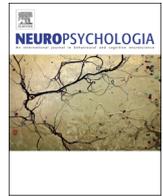




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# Object integration requires attention: Visual search for Kanizsa figures in parietal extinction



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## ABSTRACT

The contribution of selective attention to object integration is a topic of debate: integration of parts into coherent wholes, such as in Kanizsa figures, is thought to arise either from pre-attentive, automatic coding processes or from higher-order processes involving selective attention. Previous studies have attempted to examine the role of selective attention in object integration either by employing visual search paradigms or by studying patients with unilateral deficits in selective attention. Here, we combined these two approaches to investigate object integration in visual search in a group of five patients with left-sided parietal extinction. Our search paradigm was designed to assess the effect of left- and right-grouped nontargets on detecting a Kanizsa target square. The results revealed comparable reaction time (RT) performance in patients and controls when they were presented with displays consisting of a single to-be-grouped item that had to be classified as target vs. nontarget. However, when display size increased to two items, patients showed an extinction-specific pattern of enhanced RT costs for nontargets that induced a partial shape grouping on the right, i.e., in the attended hemifield (relative to the ungrouped baseline). Together, these findings demonstrate a competitive advantage for right-grouped objects, which in turn indicates that in parietal extinction, attentional competition between objects particularly limits integration processes in the contralesional, i.e., left hemifield. These findings imply a crucial contribution of selective attentional resources to visual object integration.

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## 1. Introduction

Visual scenes are typically cluttered, containing multiple objects that compete for access to awareness. In order to select relevant objects, our visual system has developed effective mechanisms that structure and organize this rather complex input. One relevant mechanism is the integration of visual object information by means of perceptual grouping. Grouping processes organize non-contiguous parts into coherent entities by segmenting regions or by linking edge segments to form continuous object boundaries (e.g. Driver et al., 2001; Koffka, 1935; Wertheimer, 1923). A prominent example illustrating grouping processes is the illusory 'Kanizsa figure', that is, the holistic percept of a bounded and foregrounded geometric figure (triangle, square) that is actually comprised of spatially disjointed elements (Kanizsa, 1976).

Models of visual perception and attention converge on the view of object integration being the outcome of separable processes of

grouping and, respectively, selective attention. However, the extent to which attention is required for integrating fragmentary object information into coherent wholes is a point of contention between the various theoretical frameworks. Some theories assume that only basic visual features are coded automatically and in parallel across the visual field at pre-attentive stages of processing, and attention is required for grouping processes to engage in the integration of features and object fragments into complete-object representations (e.g. Treisman and Gelade, 1980). Other models, by contrast, postulate that visual grouping processes operate already at low-level, pre-attentive stages prior to the engagement of selective attention (Driver and Baylis, 1998; Gilchrist et al., 1996; Scholl, 2001).

The visual search paradigm (Duncan and Humphreys, 1989; Treisman and Gelade, 1980; Wolfe, 1994) provides one approach for examining whether visual object integration operates pre-attentively or requires selective attention. Relevant studies have, for instance, used search displays containing an illusory Kanizsa figure as target presented among varying numbers of nontargets that are composed of the same "pacman" inducer elements which, however, are arranged such as not to give rise to the impression of a

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coherent shape – the task being to discern the presence of a Kanizsa figure as quickly and accurately as possible. The slope of the function relating detection latency, that is, reaction time (RT), to the number of configurations in the display (the display size) yields an estimate of search efficiency. If the slope is flat, search is considered efficient and operating spatially in parallel, pre-attentively. By contrast, an increase in RTs with increasing display size is taken as evidence for the involvement of selective attentive processes in discerning target presence (e.g. Treisman and Souther, 1985; Treisman and Gelade, 1980). Results of studies that employed visual search for Kanizsa figures are equivocal. A number of studies (Conci et al., 2007, 2009b; Davis and Driver, 1994, 1998; Gurnsey et al., 1992) reported flat slopes, indicative of Kanizsa figures being formed automatically by low-level, pre-attentive grouping mechanisms. In contrast, search for an ungrouped target configuration has turned out to be rather inefficient, indicating that an ungrouped target configuration is much harder to detect than a comparable, grouped (Kanizsa) target amongst identical nontargets (Conci et al., 2007; Conci et al., 2011; Nie et al., 2016; Wiegand et al., 2015). Consistent with this, Conci et al. (2007) also observed that nontargets interfered with Kanizsa target detection when they rendered Kanizsa-like surface information, that is, partial shape groupings that increased the similarity of the nontargets to the target. In contrast, other studies (Grabowecy and Treisman, 1989; Gurnsey et al., 1996; Li et al., 2008) reported that RTs in search for Kanizsa figures increased with increasing display size, implying that selective attention is required for integrating the (correctly aligned) pacman elements into a coherent figure. – Thus, taken together, the question of whether or not focal attention is required to effectively bind parts into coherent wholes has not yet been resolved conclusively.

An alternative approach used to examine whether attention is necessary for integrating separable elements into wholes is to investigate visual grouping in patients suffering from unilateral deficits in selective attention. Patients with left-sided hemi-neglect or extinction often fail to attend and respond to sensory stimuli located in the contralesional hemispace, without necessarily suffering from any primary disorder of sensation or movement (Corbetta et al., 2005; Corbetta and Shulman, 2011; Heilman et al., 1987; Heilman et al., 1993). These deficits typically result from right-hemisphere lesions, mostly in the inferior parietal lobe. Interestingly, in extinction, a stimulus presented in the contralesional hemifield can be detected or identified when presented alone. However, when presented simultaneously with ipsilesional stimuli, the same stimulus is disregarded, or only poorly identified (Bender, 1952). That is, patients show hemi-inattention towards the contralesional, left hemifield (Karnath, 1988; Riddoch and Humphreys, 1983), often failing to respond to stimuli on the left. However, consistent with accounts of extinction in terms of a pathological, competitive bias against the contralesional hemifield (Kinsbourne, 1993; Desimone and Duncan, 1995), the lack of attention to stimuli on the left is not absolute; rather, it is relative: fewer attentional resources are allocated to the contralesional than to the ipsilesional hemifield (see also Bays et al., 2010).

Most studies suggest that, despite their hemi-inattention, neglect patients nevertheless have preserved access to integrated object information across the whole visual field (e.g. Driver et al., 1992; Gilchrist et al., 1996; Ward et al., 1994). For instance, a single-case study by (Mattingley et al., 1997; see also Conci et al., 2009a) observed preserved access to fragmentary bilateral stimulus segments when these could be grouped across hemifields to form a Kanizsa square. Mattingley et al. presented a sequence of displays, each starting with the presentation of four circles, arranged around fixation. On each trial, quarter-segments were briefly removed from the circles either from the left, from the right, from both sides, or not at all. The task of the patient with

left-sided extinction was to detect the sides of the offsets. When the configuration of stimulus segments prevented grouping, bilateral removal of quarter-segments induced clear signs of extinction: the patient missed left-sided offsets far more often in trials with offsets on both sides compared to trials with unilateral left offsets. However, when the stimulus configuration could be grouped to form a Kanizsa square, resulting in a coherent object forming a single perceptual unit, extinction was less severe and the patient detected the offsets on both sides. This result is indicative of early, pre-attentive integration of the elements into a (illusory) figure, which can be accessed despite extinction, that is, in the absence of selective visual attention (Ro and Rafal, 1996; Vuilleumier and Landis, 1998; Vuilleumier et al., 2001).

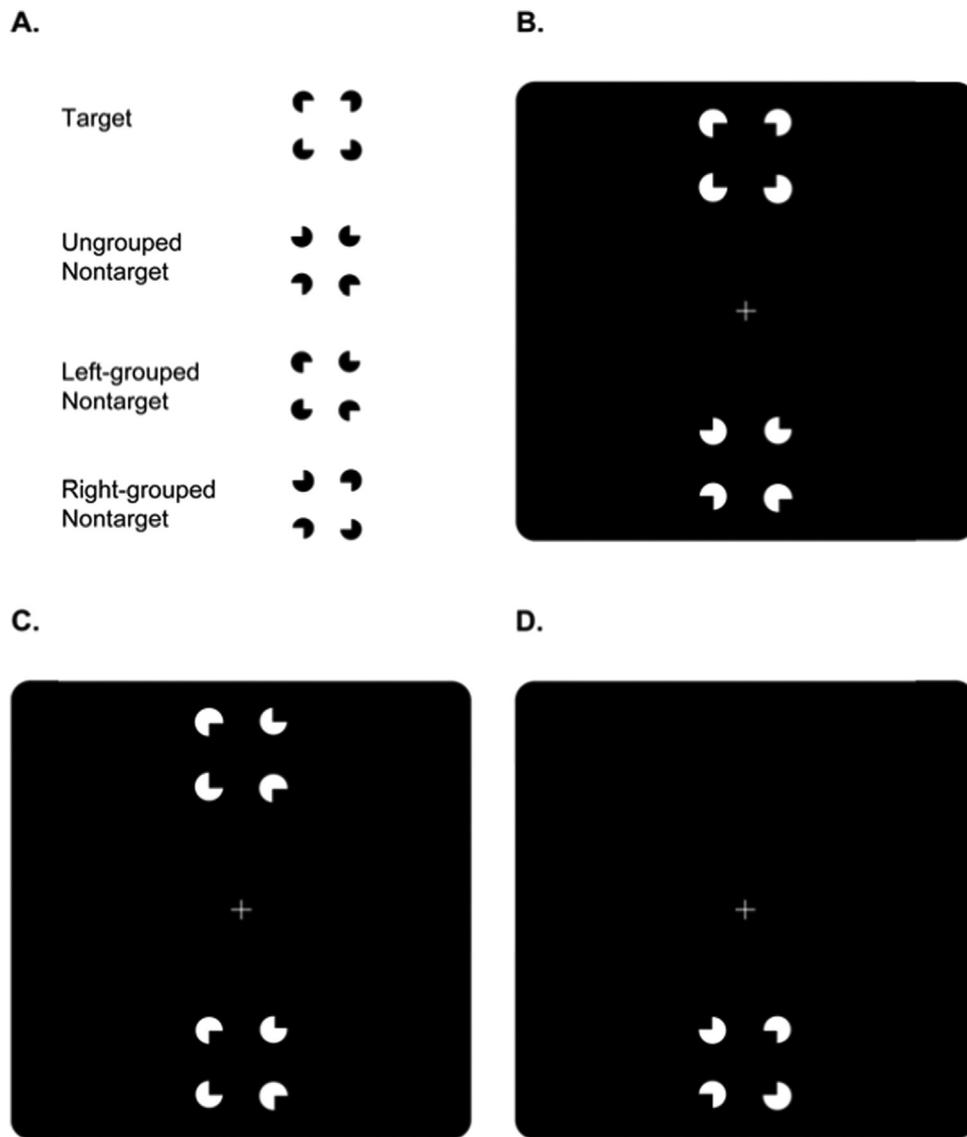
In the above-mentioned patient studies, the typical stimulus displays merely consisted of a single grouped stimulus that had to be identified. Arguably, a more realistic, or ecologically valid, scenario may be provided by visual search paradigms, in which observers are presented with multiple stimuli. Despite this, to date, there are only few studies that examined search behaviour in patients with neglect or extinction (e.g. Aglioti et al., 1997; Behrmann et al., 1997; Pavlovskaya et al., 2002; Riddoch and Humphreys, 1987). To our knowledge, none of them explicitly evaluated object integration processes in displays that contain multiple stimuli. It is thus unknown whether the pathological bias in selective attention also gives rise to a bias in visual grouping processes during search for an illusory figure. Given this, in the present study, we combined these two approaches and investigated object integration in visual search for Kanizsa squares in patients with extinction. In more detail, we compared the effect of ‘grouped’ nontarget configurations, which induce partial illusory shape groupings, versus that of symmetric but ‘ungrouped’ nontargets on the performance of visual search for Kanizsa squares (see Fig. 1 for examples of possible stimulus configurations). Critical questions were whether, in patients with extinction, (i) the additional surface information provided by grouped nontargets would interfere with Kanizsa target detection in the same way as it does in healthy participants (Conci et al., 2006; Conci et al., 2007) and (ii) whether the effects would be distinct for left- versus right-grouped nontargets.

If object integration processes indeed operate pre-attentively and are, thus, preserved in patients with extinction (Conci et al., 2009a; Mattingley et al., 1997), then the interference induced by grouped nontargets should be comparable to that in healthy participants and should generally exceed that induced by baseline, ungrouped nontargets. If, however, selective attention is needed for the integration of parts into wholes (e.g. Treisman and Gelade, 1980), a diverging pattern is to be expected in patients with extinction: left-grouped nontargets containing a partial shape in the left, less attended, hemifield should interfere less than right-grouped nontargets, containing a partial shape in the right, more attended, hemifield.

## 2. Methods

### 2.1. Participants

5 right-handed patients (4 male, 1 female; mean age: 63 years; age range: 52–72 years) who had suffered a right-hemispheric stroke and exhibited clinical signs of left-sided visual hemi-neglect were recruited from the Schoen Clinic Bad Aibling, Germany, and tested within 2–9 weeks post injury. All patients had normal or corrected-to-normal visual acuity and were tested for visual field deficits using Goldmann kinetic perimetry. Motor functioning was preserved in all patients. All patients were tested with standardized neuropsychological neglect tests such as the conventional



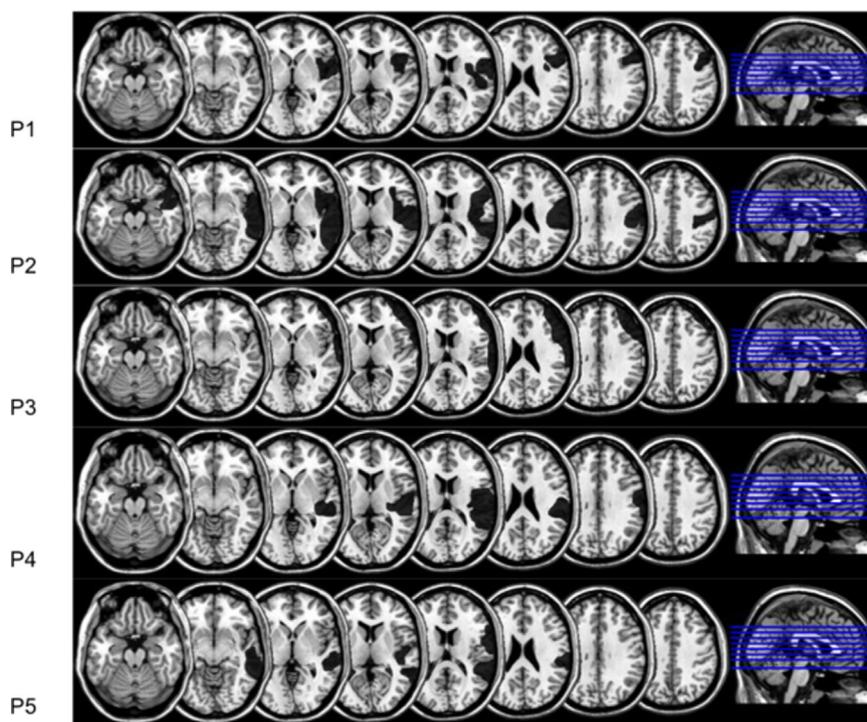
**Fig. 1.** (A) Examples of the target Kanizsa square and of the grouped and ungrouped nontarget stimuli. Example displays: (B) two-item target-present search display, (C) two-item target-absent display, and (D) one-item target-absent display presenting an ungrouped nontarget (B), two left-grouped nontargets (C), and one right-grouped nontarget (D), respectively.

part of the Behavioural Inattention Test (BIT; Wilson et al., 1987), including the cancellation, visual search, line bisection, figure copying, and representational drawing subtests, or the Bells test (Gauthier et al., 1989). Based on these assessments, mild to moderate signs of visuo-spatial neglect were verified in each patient. Lesions were confined to either right-sided inferior-parietal and temporo-parietal or frontoparietal areas (see Fig. 2).

The patients were compared against an age- and gender-matched healthy control group of 10 right-handed participants (6 male and 4 female; mean age: 68.3 years; age range: 63–72 years) who were paid for their participation. Controls did not differ significantly from patients with respect to age ( $t(13)=1.71, p=.11$ ) or gender ( $\chi^2(1)=0.60, p=.44$ ). They all had normal or corrected-to-normal vision. None of them reported any history of neurological or psychiatric disease. Informed consent according to the Declaration of Helsinki II was obtained from all participants. Table 1 summarizes the demographic and clinical data of all patients and controls.

## 2.2. Apparatus and stimuli

The experiments were performed on an IBM-PC compatible computer using Matlab routines and Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). A standard computer mouse (which was rotated by 90°) served as response device. The distance between the monitor and the eyes of the participants was approximately 57 cm; a head and chin rest was used to maintain head position. Stimuli were presented in light grey (3.81 cd/m<sup>2</sup>) against a black (0.02 cd/m<sup>2</sup>) background at 2 possible locations on a 17-in. monitor screen (1024 × 768 pixel screen resolution, 70-Hz refresh rate). Stimuli were presented centrally either above or below the fixation cross (see Fig. 1 for example displays). Each stimulus configuration, composed of four Pacman inducers with a diameter of .7°, was presented 4.1° of visual angle above or below a centrally presented fixation cross. At a viewing distance of 57 cm, each candidate grouping subtended a visual angle of 2.3° × 2.3°. As depicted in Fig. 1(A), the target was defined as a Kanizsa square.



**Fig. 2.** Lesion locations in each patient reconstructed for 8 transversal slices (left) and their positions in sagittal orientation (right).

**Table 1.**

Clinical and demographic data of patients and control participants.

	Sex	Hand	Age	Infarction Type	VF Deficit	TSI (weeks)
Patients						
P1	m	r	52	MCA	Q, l, s	2
P2	m	r	72	MCA	–	9
P3	f	r	57	MCA	–	5
P4	m	r	71	SC	–	8
P5	m	r	63	MCA	RH, l	7
Group average						
Patients	4m/1f	5r	63.0			6.2
Controls	6m/4f	10r	68.3			

[Abbreviations: VF – visual field; TSI – time since injury; m – male; f – female; r – right; l – left; MCA – medial cerebral artery; SC – striato capsular; Q – quadrantanopia; RH – residual hemianopia; s – superior]

Nontarget configurations were constructed by rotating inducer elements: for the baseline, ungrouped nontarget configuration, all four pacman inducers were rotated by 180° relative to the inducers of the target. For right-grouped nontargets, the inducers in the left half of a nontarget configuration were rotated by 180°, whereas the (other) inducers in the right half were identical in orientation to those of the target. For left-grouped nontargets, the inducers in the right half of a nontarget configuration were rotated by 180°, whereas the inducers in the left half were identical in orientation to those of the target. Accordingly, grouped nontargets were made up of partial Kanizsa shape stimuli, with partial shapes on either the left or the right side, engendering the emergence of incomplete surface information. That is, grouped nontargets gave rise to unilateral partial groupings, with the grouping location (left vs. right) being varied.

### 2.3. Procedure

The experiment was performed in a dimly lit experimental laboratory room. Each trial started with the presentation of a central fixation cross for 500 ms. The fixation cross was followed by the

search display, to which participants had to respond. The display contained either one or two candidate objects, which were presented at central positions above and/or below the fixation cross. In the one-item condition, either the target or one possible nontarget (ungrouped, left-grouped, or right-grouped) was presented at one of the two possible stimulus locations. In the two-item target-present condition, the target was always presented together with a nontarget (ungrouped, left-grouped, or right-grouped). In the two-item target-absent condition, two nontargets of the same type were displayed, that is, both nontargets were ungrouped, left-grouped, or right-grouped configurations (see Fig. 1). Following stimulus onset, participants had to maintain central fixation and to make a speeded target-absent versus target-present response by pressing the corresponding keys of the computer mouse. Target-present/-absent responses were assigned to either the upper/lower or the lower/upper keys of the rotated mouse, in counter-balanced order across participants. Participants were instructed to respond, as quickly and accurately as possible, using the right-hand index and middle fingers; their right arm positioned such that the fingers were comfortably placed on the rotated mouse. Displays remained on the screen until participants responded, with a time-out of 2500 ms. In case of an incorrect response or a time-out, a feedback signal (a “minus” sign) was presented for 1000 ms in the center of the screen. The inter-trial interval was 1000 ms.

Participants first performed one practice block, consisting of 20 randomly generated trials, prior to the actual experiment, to familiarize them with the task. Subsequently, 480 experimental trials were presented in 12 blocks consisting of 40 trials each. The independent variables of the experiment were the between-subjects factor group (patients, controls) and the within-subject factors target (present, absent), nontarget type (ungrouped, right-grouped, left-grouped), and display size (one item, two items). The type of nontarget was kept constant throughout a block of trials, in order to maximize the difference in search RTs between ungrouped and grouped nontargets (Töllner et al., 2015) while keeping the difficulty of the task appropriate for the patients. All

blocks were presented in pseudo-random order on an observer-by-observer basis. Search displays contained a target in 50% of all trials, with targets presented equally likely above or below the central fixation cross. The dependent measures obtained and analysed were the search RTs plus estimates of perceptual sensitivity,  $d'$ , and the response criterion,  $c$ , based on signal detection theory (Green and Swets, 1966). The sensitivity  $d'$ ; reflects the relationship of the rate of hits (i.e., correct detection of a target when one is present) to that of false alarms (i.e., erroneous 'target-present' response when no target is present) for each condition, where  $d'$  is estimated as:  $d' = z(\text{proportion hits}) - z(\text{proportion false alarms})$ . Technically,  $d'$  represents the distance between the means of the sensory evidence distributions produced by 'noise alone' and 'signal plus noise'; accordingly, higher scores of  $d'$  indicate enhanced ability to discriminate between signal and noise. The response criterion represents the critical strength of sensory evidence required to decide 'signal plus noise' versus 'noise alone', where  $c$  is estimated as follows:  $c = -0.5 * (z(\text{proportion hits}) + z(\text{proportion false alarms}))$ . Values of  $c < 0$  are indicative of 'liberal' responding (i.e., maximizing hits at the expense of false alarms), values  $> 0$  of 'conservative' responding (i.e., minimizing false alarms at the expense of hits). For calculating these parameters, we corrected extreme hit rates of 1.0 and, respectively, false-alarm rates of 0 as follows:  $1 - 1/(2n)$  for hits, and  $1/(2n)$  for false alarms, where  $n$  refers to the number of total hits or false alarms (Macmillan and Creelman, 1991).

### 3. Results

Data were analysed in two sequential steps. The first analysis aimed at providing an overview of the general task performance, comparing search performance for ungrouped nontargets (i.e., baseline performance) with performance for partially grouped, that is, potentially interfering nontargets. As previous work in healthy observers had shown that partial shape information in nontargets can substantially reduce search efficiency (Conci et al., 2006; 2007), the current analysis was designed to establish, in the first instance, whether comparable effects would also be seen in patients with extinction. The subsequent analysis was performed to examine more specifically how the lateralization of attention in extinction would affect search. To this end, partial groupings in the left or right half of the nontarget items were systematically compared in terms of their relative costs on performance.

#### 3.1. Target-nontarget interference effects

The first analysis compared search RTs as well as signal detection ( $d'$  and  $c$ ) scores for partially grouped vs. ungrouped (i.e., baseline) nontarget conditions. Note that, for this initial analysis, data were collapsed across left- and right-grouped nontargets. Individual mean RTs were computed for each variable combination excluding error responses. Fig. 3 presents the mean RTs for the patient group (A) and the control group (B). Each graph plots RTs as a function of display size, separately for target-absent/-present and ungrouped/grouped nontarget configuration conditions. Note that Fig. 3 depicts different data points for the single-item target-present conditions. This is due to (single-item) target-present trials being sorted according to the respective nontarget types within a given block of trials. That is, even though the single target displays were physically identical in these blocks (always consisting of one Kanizsa square target), RTs to these displays differed according to the types of nontargets that were presented in the respective blocks.

#### 3.1.1. RT analysis

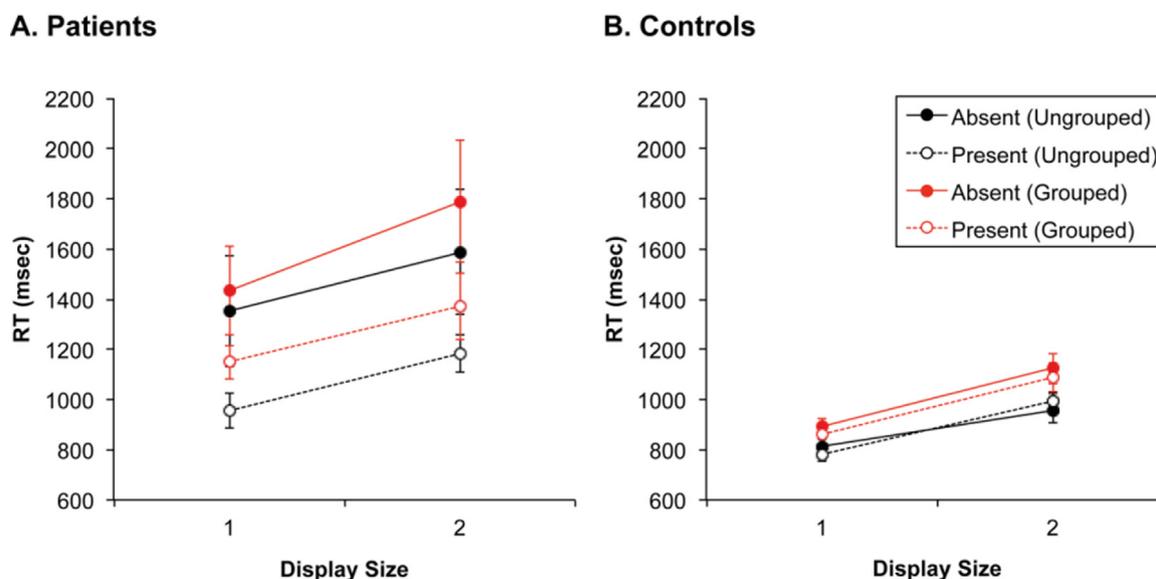
Mean RTs were compared by means of a mixed-design analysis of variance (ANOVA), with the between-subjects factor group and the within-subject factors display size, target, and nontarget type. This ANOVA revealed significant main effects of display size [ $F(1, 13) = 44.55, p < .01$ ], target [ $F(1, 13) = 12.58, p < .01$ ], nontarget type [ $F(1, 13) = 28.97, p < .01$ ], and group [ $F(1, 13) = 15.14, p < .01$ ]. Mean RTs increased with the number of to-be searched items (103 ms vs. 126 ms) and were overall faster in target-present than in target-absent conditions (105 ms vs. 124 ms). In addition, responses were slower in the grouped compared to the ungrouped nontarget condition (121 ms vs. 108 ms), and for the patient group compared to control participants (135 ms vs. 94 ms). Moreover, several interactions were significant. First, the target  $\times$  group interaction [ $F(1, 13) = 10.67, p < .01$ ] was due to the patients exhibiting slower responses (by 37 ms) to target-absent than to target-present displays, while the control participants showed no difference (2 ms). Furthermore, the display size  $\times$  target  $\times$  group was significant [ $F(1, 13) = 6.33, p = .03$ ], due to patients showing consistent increases, with display size, in target-present and target-absent RTs (increases of 22 and 29 ms/item, respectively,  $p = .24$ ), while for controls target-present slopes were somewhat steeper than target-absent slopes (22 and 19 ms/item, respectively,  $p = .07$ ). Finally, a significant display size  $\times$  target  $\times$  nontarget type interaction [ $F(1, 13) = 6.85, p = .02$ ] showed that additional surface information in grouped nontargets reduced search efficiency particularly on target-absent trials (search slopes in ungrouped and grouped nontargets were 17 and 26 ms/item, respectively,  $p = .01$ ), while no difference in search efficiency was evident for target-present trials (ungrouped and grouped nontarget slopes: 22 and 23 ms/item, respectively,  $p > .05$ ). No other significant effects were obtained (all  $ps > .11$ ). In summary, patients were slowed overall, but particularly so when the target was absent and when the display size was high. Importantly, however, there was no indication that the overall effect induced by grouped nontargets differed between groups. That is, nontargets that induce partial shape groupings seemed to affect RTs similarly in both groups, particularly on target-absent trials. This suggests that patients based their search on an integrated (grouped) target representation, rather than on the constituent, individual local elements; in the latter case, search would have been expected to be much more inefficient (Conci et al., 2007).

#### 3.1.2. Sensitivity and criterion analysis

Accuracy data was used to obtain estimates of perceptual sensitivity and response criteria in target-present/-absent decisions. The overall level of accuracy was reasonably comparable in patients and controls ( $t(13) = -1.67, p = .12$ ), with a mean error rate of 5.3% (SD = 6.91) and 1.8% (SD = 1.23), respectively. Next,  $d'$  and  $c$  scores were analysed using (separate) mixed-design ANOVAs, with the between-subjects factor group and the within-subject factors display size and nontarget type, analogous to the RT analysis above (note that RT and sensitivity/criterion measures are essentially unrelated and may therefore reveal a diverging pattern of effects). Both ANOVAs revealed the main effect of display size to be significant: sensitivity scores  $d'$  were reduced for two-item compared to one-item displays (mean  $d'$ : 3.8 vs. 4.2,  $F(1, 13) = 14.57, p < .01$ ); at the same time, the response criterion was set somewhat more conservatively for two-item compared to one-item displays (mean  $c$ : .28 vs. .01,  $F(1, 13) = 17.42, p < .01$ ). No other significant effects were obtained (all  $ps > .09$ ).

### 3.2. Nontarget lateralization

A second set of analyses was performed to examine whether and how target-nontarget interference differs when partial shape



**Fig. 3.** Mean RTs in the patient (A) and the control (B) group as a function of display size (1 item, 2 items) for the different target (solid line: absent, dotted line: present) and nontarget type (black: ungrouped, red: grouped) conditions. Error bars represent  $\pm 1$  standard error of the mean. Note that, as the nontarget type was kept constant throughout a block of trials, the data points obtained differed between the nontarget type conditions; this also applies to the single-item condition, in which the respective nontarget was presented only on target-absent trials (but not on target-present trials). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

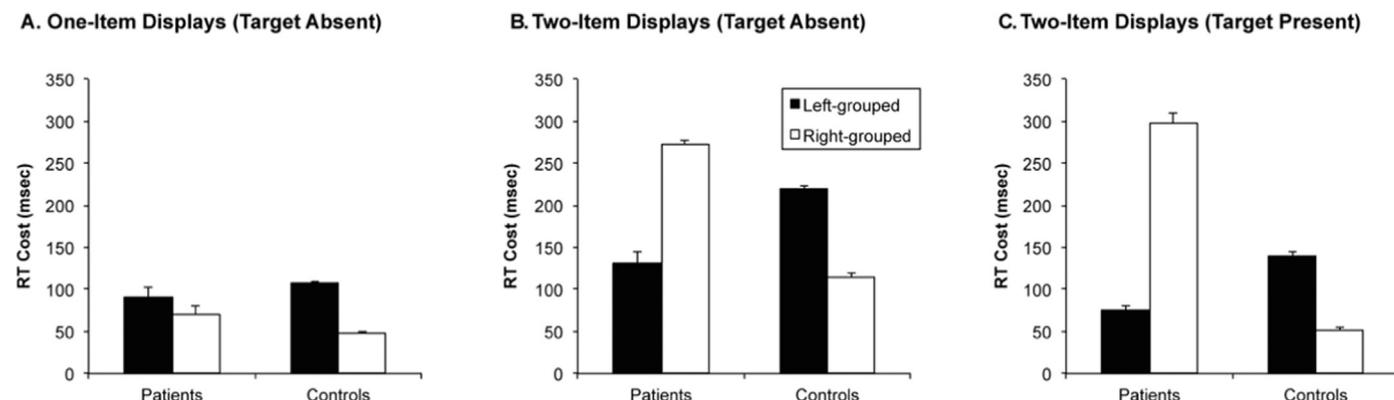
information in nontargets is present in the less attended versus the more attended hemifield. To this end, we determined the costs engendered by the distinct, unilateral groupings, by subtracting RTs and, respectively,  $d'$  and  $c$  in the ungrouped nontarget condition from those in the left- and right-grouped nontarget-type conditions. Fig. 4 depicts the RT costs (in ms) as a function of the nontarget grouping location for both patients and controls. Separate graphs depict the results for one-item displays (target-absent) and two-item displays (for target-present and target-absent conditions, respectively). Note that, because of the (logical) lack of nontargets in target-present one-item displays, costs could not be computed for this condition.

### 3.2.1. RT analysis

**One-item displays.** For the RT analysis, one-item displays were analysed by a mixed-design ANOVA with the between-subjects factor group (patients, control) and the within-subject factor nontarget grouping location (left-grouped, right-grouped nontarget), which did not reveal any significant effects (all  $ps > .10$ ). As depicted in Fig. 4A, the RT costs were statistically comparable for left- and right-grouped nontargets (99 ms vs. 59 ms; non-significant main effect of grouping location). Also, the costs were

comparable between patients and controls (81 ms vs. 77 ms; non-significant main effect of group). These findings show overall comparable RT patterns in both patients and controls, and no evidence for any type of strategy, such as a tendency of the patients to perform the task by primarily responding to the cut-out segments in the right, unimpaired hemifield.

**Two-item displays.** A mixed-design ANOVA on two-item displays with the between-subjects factor group (patients, control) and the within-subject factors nontarget grouping location and target (absent, present) yielded no significant main effects (all  $ps > .16$ ). However, the nontarget grouping location  $\times$  group interaction [ $F(1, 13)=8.26, p=.01$ ] was significant: while costs were statistically comparable for left-grouped nontargets in both patients and controls (103 ms vs. 180 ms) [ $t(13)=.975, p=.35$ ], the costs for right-grouped nontargets were much greater in patients than in control participants (285 ms vs. 83 ms) [ $t(13)=-2.48, p=.03$ ]. No other significant effects were obtained (all  $ps > .34$ ). To summarize, in patients with extinction, the RT costs induced by grouped nontargets in visual search for a Kanizsa figure were comparable to those of control participants only with single-item displays. When display size increased to two items, patients showed systematic unilateral deficits, namely: enhanced costs for



**Fig. 4.** Mean RT costs as a function of nontarget grouping location (black: left-grouped, white: right-grouped) for patients and controls, separately for one-item displays [target-absent (A)] and two-item displays [for target-absent (B) and -present (C) conditions, respectively]. Error bars represent  $\pm 1$  standard error of the mean.

nontarget objects with a partial shape in the right, that is, the more attended hemifield.

### 3.2.2. Sensitivity and criterion analysis

For one-item displays, analogous ANOVAs of the  $d'$  and  $c$  costs did not reveal any significant main or interaction effects (all  $ps > .26$ , overall mean costs in  $d' = -.06$  and in  $c = .07$ ). For two-item displays, the ANOVAs revealed a significant main effect of nontarget grouping location [ $F(1, 13) = 13.01, p < .01$ ] for  $d'$ : sensitivity costs were increased with left- as compared to right-grouped nontargets ( $-.47$  vs.  $.07$ ). Note that more negative values of  $d'$  costs, as depicted here, are indicative of a reduction in sensitivity for the grouped relative to the ungrouped condition. No other significant effects were obtained (overall mean costs in  $c: -.52$ ; all  $ps > .25$ ). The lack of group effects indicates that patients and controls differ neither with respect to the response criterion (i.e., the strength of sensory evidence required to respond target-present rather than target-absent), nor with respect to perceptual sensitivity (i.e., the ability to discriminate signal from noise), despite of an overall reduction in sensitivity in both groups for left-grouped nontargets.

## 4. Discussion

The present study was designed to assess the relationship between selective attention and object integration (in the left and the right visual field) in a visual search paradigm that presented to-be-grouped targets and nontargets to both extinction patients with unilateral deficits of selective attention and healthy controls. Our main results were that (i) partially grouped nontargets induced overall comparable interference in patients and controls and that (ii) for single item configurations, effects of left-sided groupings were comparable to those of right-sided groupings in both participant groups. Finally, (iii) clear effects of extinction manifested in particular with two-item displays, where stronger RT costs emerged for nontargets that were similar to the targets in the intact, more attended hemifield, compared to the less attended hemifield. From these findings, we conclude that a bias in attention leads to biased grouping operations in competitive search situations in particular, i.e. preserved grouping in the right, attended, and compromised grouping in the left, less attended, hemifield. In our view this points to a crucial contribution of selective attention to visual object integration processes.

### 4.1. Target-nontarget shape interference

In an initial, overall analysis, we assessed the effect of partial shape information in nontargets on visual search for a target Kanizsa figure, without differentiating between left- and right-grouped nontargets. Results revealed a pronounced slowing of search for grouped nontargets relative to the ungrouped (i.e., baseline) condition with increasing display size and particularly on target-absent trials. This reduction in search speed brought about by grouped nontargets was in general comparable between patients and controls, suggesting an overall similar pattern of nontarget interference. However, extinction patients were particularly slowed when no target was present. Signal detection analysis further revealed a similar pattern of performance in patients and controls, with a reduced sensitivity and a slight shift in the decision criterion (towards more conservative responding) for two-item compared to one-item displays.

Our finding that partial shape information in nontargets reduces search efficiency in both patients and controls is in line with previous reports from healthy participants (Conci et al., 2006; Conci et al., 2007; Töllner et al., 2015). This pattern of interference

can be explained in terms of similarity-based (interference) search models (Duncan and Humphreys, 1989), which assume that an increase in similarity between targets and nontargets reduces the efficiency of target detection. In terms of biased-competition accounts (Desimone and Duncan, 1995), grouped nontargets would gain more attentional weight, compared to ungrouped nontargets, due to their better match with the task-relevant Kanizsa square target; as a result, the grouped nontarget would be favoured for visual selection (Conci et al., 2006; Conci et al., 2007). In the context of the current experiment, with Kanizsa figures (i.e., grouped objects) presented as targets, it is reasonable to assume that target-nontarget similarity is largely determined by integrated object attributes, that is, the output of object completion processes that involve grouping mechanisms, such as grouping by closure/good continuation. In this view, target selection and similarity-based interference effects in both healthy participants and patients are driven by integrated object information (Conci et al., 2007).

In line with the assumption that grouping and similarity interact, search efficiency was previously shown to be markedly reduced for ungrouped relative to grouped target configurations, even though the similarity between targets and nontargets was the same in both cases (Conci et al., 2007). Thus, if patients' search was based on the individual local elements (i.e., the ungrouped pacman inducers) rather than an integrated (grouped) target representation, a divergent pattern of performance would be expected, with patients exhibiting significantly reduced search efficiency compared to controls. This was clearly not the case. Hence, the pattern of search performance observed in the present study most likely reflects processing of grouped objects, rather than being akin to search for ungrouped items that do not require object integration to the same extent.

The finding that target-absent trials in particular exhibited a difference in search efficiency between grouped and ungrouped nontargets indicates that partial surface information primarily affected search when participants allocated attentional resources to the nontargets. In contrast, according to a biased-competition account of attention (Bundesen, 1990; Desimone and Duncan, 1995), on target-present trials, nontarget stimuli compete with the more salient target stimulus. Attentional weight, which is biased towards the most salient stimulus, is thus withdrawn from the nontargets. Equal search performance for target-present grouped and ungrouped nontarget trials thus indicates that when less attentional capacity was allocated towards partial groupings, these might have been reduced in priority (in both healthy controls and extinction patients). We interpret this finding as an indication that attentional resources can modulate partial shape groupings.

### 4.2. Spatial attentional bias modulates grouping

Follow-on comparisons of interference effects induced by left-versus right-grouped nontargets revealed a specific pattern related to extinction, with a crucial difference between conditions with two-item, relative to one-item, search displays. With displays containing only one item, extinction patients showed the same pattern of search interference effects as healthy participants, without any differential RT costs between left- and right-grouped nontargets. This indicates that patients were able to integrate the stimulus configurations presented into completed shapes, without differences as to whether a given partial shape was present on the left, less attended, or on the right, more attended, side. That is, in essence, both types of grouped nontargets could be differentiated reliably from the completed square in the target Kanizsa figure. This finding in principle confirms previous reports in patients with unilateral deficits in selective attention, who, in general, showed preserved grouping with displays that presented a single, to-be-

grouped object configuration (e.g. Conci et al., 2009a; Driver et al., 1992; Mattingley et al., 1997; Ro and Rafal, 1996; Vuilleumier and Landis, 1998; Vuilleumier et al., 2001). Thus, in one-item displays, access to left- as well as right-grouped stimulus configurations was unaffected by extinction, that is: object integration mechanisms were functioning uncompromised across both halves of the visual field. This agrees with behavioural and electrophysiological studies of healthy participants, which revealed search for Kanizsa figures to be efficient, with object completion being associated with early stages of visual processing (e.g. Abu Bakar et al., 2008; Conci et al., 2009b, 2011; Wiegand et al., 2015). Our findings also agree with studies reporting an influence of unconscious access to contralesional visual information in extinction patients (Conci et al., 2009a; Driver and Vuilleumier, 2001; Finke et al., 2009; Marshall and Halligan, 1994; Mattingley et al., 1997). Accordingly, at least in conditions that require basic perceptual processing of a single candidate target object, patients with deficits in attentional orienting are not necessarily impaired in integrating parts into wholes – thus, in principle supporting object-based accounts of attention (see also Driver et al., 1992; Ward et al., 1994).

In contrast to 'normal' performance with single-item presentations, when attention had to be distributed among multiple stimuli (i.e., in two-item displays), a spatially lateralized interference pattern emerged in extinction patients: relative to controls, patients showed a marked increase in interference when nontargets induced a partial shape grouping on their right, more attended, side – whereas nontargets with a partial shape grouping on the left, that is, their less attended, side interfered comparably (or numerically even less) relative to control participants. Restated, extinction patients showed less efficient search than controls when presented with multiple (i.e., two) objects that contained similar shape information as the target in the right hemifield; by contrast, interfering information in the left hemifield did not lead to elevated costs at all.

In the control group, we found a tendency towards the opposite effect: left-grouped nontargets interfered (at least numerically) more than right-grouped nontargets. Thus, in healthy participants, object integration processes were biased towards the left when attentional resources had to be distributed in a competitive search situation. This may be associated with a slight, though highly replicable, attentional bias towards the left in healthy participants with both unilateral and bilateral stimulation, which has been referred to as 'pseudo-neglect' (Jewell and McCourt, 2000) and 'pseudo-extinction' (Goodbourn and Holcombe, 2015), respectively.

The spatially lateralized pattern of interference with two-item displays might be explained in terms of biased competition among visual inputs for limited processing capacity (Bundesen, 1990; Desimone and Duncan, 1995). In a non-competitive search situation, that is, when only a single item is presented in the display, there is no need for attention to be distributed. Accordingly, despite the well-documented attentional bias towards ipsilesional stimuli in extinction (e.g. Baylis and Driver, 1993; Humphreys et al., 1994), a left- or right-grouped nontarget would receive the full amount of available capacity, enabling a decision to be made between target presence and absence. However, distributing attention among multiple candidate target stimuli (in two-item displays) reduces the amount of attention that can be allocated to each single stimulus. In this situation, extinction patients allocate attentional weight predominantly to the right hemifield (Duncan et al., 1999), as a result of which target-nontarget similarity is primarily evaluated in the right (rather than the left) half of a given stimulus configuration. Due to this extinction-specific spatial attentional bias, right-grouped nontargets have a competitive advantage in the race for selection.

Overall, this pattern of results suggests a crucial link between

perceptual grouping and attention: faced with multiple stimuli, extinction patients are impaired in engaging mechanisms of perceptual grouping in the contralesional field that would permit the target to be discerned from more or less similar nontargets. Thus, contrary to the interpretations drawn from a number of previous studies of extinction patients (e.g. Conci et al., 2009a; Driver et al., 1992; Gilchrist et al., 1996; Mattingley et al., 1997; Ward et al., 1994), grouping operations are not (completely) automatic and (fully) available at pre-attentive stages; rather, attention is required to effectively bind parts into coherent wholes. It follows, in line with the notion of a competitive bias against left-sided information in extinction (Driver et al., 1997; Duncan et al., 1997; Kinsbourne, 1993), that object integration depends on the degree of competition among the elements in the visual input: integration is successful only if sufficient attentional capacity is available, in which case the spatial bias in extinction patients is considerably reduced. By contrast, when there is competition among several stimuli, the (distributed) attentional resources are insufficient to permit object integration, leading to a strong bias. This implies that the pathological attentional bias gives rise to a grouping bias, with less effective grouping in the unattended field.

While processes of object integration were clearly impaired in extinction patients presented with multiple objects, the account sketched above – in terms of multi-item 'competition' and 'distributed attention' – would imply that some basic grouping processes are actually functioning relatively normally. The notions of competition and distributed attention presuppose that there are primitive entities that compete for the allocation of attention or across which attentional resources can be distributed. In this view, a first, unselective wave of processing would determine potentially relevant clusters, whereas the selection of grouped items is then determined in a second wave of processing, which crucially depends on attention (Bundesen et al., 2005). Phenomenally, the pacman stimuli in Fig. 1B and C form two clusters discernible (even or especially) at low spatial scale: one above and one below the fixation cross. That these stimuli are clustered into separate entities already implies a grouping process: grouping based on proximity (and perhaps similarity), and this process would have to operate logically prior to the allocation or distribution of attention (e.g., attention can only be spread across both clusters if these are in some way represented, for instance, on some attention-guiding saliency map). This base-level process would precede Kanizsa-type Gestalt formation, where the processes involved in the latter – contour interpolation and region filling-in – may be dependent on attention. In other words, there are likely to be more primitive grouping processes that presumably operate pre-attentively (rough formation of clusters) and more complex processes that render the boundary contour and enclosed, filled-in regions (object integration), which are dependent on attention (see also Roelfsema, 2006 for a comparable theoretical framework). Although the task used in the present study was not designed to dissociate these two stages of grouping, the pattern of deficits displayed by the extinction patients (increased difficulty with multiple objects) implies that it is the latter, more sophisticated processes of object integration that are especially compromised by the non-availability of attentional resources.

Taken together, our results in patients and healthy participants indicate that object binding requires attention, thus challenging accounts according to which pre-attentive processing suffices to render and represent complete objects (Driver and Baylis, 1998; Scholl, 2001, for reviews). Our results imply that integrating features into complete objects can only be achieved efficiently when sufficient attention is distributed across fragmentary, to-be-grouped visual elements.

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