, and target type, $F(1,22) = 51.3$, $p < .001$, $\eta^2 = .70$, $BF_{10} = 1.844e +10$. Performance was overall more accurate in the control (95%) than in the patient group (69%). In addition, performance varied for the various object groupings (Kanizsa: 89%, Shape: 82%, Contour: 81%, Ungrouped: 77%), while also showing overall more accurate responses to unilateral left (92%) than to bilateral (73%) targets.

There were also several significant interactions. The target type x group interaction, $F(1,22) = 43.5$, $p < .001$, $\eta^2 = .66$, $BF_{10} = 3.69e +12$, was owing to the fact that performance was comparable for unilateral left (96%) and bilateral (95%)

target presentations in the controls, $t(11) = 1.0$, $p = .33$, whereas the patients showed a clear drop in performance for bilateral (51%) relative to unilateral left (88%) targets, $t(11) = 7.2$, $p < .001$ – that is, they exhibited the typical pattern of extinction behavior with bilateral target displays.

Next, the object type x group interaction, was significant $F(3,66) = 13.2$, $p < .001$, $\eta^2 = .37$, $BF_{10} = 6.1$: For the controls, the various configurations yielded comparable levels of performance (Kanizsa: 95%, Shape: 96%, Contour: 95%, Ungrouped: 96%), without any differences between object types, $F(3,33) = 0.2$, $p = .91$, $\eta^2 = .01$, $BF_{10} = 0.1$. The patients, by contrast, showed a clear modulation of performance as a function of object type, $F(3,33) = 15.7$, $p < .001$, $\eta^2 = .59$, $BF_{10} = 12976.6$, with the Kanizsa configuration being detected more accurately than all other configurations (Kanizsa: 84%, Shape: 68%, Contour: 67%, Ungrouped: 58%); (Bonferroni-corrected) pairwise comparisons revealed a significant difference between the Kanizsa square and all other configurations, all $ps < .009$, while there were no differences when comparing partial (shape, contour) and ungrouped configurations with each other, all $ps > .25$.

In addition, the interaction between object type and target type was significant, $F(3,66) = 4.1$, $p < .02$, $\eta^2 = .16$, $BF_{10} = 2.1$. Overall, that is, for both groups, the accuracies in detecting unilateral left targets were comparable across object types, $F(3,69) = 1.0$, $p = .38$, $\eta^2 = .04$, $BF_{10} = 0.2$ (Kanizsa: 94%, Shape: 93%, Contour: 92%, Ungrouped: 90%), but there was a clear modulation of performance for bilateral targets, $F(3,69) = 7.9$, $p < .001$, $\eta^2 = .26$, $BF_{10} = 195.6$. The Kanizsa square (84%) was again detected more accurately than shape (71%), contour (70%), or ungrouped (64%) configurations, all $ps < .03$ (all other $ps > .74$, Bonferroni-corrected).

Finally, the three-way interaction was not significant ($p = .22$, $BF_{10} = 0.4$).

Effects of grouping direction. A second analysis was performed to compare extinction behavior in the current study, presenting groupings that departed from the impaired hemifield (left to right), directly with data from a previous study (Conci et al., 2009) that presented groupings that departed from the preserved hemifield (right to left). To complement the results as presented in the main manuscript, another mixed-design ANOVA was performed on the mean accuracies with the between-subjects factor grouping direction (leftward, rightward) and the within-subject factors object type (Kanizsa, Shape, Contour, Ungrouped) and target type (unilateral left, bilateral).

This analysis revealed comparable levels of performance across the two patient groups (main effect of grouping direction, $F(1,17) = 0.4$, $p = .54$, $\eta^2 = .02$, $BF_{10} = 0.3$), indicative of comparable levels of extinction behavior, irrespective of whether the patients were presented with leftward, or rightward groupings (mean accuracies: 66% and 69%, respectively). All other main and interaction effects were significant, including the three-way interaction: object type, $F(3,51) = 27.9$, $p < .001$, $\eta^2 = .62$, $BF_{10} = 213.5$; target type, $F(1,17) = 35.1$, $p < .001$, $\eta^2 = .67$, $BF_{10} = 7.810e +9$; object type x group, $F(3,51) = 4.0$, $p < .02$, $\eta^2 = .19$, $BF_{10} = 1.3$; target type x group, $F(1,17) = 8.9$, $p < .009$, $\eta^2 = .34$, $BF_{10} = 48.1$; object type x target type, $F(3,51) = 9.5$, $p < .001$, $\eta^2 = .35$, $BF_{10} = 1.1$; object type x target type x group, $F(3,51) = 3.2$, $p < .04$, $\eta^2 = .15$, $BF_{10} = 5.9$. Together, this pattern of results indicates that the direction of grouping differentially affected target processing for the various types of object. As described above, when groupings departed from the impaired hemifield (rightwards), *only* the Kanizsa square configuration was effective in reducing the extinction behavior. By contrast, when groupings departed from the preserved hemifield

(leftwards), partial contour and shape configurations sufficed to elicit at least a partial reduction of the extinction behavior in bilateral configurations (Kanizsa: 77%, Shape: 74%, Contour: 68%, Ungrouped: 41%, all ps < .05). Only the comparison between Kanizsa and shape was not significant (p = .7; see Conci et al., 2009, for further details).

While there were clear differences when comparing grouping directions, it should be noted that performance in the (bilateral) Kanizsa square condition showed no statistically significant difference between patients that were presented with leftward groupings as compared to patients presented with the rightward groupings, $t(17) = 0.97$, $p = .34$ (77% vs. 84%). That is, the reduction of extinction by the identical, complete grouping was overall comparable in the two samples of patients.

Discussion

In sum, the pattern described here for the raw percent-correct data is essentially comparable to the relative accuracy scores presented in the main manuscript. The results reveal that healthy controls can detect both unilateral and bilateral targets without any costs in performance and without major differences for the various types of object. By contrast, the patient group in the current experiment exhibited clear signs of extinction when presented with bilateral (but ungrouped) target segments. A reduction of extinction occurred exclusively for the Kanizsa square configuration, thus replicating previous findings (Mattingley, Davis, & Driver, 1997). A subsequent analysis further demonstrated a dissociation of the grouping direction, namely: a reduction of extinction may occur for partial groupings when surface- and contour-based completion originates from the attended hemifield (Conci et al., 2009), but not when these groupings depart from the unattended hemifield. Together, these findings

substantiate the results reported in the main manuscript, supporting a strong link between the allocation of attention and the completion of objects across regions of space (see also Gögler, Finke, Keller, Müller, & Conci, 2016).

Interestingly, the above analysis of the current experiment revealed a significant object type by target type interaction, reflecting an advantage for bilateral Kanizsa configurations relative to bilateral shape, contour, and ungrouped object types. By contrast, the unilateral left targets showed no significant modulation, which is not surprising given that all unilateral left displays presented an identical configuration, namely two inward-facing pacmen, in the left hemifield. At the same time, this lack of a difference for unilateral left targets further shows that the block-wise presentation of the various object types, rather than engendering some strategic bias within a given block, gave rise to performance that was primarily determined by the perceptual structure displayed on a given trial.

References

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