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Illusory contours and spatial neglect

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It has been controversial whether the perception of illusory contours arise from higher level cognitive mechanisms that require attention or from early preattentive visual processes. We studied three patients with left spatial neglect who were unable to detect the left inducers of Kanizsa illusory figures in a same/different judgment task but nonetheless showed implicit perception of the figures in a midpoint judgment, in that they made identical bisection for figures with illusory or real contours but very different bisection for other spatially discontinuous figures that did not yield illusory filling-in. Grouping and filling-in mechanisms can thus occur without explicit detection of, or attention to, the inducing features, consistently with the hypothesis that they involve preattentive visual processes. *NeuroReport* 9: 2481–2484 © 1998 Rapid Science Ltd.

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Introduction

Illusory contours are perceived in the absence of any real physical luminance gradients between inducers that are spatially discontinuous (Fig. 1a,b).[1–3] It has been controversial whether the perception of these subjective contours arise from higher level cognitive mechanisms that depend on attention and serial search[4–6] or from lower level parallel processing in the early automatic, preattentive stages of vision.[7–9] In support of lower level processes, neurophysiological studies in monkeys showed that neurons in the visual cortex (areas V1 and V2) respond to illusory contours as well as to real contours of identical orientation.[10,11] However, unlike subjective contours that are induced by offset gratings, Kanizsa-style illusory contours elicit responses only from V2 neurons and not from V1 neurons.[11,12] Nevertheless, recent evidence suggests that even this type of subjective figure can be detected without focal attention or serial search.[8]

In patients with unilateral neglect who may fail to deploy attention to the contralesional side of space, Kanizsa-style illusory figures provide a special opportunity to investigate the role of attention in the perception of illusory contours. We carried out two experiments in neglect patients to investigate whether the spatial discontinuous inducers of Kanizsa figures might group together despite unilateral neglect and generate subjective filling-in of surfaces bounded by illusory contours; and whether the perception of illusory surfaces themselves might be dissociated from the explicit detection, or awareness, of their inducers.

Patients and Methods

The patients were three right-handed patients aged 64, 68 and 74, respectively, who had suffered a single unilateral stroke in the posterior right hemisphere 20, 28 and 30 days before the present investigation, respectively. Lesions were demonstrated by MRI in all cases, involving frontoparietal cortical areas in patient 3 and the posterior internal capsule, posterior thalamus and temporal cortex in patients 1 and 2 (Fig. 2).[13] Primary and secondary visual areas were spared in all cases. Patients 1 and 2 had a left superior quadranopia, whereas patient 3 had no visual field defect. All showed left visual extinction on double simultaneous stimulation and severe left spatial neglect as evidenced by standardized neuropsychological tests. On line cancellation and letter cancellation tasks,[14] respectively, patient 1 omitted 16/32 and 47/56 left targets, patient 2 omitted 8/32 and 25/56 left targets, and patient 3 omitted 30/32 and 48/56 left targets. They all showed left neglect on reading single words, and patient 1 and 3 also had neglect on spontaneous and copy drawing. Patient 1 was mildly impaired in recognizing known faces. Other cognitive functions were intact in the three cases.

In experiment 1, as in a typical bisection task, the patients had to mark the midpoint of four types of stimuli (shown in Fig. 1) at each of two possible lengths (120 mm and 60 mm): (1) Kanizsa-style illusory bars and rectangles (Fig. lab); (2) standard horizontal lines, 1 mm thick (Fig. 1c); (3) bars and rectangles delimited by real contours (Fig. 1d); (4)

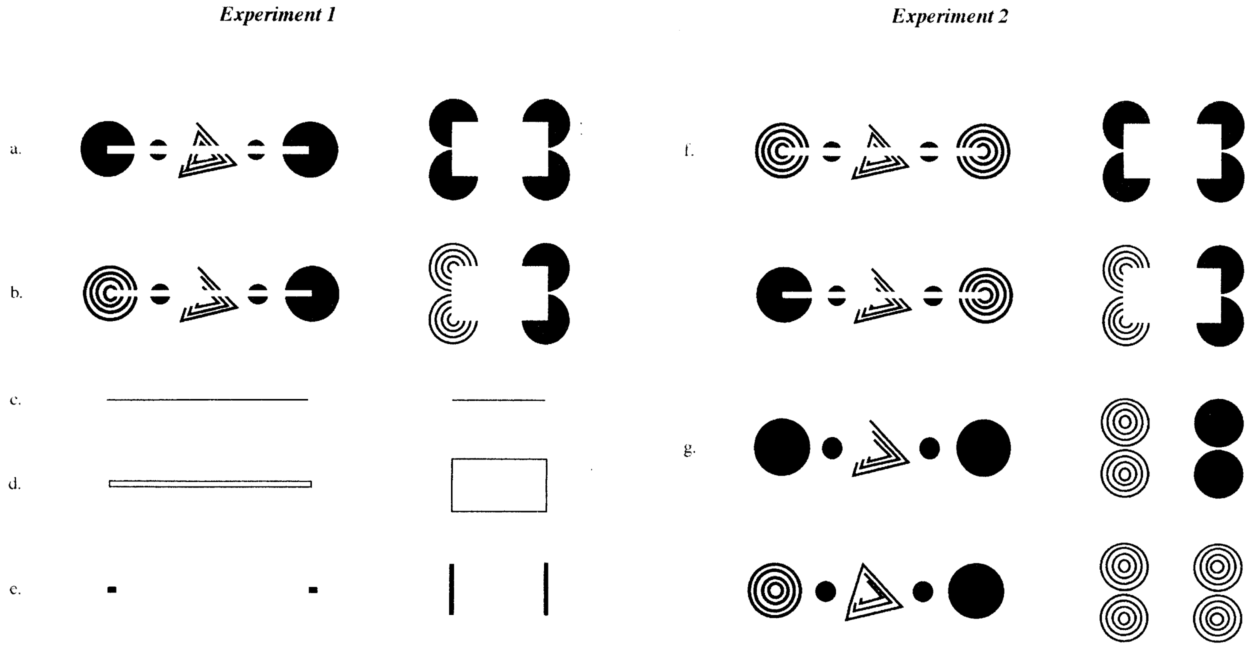

FIG. 1. Example of the stimuli used in both experiments. Four types of stimuli were used in experiment 1: Kanizsa-style illusory bars and rectangles that could have either identical or different inducers on their left and right sides (**a**,**b**); standard horizontal lines (**c**); bars and rectangles delimited by real contours (**d**); gap figures delimited by two vertical lines having comparable heights and horizontal extent (**e**). There were two types of stimuli in experiment 2: pairs of Kanizsa-style illusory figures that could have either identical or different inducers on their left and right sides, as in experiment 1 (**f**) and pairs of non-illusory figures with similar features as the Kanizsa figures except for the removed segments (**g**). Both long (120 mm) and short (60 mm) stimuli were used in each condition.

gap figures delimited by two vertical lines having comparable heights and horizontal extent (Fig. 1e). All stimuli were printed in black on white 29 × 21 cm sheet of paper and presented sequentially in free vision. There were eight trials for each stimuli type at each length. Long (120 mm) and short (60 mm) stimuli were alternated in a pseudo-random order.

In experiment 2, the patients had to make same–different judgments for pairs of illusory figures similar to those used in experiment 1. These were presented in free vision one above the other and could either be identical or differ by their right or left inducers (e.g. Fig. 1f, right pair or left pair, respectively). This was compared with same–different judgments for pairs of non-illusory figures that entailed similar lateral features except for the removed segments inducing the illusory contours (e.g. Fig. 1g, right and left pairs). Long (120 mm) and short (60 mm) stimuli were given in separate blocks of 12 trials each (i.e. four similar, four right-different, and four left-different pairs for each length and each type of stimuli).

Results

In experiment 1, deviation from the true midpoint was measured in each condition as the proportion of mean deviation errors (in mm) divided by the total length of stimuli (120 or 60 mm), with rightward errors denoted positive and leftward errors denoted negative values.

Figure 3 shows the results for the three patients. A two-factors ANOVA on data combined across the patients revealed significant effects of both stimuli length ($F(1,46) = 55.3$, $p < 0.0001$) and type ($F(3,138) = 37.4$, $p < 0.0001$), as well as a significant interaction ($F(3,138) = 3.4$, $p = 0.02$). Deviation errors were greater for longer than for shorter stimuli in all conditions (Fig. 3a), as typically found in studies of line bisection in spatial neglect.[15,16] In *post hoc* comparisons, only deviation errors on the gap figures significantly differed from errors in the other conditions (Bonferroni/Dunn, $p < 0.0001$); all other comparisons were not significant. In the three patients, Kanizsa figures produced deviation errors that were similar to the physically continuous stimuli, i.e. the lines and real contours figures (Fig. 3b), but clearly different from the other spatially discontinuous, non-illusory stimuli (i.e. the gap figures). The latter even produced deviation errors in the reverse leftward direction in two patients. A separate analysis showed no effect on bisection of same *vs* different inducers in the Kanizsa figures ($t(22) = 0.325$ and 0.301, $p = 0.75$ and 0.77, for short and long stimuli, respectively).

In experiment 2, each patient correctly judged as ‘same’ all pairs of illusory figures that were identical and as ‘different’ all pairs of illusory figures that

FIG. 2. Anatomical plotting of brain lesions in the three patients as shown by MRI 4 days post-stroke onset in patient 1 and 6 days post-stroke onset in patients 2 and 3, following methods described by Damasio and Damasio.[13]

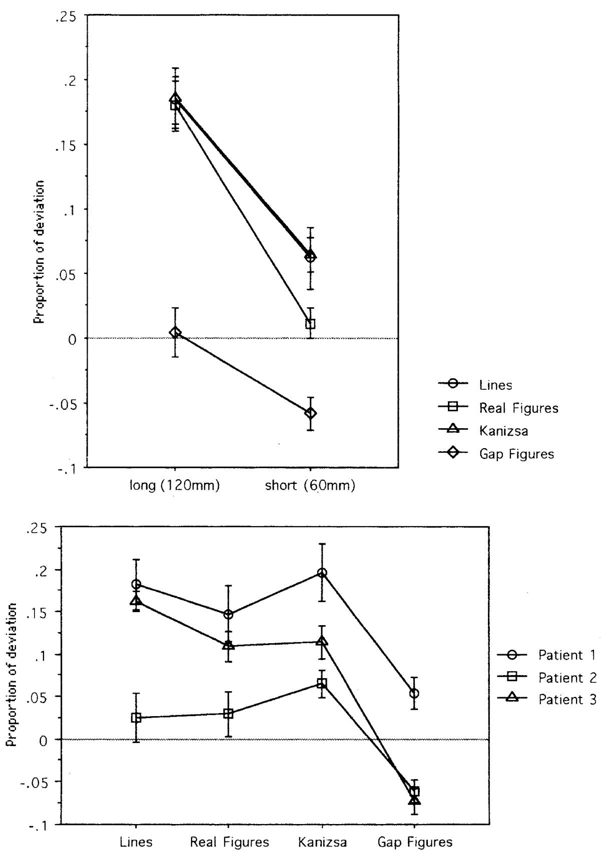

FIG. 3. Deviation errors in bisection judgments. Data are means ± s.e. Upper: in the three patients, rightward deviation errors were greater on long than on short figures for all types of stimuli except for the gap figures. Lower: in each patient, deviation errors produced on Kanizsa figures were similar to those produced on physically continuous stimuli (lines and real contours figures) but clearly differed from those made on the other spatially discontinuous stimuli (gap figures).

differed on the right side, but consistently failed to report the correct difference for the pairs of illusory figures which differ on their left side (Table 1). There was no significant effect of stimuli length. By contrast, the patients made no errors on the non-illusory figures.

Discussion

Experiment 1 showed that the spatial bias in bisection judgment for stimuli defined by illusory contours is similar to the bias observed for stimuli of the same horizontal extent that are physically continuous (i.e. lines or real contours figures), but clearly different from the bias observed for other discontinuous stimuli of the same extent that do not induce illusory filling-in. This indicates that, despite left neglect, the features of illusory figures were effective in grouping together in order to generate a single visual object for midpoint judgments, whereas the non-illusory gap figures forced the patients to orient

Table 1. Explicit detection of the lateral inducers in illusory figures.

	Same on both sides	Right-sided differences	Left-sided differences
Patient 1	8/8	8/8	2/8
Patient 2	8/8	8/8	1/8
Patient 3	8/8	8/8	1/8

The number of correct responses is shown for each patient according to the presence/absence and the side of the actual differences in the lateral inducers of the figures. The patients made no errors on non-illusory figures (data not shown).

deliberately their attention to left-sided features in order to mark the midpoint, thereby reducing or even reversing the bisection bias.[16,17] Consistent with the current observation, the only previous study that investigated perception of illusory contours in a patient with neglect found that left extinction for bilateral simultaneous visual events decreased when these were part of an illusory figure surface.[18]

Experiment 2 showed that the patients had no explicit awareness of the inducing features on the left side of the figures and consistently failed to attend to them for same-different judgments. Altogether, this implies that neglect patients can perceive a subjective figure bounded by illusory contours without being aware of its left inducers. This dissociation between the perception of the illusory figures themselves and the detection of their inducing features strongly suggest that the latter were processed at preattentive stages of vision. Early preattentive visual processes might derive a single illusory surface from bilateral inducers through long-range interactions in visual cortex.[10,19,20] In particular, it has been assumed that illusory boundary representations might occur by virtue of the integration of converging signals from 'end-stopped' neurons (e.g. in V2) that detect contrast discontinuities along the same orientation.[3,10] Preattentively derived illusory figures could then be available for attentive vision and midpoint judgments even though the left-sided inducers are not overtly attended to, and hence not available for explicit detection and awareness. It must be noted that primary and secondary visual areas (i.e. V1 and V2) were spared in all three patients. These findings extend previous evidence that automatic visual mechanisms can proceed to advanced stages of perceptual processing in the absence of attention, so as to parse and group candidate objects in the visual scene.[21] Similar observations have been made in neglect patients for the Müller-Lyer/Judd illusion[22,23] and figure–ground segregation based on symmetry,[24] showing that some neglect patients may be influenced by left-sided features, yet without overt perception of these features. However, both Müller-Lyer/Judd illusion and figure–ground segregation differ from the Kanizsa-style illusory figures we used here, in that the stimuli are physically and spatially single visual objects. Furthermore, the neurophysiological and neuroanatomical substrate which subserve them are largely unknown. Additional patients must be investigated to find out how performance on illusory stimuli is affected by the lesion location in extrastriate visual areas.

Conclusion

Patients with spatial neglect may show implicit perception of illusory figures induced by spatially discontinuous inducers in a bisection task even though they fail to explicitly detect, or attend to, the left-side inducers. This suggests that preattentive visual processing of the inducing features may allow for grouping and filling-in mechanisms to generate the subjective contours of illusory figures even though these features are not available for attentive vision and awareness.

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