

A systematic study of visual extinction

Between- and within-field deficits of attention in hemispatial neglect

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Summary

Mechanisms of visual extinction were investigated in four patients with right hemisphere damage using a partial report paradigm. Different shapes (star or triangle) were displayed in one, two or four possible locations so that double simultaneous stimuli occurred either across the two hemifields or within the same hemifield. Patients attended either to the location (right, left or both), number (one, two or four) or shape (no, one or two stars among the shapes presented) of stimuli in three separate experiments using the same displays and exposure duration. Reporting the location (Experiment 1) produced marked contralesional extinction, although reaction time was delayed compared with unilateral right trials, indicating unconscious processing. Reaction time was also delayed on correct bilateral and unilateral left trials. In contrast, enumerating stimuli (Experiment 2) caused no significant contralesional extinction on bilateral displays and reaction time was similar on bilateral and unilateral right trials, suggesting that information from both fields was grouped in a single numerable percept in this task. However, patients often detected only one of two stimuli within the left field. Whereas similarity of shapes improved localization and did not affect enumeration, identifying stars among shapes (Experiment 3) revealed a severe

inability to detect two similar targets between hemifields as well as within each of the hemifields. Distracting triangles were generally less detrimental to the perception of a concurrent target on either side, but slowed the reaction time regardless of whether they were in the same or the opposite field. Relative difficulty in ignoring distractors correlated with neglect severity on a cancellation task, and was most prominent in one patient with a large amount of frontal damage. These findings suggest that (i) allocation of attention to identical stimuli can be modulated by task demand; (ii) enumerating a small set of items across fields may not require attending to individual stimuli but relies on preattentive subitizing ability, as found in normal subjects; (iii) location information may be critical for attentional mechanisms subserved by the parietal cortex and pathological competition for awareness in extinction; (iv) extinction entails a bilateral deficit in attending to two concurrent similar targets when their features must be identified; and (v) the relevance of the stimuli can modulate the distribution of attention, possibly through frontal top-down control. These findings are consistent with recent neurophysiological evidence of parietal and frontal attentional influences on ventral visual pathways.

Keywords: visual attention; spatial neglect; parietal lobe; grouping; subitizing

Abbreviations: LVF = left visual field; RT = reaction time; RVF = right visual field

Introduction

Attention allows us to perceive and respond to relevant objects in visual space while ignoring irrelevant objects. Patients with unilateral brain damage, in particular to the right parietal lobe, may fail to attend and orient to events in the contralateral space, and present with neglect (Mesulam, 1985; Heilman *et al.*, 1993; Rafal, 1994). Among the multiple deficits of perception and exploratory behaviour that constitute the neglect syndrome, extinction is often taken as

a cardinal sign indicating an attentional deficit (Critchley, 1953; Bisiach, 1991; Rafal, 1994). Patients with visual extinction can perceive a single stimulus in either hemifield if it is presented alone but are unaware of the same stimulus in the contralesional field when another is presented simultaneously on the ipsilesional side. Extinction is more frequent with right hemisphere damage (Barbieri and De Renzi, 1989; Vallar *et al.*, 1994) and often persists after

recovery from a more severe neglect disorder (Karnath, 1988). However, some early (Bender and Teuber, 1946; Denny-Brown *et al.*, 1952; Bay, 1953) and more recent (Birch *et al.*, 1967; Farah *et al.*, 1991; Vallar *et al.*, 1994; Marzi *et al.*, 1996) studies have suggested that extinction might result from sensory imbalance due to weakened or delayed afferent inputs in the affected hemisphere rather than from attentional factors. Further, the view that extinction and spatial neglect share a common underlying mechanism has been questioned on the basis of a few patients with spatial neglect but no clinically noticeable extinction (Barbieri and De Renzi, 1989; Bisiach, 1991; Liu *et al.*, 1992) and the somewhat different neuroanatomical correlates of the two disorders (Vallar *et al.*, 1994).

Several observations nonetheless support an attentional account of visual extinction, whereas physical characteristics of contralesional stimuli, such as increased brightness, size or duration, have little or no effect on detection (Di Pellegrino and De Renzi, 1995; Smania *et al.*, 1996), patients with damage to the parietal lobe are impaired in detecting a contralesional target even in the absence of another competing target if their attention is invalidly cued to the ipsilesional field (Posner *et al.*, 1984, 1987). Likewise, simply instructing the patients to attend to the contralesional side and ignore ipsilesional events can partially overcome extinction (Critchley, 1953; Karnath, 1988; Di Pellegrino and De Renzi, 1995), whereas directing attention ipsilesionally can cause extinction of the most contralesional stimulus on double stimulation within the intact hemifield (Kinsbourne, 1987; Di Pellegrino and De Renzi, 1995). Extinction is also influenced by expectancy as to where a stimulus is likely to occur based on the preceding stimulus contingencies (Kaplan *et al.*, 1990). More importantly, it may vary according to the task demand (Volpe *et al.*, 1979; Bisiach *et al.*, 1989; Smania *et al.*, 1996) or the similarity of contralesional and ipsilesional stimuli (Karnath, 1988; Baylis *et al.*, 1993; Ward *et al.*, 1994).

Understanding what factors determine whether a contralesional event is detected or extinguished may therefore provide valuable insights into the mechanisms of attention and its operation in visual processing. The present study investigated visual extinction in three experiments in which the stimuli were the same but the attentional requirement of the task varied. We employed an original procedure that allowed us to contrast the perception of identical sensory events in different goal settings, as well as to derive some new quantitative ways of measuring attentional effects or deficits in visual processing. Our purpose was fivefold.

(i) We assessed how simple changes in task demands affect the rate of extinction for physically similar stimuli. Typically, studies of extinction confound three possible sources of attentional limitation, *viz.* detecting how many (one versus two), where (right versus left) or what (on each side) stimuli are presented. Here, double simultaneous stimuli were presented either across both hemifields or within the same hemifield, and patients were required to attend to the number, location or shape of stimuli in three separate tasks. Differences

between the first and second tasks, *i.e.* enumeration and localization, may not be trivial since detection of something does not necessarily imply information about its place or its nature, and empirical evidence suggests that item individuation and enumeration does not always require spatial attention (Trick and Pylyshyn, 1993, 1994). In support of such a distinction, some data from these two tasks were described in a previous brief report for three of our patients (Vuilleumier and Rafal, 1999). In the third task, shapes were sufficiently similar (star versus triangle) to ensure that their discrimination would require focal attention and not rely on pop-out features (Treisman and Gelade, 1980). These displays further allowed us to examine attentional competition not only across fields but also within the contralesional and ipsilesional fields.

(ii) We examined whether competition for spatial attention differs when simultaneous stimuli have the same shape or different shapes within or across hemifields, as well as when they occupy symmetrical or asymmetrical locations across visual hemifields. Previous studies have provided conflicting claims about whether similarity or symmetry of shapes may allow perceptual grouping, and thus decrease competition for attention and extinction (Ward *et al.*, 1994), or whether similarity may place more demands on processes of item individuation, and thus rather increase competition and extinction (Baylis *et al.*, 1993).

(iii) We asked whether relevance of stimuli in the shape discrimination task can exert a selective influence affording preferential allocation of attention to relevant objects over concurrent distractors, and thus modulate extinction. This condition is not only more typical of attentional search in the real visual world but also follows the partial report paradigm that has been used extensively to study attention in normal subjects (Sperling, 1960; Pashler, 1998).

(iv) We measured the patients' performance using both detection accuracy and vocal response latency on the same trials to compare explicit report and possible implicit processing of unattended stimuli (Mijovic-Prelec *et al.*, 1994).

(v) We asked whether attention deficits revealed in extinction would correlate with the severity of neglect behaviour as examined in standard clinical tests.

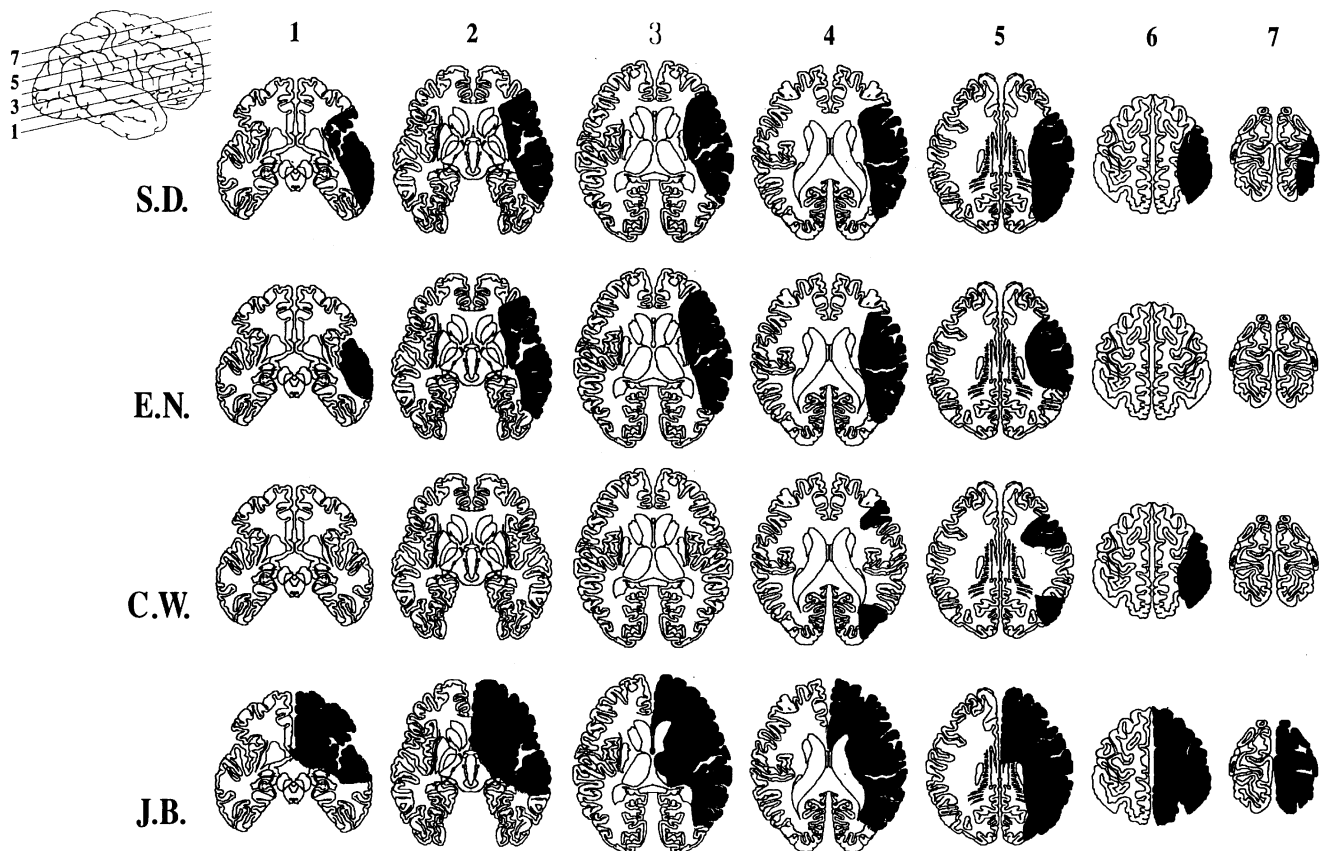
Patients and methods

Four right-handed patients (S.D., E.N., C.W. and J.B.) with chronic unilateral right hemisphere lesions from stroke were studied. Table 1 shows their clinical characteristics. Figure 1 shows the anatomical reconstruction of brain damage as demonstrated by CT (S.D. and E.N.) or MRI (C.W. and J.B.) scans (Frey *et al.*, 1987). At the time of investigation, all patients had consistent left visual extinction on double simultaneous stimulation in clinical confrontation testing and mild visuospatial neglect on standard tests, including a line bisection task, letter cancellation and drawing (Table 1). Three patients (S.D., E.N., C.W.) had intact visual fields and one (J.B.) had a partial left hemianopia with macular sparing

Table 1 Clinical characteristics of patients

Patient	Gender, age (years)	Lesion	Time since stroke onset	Visual field	Motor deficit	Line bisection:* magnitude of deviation mean \pm SD (%)	Letter cancellation [†]	
							L/R omissions	Time
S.D.	F, 60	Infarct	3 years	Intact	L hemiplegia	13 \pm 2 mm (7.8)	15/2	3'50''
E.N.	M, 58	Infarct	30 months	Intact	L hand paresis	30 \pm 4 mm (17.8)	16/5	3'10''
C.W.	M, 66	Infarct	12 months	Intact	L hand paresis	59 \pm 8 mm (34.8)	8/7	2'50''
J.B.	M, 77	Infarct	7 years	L hemianopia, parafoveal sparing	L hemiplegia	17 \pm 6 mm (10.0)	29/22	1'00''

*Line length = 170 mm; [†]total number of targets = 30 L + 30 R. L = left; R = right.

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

which allowed presentation of stimuli in the parafoveal field (on both sides). All patients were independent in self-care and everyday life except J.B., who lived in an extended care facility. They were paid for their participation and signed informed consent statements approved by the Institutional Review Board of the Martinez Department of Veterans Affairs and the University of California, Davis. Each experiment was conducted in two blocks in two different sessions 2 or 3 weeks apart in patients S.D., E.N. and C.W., and in four different sessions over 2 weeks in patient J.B.

Experimental procedure

In all tasks, stimuli were shapes outlined in black (star or triangle, $\sim 1.7^\circ$) presented on a white computer screen. Patients

sat ~ 50 cm from the computer. On each trial, a fixation point ($\sim 0.4^\circ$) was presented at the centre of the screen for 550 ms and then replaced by a brief display in which shapes appeared in one, two or four locations at the corners of an imaginary square centred on fixation (Fig. 2). Shapes were $\sim 8^\circ$ away from fixation, except for patient J.B., in whom stimuli were presented at $\sim 2.5^\circ$ in the parafoveal field on both sides.

There were four equiprobable types of display and as many unilateral as bilateral trials (Fig. 2). Unilateral trials consisted of one shape (single displays) or two shapes (double displays) presented in either the right or the left hemifield; bilateral trials consisted of one shape (single displays) or two shapes (double displays) presented simultaneously in both fields. In unilateral single displays, one shape appeared in either the upper or the lower location (half of the trials each).

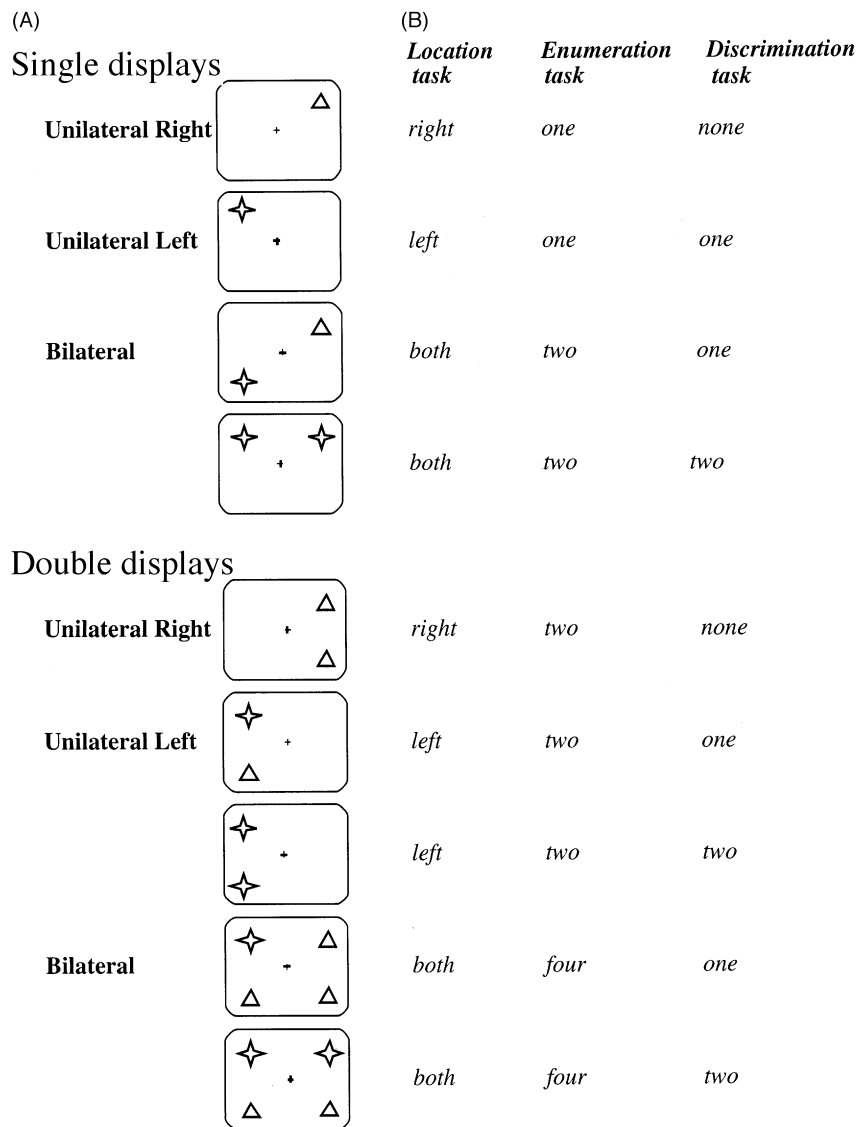


Fig. 2 (A) Examples of stimuli and trials used in all three experiments. (B) Examples of corresponding correct responses in each task.

In double unilateral displays, the two shapes were either identical (two triangles or two stars; half of the trials each) or different (one triangle and one star; half of the trials each). In bilateral single displays, the two shapes were arranged either horizontally or diagonally (half of the trials each) and were either identical or different (half of the trials each). In bilateral double displays, the four shapes were arranged either symmetrically, with four identical shapes or two identical shapes in a row (across hemifields), or asymmetrically, with two identical shapes in a column (within hemifield) or one star at any of the four corners and three triangles at the remaining corners (a quarter of the trials each). This resulted in 64 trials, each repeated twice within a block.

The same visual stimuli and exposure duration were used in three experiments, so that only the instructions differed and all other conditions remained unchanged. The number of alternatives in the response set was maintained constant

across tasks (three possible correct answers). The location task required patients to report where shapes appeared, i.e. ‘on the right’, ‘on the left’ or ‘on both sides’. The enumeration task required them to report how many shapes appeared, i.e. ‘one’, ‘two’ or ‘four’. The discrimination task required them to report how many stars appeared among the shapes, i.e. ‘none’, ‘one’ or ‘two’.

The order of trials was randomized by the computer and differed for every patient, task and session. Patients received two blocks (256 trials) in each of Experiments 1 and 2 (location and enumeration) and three blocks (384 trials) in Experiment 3 (discrimination). Blocks were alternated and given in a counterbalanced order across patients and sessions (Table 2). The stimulus duration was set during a practice phase so as to avoid ceiling and floor effects, and was then kept constant for each patient across the different tasks and sessions (100 ms for C.W., 50 ms for S.D., 25 ms for E.N.)

Table 2 Order of blocks and stimulus duration

Patient	Number of session			
	1	2	3	4
S.D.	Loc50–Enu50–Disc50	Disc50–Loc50–Enu50–Disc50	(Disc150–Disc150)*	
E.N.	Loc25–Enu25–Disc25	Enu25–Disc25–Loc25–Disc25		
C.W.	Loc100–Enu100–Disc100	Enu100–Disc100–Disc100–Loc100		
J.B.	Loc250–Enu250	Enu400–Disc250	Disc400–Loc400	Disc400

Loc = location task (right left or both sides); Enu = enumeration task (one, two or four); Disc = discrimination task (number of stars). Numbers refer to duration of stimuli presentation in milliseconds. *This additional session was given to S.D. several weeks later as a control (see Results) and is not included in analysis.

except for J.B. (250 ms for the first block of each task and 400 ms for subsequent blocks). After each stimulus presentation, the examiner entered the patient's response into the computer. In the second and following sessions, vocal response time was also recorded by a microphone connected to the computer. There was an interval of 1 s before the next trial was initiated.

Given the small sample and the variability of the patients, their performance was compared across conditions using non-parametric statistical tests for each individual (e.g. Fisher's exact test) as well as for the group data (e.g. Wilcoxon and Friedman rank tests) whenever possible.

Results

Experiment 1: location

Accuracy

In this task, patients reported whether shapes appeared on the right, left, or both sides. They missed only a few unilateral stimuli (Fig. 3A). Accuracy was similar in the left and right hemifields, except for J.B., who had a partial hemianopia and was presented with stimuli in his spared parafoveal field [36% missed in the left visual field (LVF) and 5% in the right visual field (RVF) for J.B.; 6–11% in the LVF and 0–3% in the RVF for other patients; $P \leq 0.005$ by Fisher's test for J.B. and C.W. on single displays, $P \geq 0.11$ in other cases; $P = 0.07$ by Wilcoxon's test for the group]. Performance was slightly better on unilateral displays with double left targets (34% missed in J.B., 0–3% in other patients) than with a single left target (37% in J.B., 9–21% in others). All unilateral errors were real misses with no left-right transposition or false bilateral responses.

On bilateral trials, all patients showed marked extinction and missed many stimuli in the left hemifield for both single (45–67%) and double displays (27–66%). Performance was again slightly better on double displays. The difference between bilateral and unilateral left trials was highly significant ($P \leq 0.003$ by Fisher's test across single and double displays in each patient; $P = 0.011$ by Wilcoxon's test for the group).

Extinction increased when shapes (triangle or star) differed on the left and right sides compared with when they were identical (Fig. 3A); this was more consistent with single (50–

78 versus 41–56% missed) than double displays (25–69 versus 21–65%) and significant only in two patients ($P \leq 0.044$ in S.D. and C.W. by Fisher's test, $P \geq 0.71$ in E.N. and J.B.; $P = 0.067$ by Wilcoxon's test for the group). It was not affected by the arrangement of shapes in bilateral single displays (horizontal versus diagonal), but stimuli in the lower left position were more often missed than those in the upper left position, both in bilateral and unilateral displays. A 2×2 analysis of variance (ANOVA) of the number of misses in bilateral trials using the stimuli position in each field (upper, lower) as factors showed a strong effect of LVF position [$F(1,12) = 10.8$, $P = 0.006$] but not RVF position [$F(1,12) = 1.3$, $P = 0.27$] and no interaction [$F(1,12) = 0.15$, $P = 0.71$].

The rate of extinction in this task showed no relation with clinical measures of neglect severity as assessed by the number of omissions in the cancellation test ($r^2 = 0.32$; $P = 0.26$; Kendall's rank test) and, if anything, rather a negative correlation with the magnitude of deviation in line bisection ($r^2 = 0.87$; $P = 0.06$; Kendall's rank test).

Vocal reaction time

In all patients, correct responses were slower for both unilateral left (mean 1276 and 1280 ms for single and double displays, respectively) and bilateral stimuli (mean 1320 and 1263 ms) than for unilateral right stimuli (mean 1148 and 1113 ms; Fig. 3B). These differences were significant for the group as a whole [$\chi^2(2) = 7$, $P = 0.030$; Friedman rank analysis of variance across displays]. Symmetry in bilateral displays had no effect (mean 1287 versus 1301 ms for identical versus different shapes).

We also compared reaction times (RTs) on bilateral trials in which left shapes were extinguished to unilateral right trials (different stimuli but same percept) and correct bilateral trials (same stimuli but different percept). In three patients (E.N., S.D. and J.B.), 'right-side' responses were much slower when left stimuli were extinguished than for true right-side stimuli (Fig. 3B). Taken as a group, extinguished bilateral trials differed reliably from right trials but not from correct bilateral trials [$\chi^2(2) = 9.8$, $P = 0.008$ by Friedman test across displays; *post hoc* pairwise comparisons, $P = 0.035$ and 0.4, respectively].

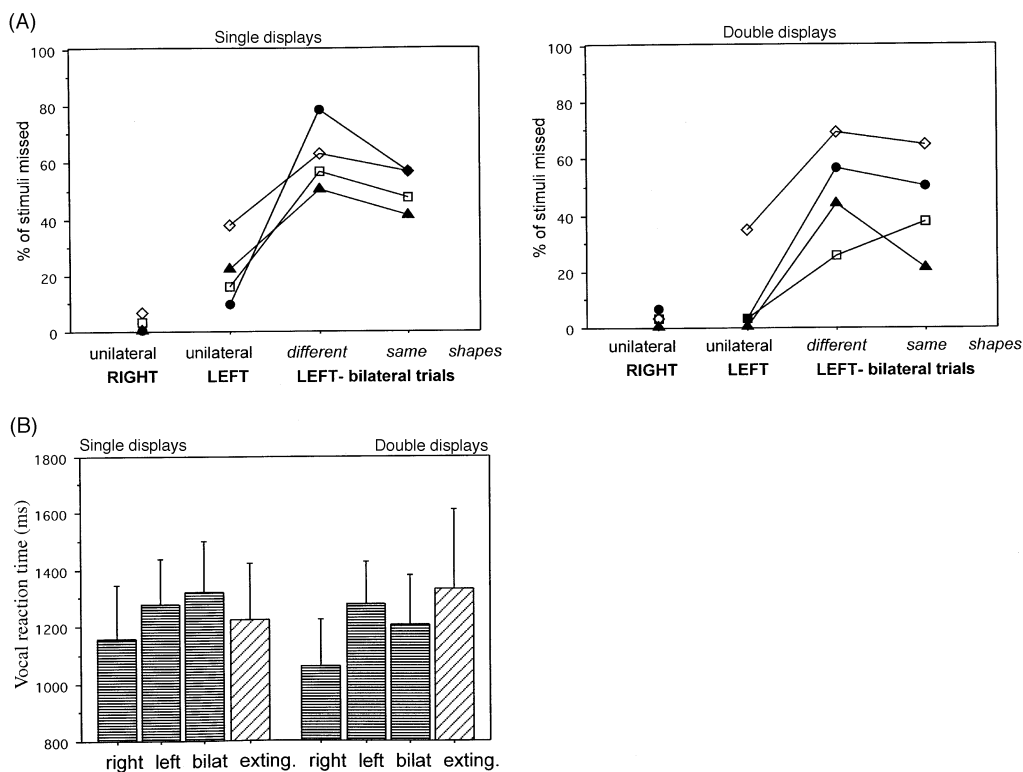


Fig. 3 Results from the location task. **(A)** Proportion of stimuli missed in unilateral and bilateral trials for each type of display and each patient. **(B)** Mean vocal reaction times on correct responses for unilateral right, unilateral left and bilateral trials, and for extinguished trials. Filled circles = S.D.; open squares = E.N.; filled triangles = C.W.; open diamonds = J.B.

Experiment 2: enumeration

Accuracy

In this task, patients reported if they saw one, two or four shapes, regardless of their location. Although all stimuli and trials were identical to those in the previous task, a very different pattern of performance emerged (Fig. 4A).

First, all patients had difficulty enumerating two stimuli in the contralesional hemifield and missed many stimuli in unilateral left displays with double targets (28–56%) compared with single targets (6–22%), reporting one instead of two shapes on these trials [Fisher's test, $P \leq 0.025$ in all cases except C.W. ($P = 0.77$); Wilcoxon's test, $P = 0.068$ for the group]. This contrasted with the slight advantage of double over single displays in the location task. Whether the two shapes were identical (two triangles or two stars) or different (one triangle and one star) had no effect (4–10 versus 5–8 missed out of 16 trials for same and different shapes, respectively; Fisher's test, $P \geq 0.5$ in all patients; Wilcoxon's test, $P = 0.41$ for the group). Single and double displays did not differ in the right hemifield (0–6 versus 0–9% missed).

Secondly, no contralesional extinction was obtained in bilateral trials (Fig. 4A). Apart from J.B., all patients extinguished very few left stimuli in both single (37% in J.B. 5–16% in others) and double bilateral displays (50% in J.B., 0–5% in other patients). In single displays, the

left miss rate was no greater in bilateral than in unilateral trials, and even the trend to extinction in patient J.B. was not significant ($P = 0.17$ in J.B., $P \geq 0.4$ in others; $P = 0.58$ for the group). On double displays, performance was usually better in bilateral than unilateral left trials ($P = 0.67$ in J.B., $P \leq 0.039$ in others; $P = 0.068$ for the group), presumably because patients could sometimes infer four shapes when they actually saw three. Thus, all patients were better at detecting two shapes across fields than within the left hemifield.

A direct comparison of individual data in the location and enumeration tasks confirmed that extinction of contralesional stimuli was more severe in the former. This difference was highly significant for single ($P \leq 0.0005$; Fisher's test) and double ($P \leq 0.01$) displays in all patients except J.B. ($P = 0.11$ and 0.071 , respectively), in whom it was significant if his data on single and double displays were combined ($P = 0.013$).

On bilateral trials, enumeration was not affected by shapes being identical or different on the right and left sides (45 versus 42% missed in J.B., 5–10 versus 2–17% in others; Fisher's test, $P \geq 0.28$ in each; Wilcoxon's test, $P = 0.85$ for the group) or by their arrangement (horizontal versus diagonal). Stimuli were missed equally in the lower and upper left positions. A 2×2 ANOVA of the number of misses in bilateral trials showed no significant effect

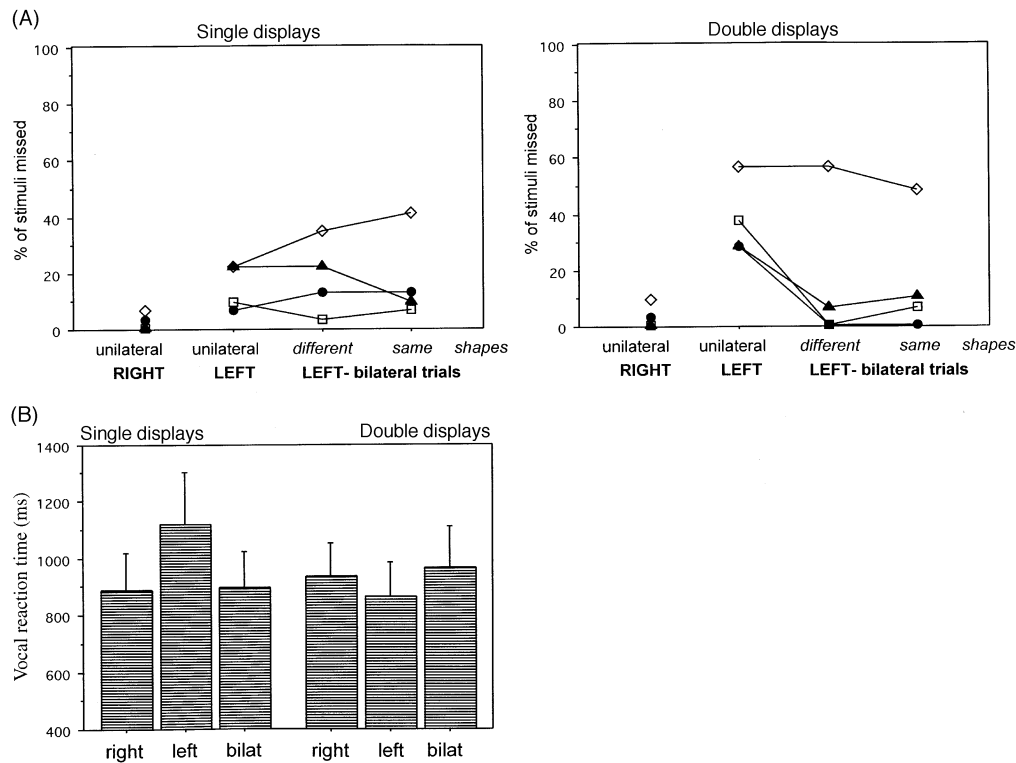


Fig. 4 Results from the enumeration task. **(A)** Proportion of stimuli missed in unilateral and bilateral trials for each type of display and each patient. **(B)** Mean vocal reaction times on correct responses for unilateral right, unilateral left and bilateral trials. No data are shown for left misses on bilateral trials, given the absence of significant left extinction. Filled circles = S.D.; open squares = E.N.; filled triangles = C.W.; open diamonds = J.B.

of LVF position [$F(1,12) = 0.39$, $P = 0.54$] or RVF position [$F(1,12) = 1.3$, $P = 0.27$] and no interaction [$F(1,12) = 0.07$, $P = 0.79$].

Vocal reaction time

Correct responses to single displays were always slower for contralesional stimuli (mean 1122 ms) but faster for bilateral (mean 899 ms) and for ipsilesional stimuli (mean 888 ms) (Fig. 4B). Correct responses to double displays were similar whenever they were presented ipsilesionally (mean 938 ms), contralesionally (mean 863 ms) or bilaterally (mean 965 ms). Differences between field conditions (right, left or bilateral) were significant for the group as a whole on single displays [$\chi^2(2) = 6.5$, $P = 0.038$; Friedman rank test] but not double displays [$\chi^2(2) = 0.5$, $P = 0.78$]. Symmetry in bilateral displays had no effect (mean 966 versus 970 ms for identical versus different shapes).

RTs when patients reported one instead of two shapes in left double displays (mean 1185 ms) did not differ from trials with a single left target in any patient (mean 1122 ms) but differed from trials in which a double left target was correctly detected (mean 863 ms). Faster RTs to double targets are consistent with a normal redundancy effect (e.g. Marzi *et al.*, 1996) but depended on awareness of both stimuli.

Experiment 3: discrimination

Accuracy

Between visual hemifields. In this task, patients reported how many stars appeared regardless of location or distractor triangles. They rarely reported a star when none was present ($\leq 6\%$ of trials) except for E.N., who was shown stimuli with the briefest duration (25 ms) and made such errors in 20% of trials, but, importantly, in similar percentages of trials across conditions (19, 20 and 22% for right, left and bilateral stimuli, respectively). A 3×2 ANOVA on the total number of these errors showed no significant effect of side [RVF, 2–19%; LVF, 4–21%; bilateral, 0–22%; $F(2,18) = 0.9$, $P = 0.92$] or display size [single, 1–14%; double, 3–25%; $F(1,19) = 0.13$, $P = 0.72$] and no interaction [$F(2,18) = 0.6$, $P = 0.56$]. No patients reported two stars when only one was present. Thus, overall, all patients correctly denied the presence of a star in 78–100% of trials with triangles on both sides.

Accuracy for detecting one star alone varied but was generally similar in the RVF and LVF (Fig. 5A). While C.W. performed the worst on both sides (37% of left and 46% of right single stars missed), other patients missed a single star in 8–20% of left and 0–8% of right trials [difference between fields not significant; Fisher's test, $P \geq 0.19$ in each case except S.D. ($P = 0.025$); Wilcoxon's test, $P = 0.29$ for the

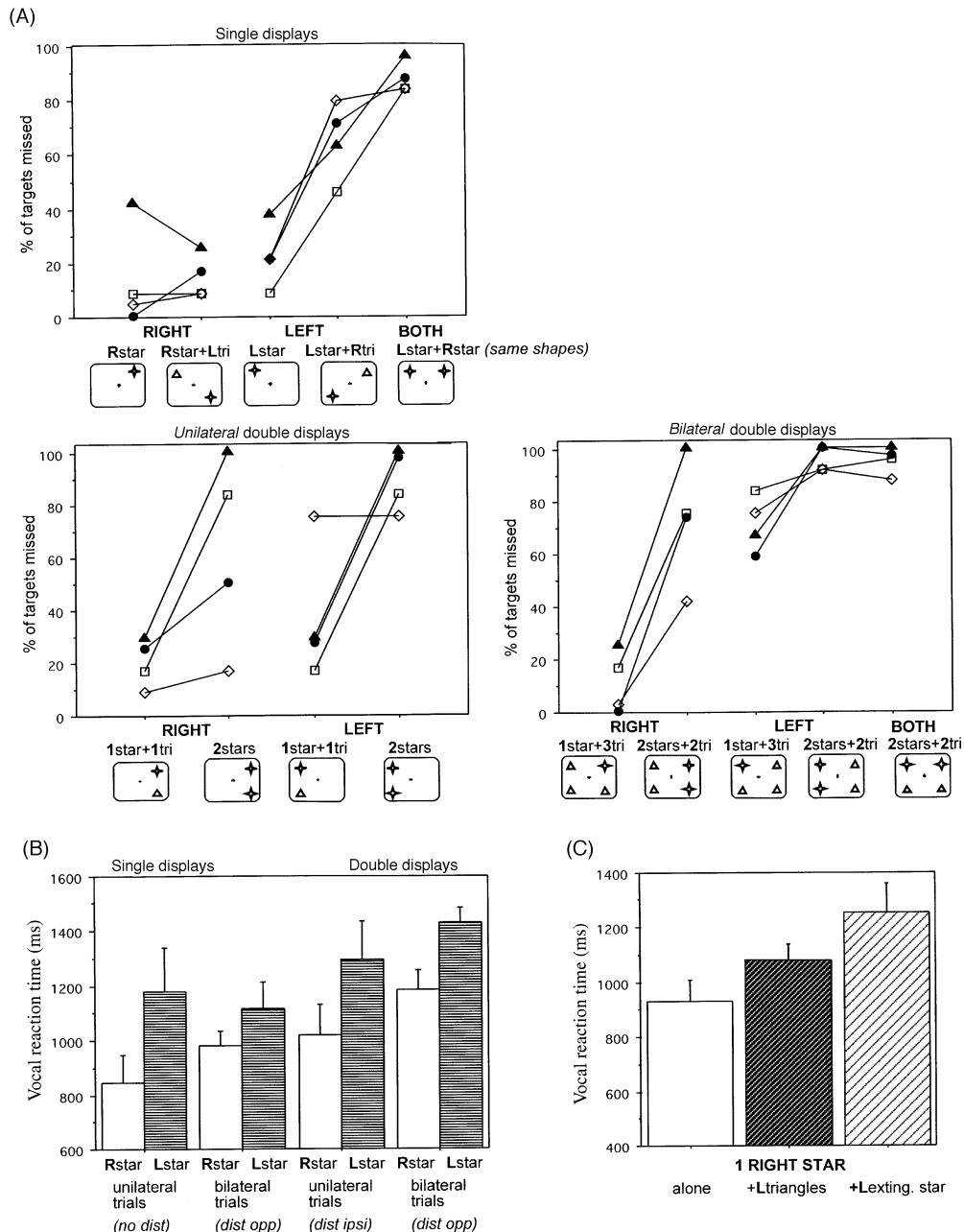


Fig. 5 Results from the discrimination task. (A) Proportion of targets (stars) missed for all types of display and each patient as a function of the target side and presence or absence of distractors (triangles). Both single and double bilateral displays show that extinction of a left-side star increased with a concurrent right-side star compared with a right-side triangle. Double displays show that extinction of a second target was similar within the right and left hemifields, and between hemifields. Filled circles = S.D.; open squares = E.N.; filled triangles = C.W.; open diamonds = J.B. (B) Mean vocal reaction times for correct responses on trials with one star according to the target side and presence or absence of distractors (triangles) in the hemifield ipsilateral or opposite to the targets. RTs on trials with no or two stars are not shown. (C) Mean vocal reaction times on trials with one right-side target either alone or together with a left-side distractor (triangle) or an extinguished left-side target.

group]. All patients showed marked contralesional extinction and missed a left star in 65–81% of single and 77–89% of double bilateral displays. Importantly, extinction of a contralesional star depended on whether the ipsilesional field contained an irrelevant triangle or a second target (Fig. 6A), and patients especially failed to detect two stars across fields.

A left star was missed in 83–96% of single and 88–100% of double displays with another star on the right but only 46–79 and 58–83% with right-side triangles, respectively. This difference was highly significant in each case (Fisher's test, $P \leq 0.005$) except for J.B. ($P = 0.40$) (Wilcoxon's test, $P = 0.0117$ for the group including J.B.).

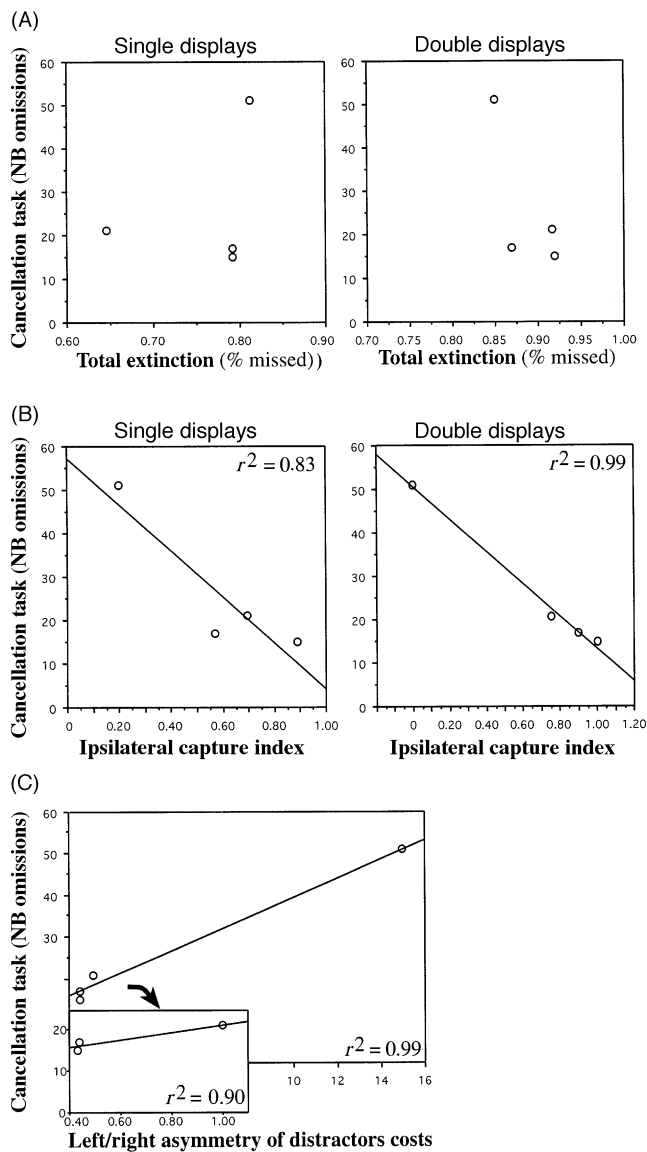


Fig. 6 Scatterplots relating neglect severity in a clinical cancellation test and different measures of extinction in the discrimination task. Unlike the total rate of extinction for left-side targets (A), indices of capture by ipsilesional distractors on single or double displays (B), and the left–right field asymmetry of distractors costs (C) show a strong correlation with the number of omissions in the cancellation test. In the case of distractor costs, this relation remains strong even when patient J.B.’s extreme value is excluded (C, inset). See text for computation of these indices.

This suggests that distractors in the ipsilesional field did not compete for attention as much as targets, because if attention was equally allocated to all shapes a left star should be missed as often when there is a triangle as when there is a star on the right side. To evaluate more precisely how this might reflect greater selectivity of attention and better disengagement from a non-target than from a target, we calculated for each patient a ratio of ‘ipsilesional capture’ as an index of the relative degree to which ipsilesional targets and distractors induced contralesional extinction. Thus,

ipsilesional capture was defined as the difference in the percentage of trials in which a left star was detected when presented with a right triangle and when presented with a right star, divided by the former. Higher ratios should reflect little capture by ipsilesional distractors compared with targets and greater selectivity, while a ratio close to zero should reflect more capture and poorer selectivity. Ipsilesional capture values varied among patients and displays (Table 3) but showed a remarkable relation with neglect severity on the cancellation test (Kendall’s rank test for single and double displays, $r^2 = 0.83$ and 0.99 , $P = 0.17$ and 0.04 , respectively) (Fig. 6B). There was no similar relation with the magnitude of deviation on line bisection ($r^2 \leq 0.61$). By contrast, the total rate of extinction of left-side targets did not correlate with neglect severity on cancellation or line bisection ($r^2 < 0.5$) (Fig. 6A).

Within visual hemifields. The different displays allowed examination of the relative competition for attention by an irrelevant shape (triangle) or a second target (star) not only across hemifields but also within each hemifield. Compared with a unilateral star alone, adding a distractor triangle in the same field did not impair performance on either side except for patient J.B.’s left side (Fig. 5A; compare unilateral single and unilateral double displays in the upper and lower left graphs, respectively). In left double displays with two dissimilar shapes (one star and one triangle in same field), J.B. failed to detect one star in 75% of trials but the other three patients failed in 17–29% of trials; this did not differ significantly from detecting a single left target [Fisher’s test, $P \geq 0.43$ in each case except J.B. ($P \leq 0.001$); Wilcoxon’s test, $P = 0.35$ for the group]. Similarly, one star was missed in 4–29% of right double displays; this did not differ significantly overall from a single right target ($P \geq 0.25$ in three cases, $P = 0.01$ in S.D., $P = 0.71$ for the group). Further, except for J.B. all patients performed similarly on left and right double displays [Fisher’s test, $P \geq 0.43$ except J.B. ($P \leq 0.001$); Wilcoxon’s test, $P = 0.18$ for the group].

In contrast, adding a second star within the same field severely taxed performance in all cases (Fig. 5A, lower left graph). In unilateral double displays with two stars, a target was missed in 75–100% of left and 17–100% of right trials, so that one star was reported instead of two on most trials. Remarkably, performance was only slightly better in the RVF than in the LVF (Fisher’s test, $P \leq 0.012$ in S.D. and J.B., $P \geq 0.12$ in E.N. and C.W.; Wilcoxon’s test, $P = 0.18$ for the group). Compared with double displays with dissimilar shapes, errors increased consistently in both fields alike, contralesionally [$P \leq 0.0002$ in each patient except J.B. ($P \geq 0.99$); $P = 0.068$ for the group] as well as ipsilesionally ($P \leq 0.0005$ in E.N. and C.W., $P \geq 0.16$ in S.D. and J.B., $P = 0.14$ for the group). A similar pattern was observed for bilateral double displays, for which all patients were worse at reporting two stars than one on either side (11–12 and 6–12 missed versus 7–10 and 0–3 missed out of 12 trials in LVF and RVF, respectively) (Fig. 5A, lower right graph).

Table 3 Quantitative indexes of attentional selectivity and capacity

	Patient			
	S.D.	E.N.	C.W.	J.B.
Between fields				
Ipsilateral capture by distractors				
Single displays	0.57	0.69	0.89	0.20
Double displays	0.90	0.75	1	0
Within fields				
Distractor costs				
LVF cost	0.11	0.10	-0.13	0.68
RVF cost	0.25	0.10	-0.30	0.04
LVF/RVF ratio	0.44	1	0.43	15
Target costs				
LVF cost	1	0.8	1	0
RVF cost	0.33	0.8	1	0.09
LVF/RVF ratio	3	1	1	0

For between-field measures, high values of ipsilesional capture by distractors indicate greater attentional selectivity; for within-field measures, high cost values of distractors indicate less selectivity.

Thus, except in the case of J.B., detecting a second concurrent target required more attention than rejecting a concurrent triangle distractor. Moreover, extinction within the left and right fields in the presence of two targets was generally as great as extinction between fields with a target on each side.

Again, this suggests some selectivity in the allocation of attention, as well as a limited capacity for its deployment to two concurrent targets irrespective of field. If spatial attention has to be distributed equally between distractors and targets to discriminate their shapes, so as to identify targets and reject distractors, a star should be missed just as often when accompanied by a triangle on the same side as when accompanied by a further star. The relative attentional cost of distractors and targets was therefore evaluated more precisely for each hemifield and each patient. We calculated an index of 'distractor cost' as the difference in accuracy for one star presented alone and one star presented with a triangle on the same side, divided by the former. Lower values (close to zero) indicate that the distractor has no cost, while values close to 1 indicate greater cost and diversion of attention in favour of distractors. Likewise, a 'target cost' was calculated as the difference in accuracy for one star with a triangle and two stars on the same side, divided by the former. Lower values indicate no differential cost of a second target relative to a distractor, while higher values indicate greater cost for target detection than distractor rejection.

Table 3 shows that, except for J.B., distractor costs were weak (close to or below zero) and similar in the two hemifields [paired $t(3) = 0.99$, $P = 0.2$, one-tailed], indicating a small 'weight' of distractors and no gross asymmetry between contralesional and ipsilesional sides in the relative distribution of attention to targets and non-targets. However, individual LVF/RVF ratios of these costs suggest that distractors diverted exactly the same amount of attention capacity on each side in one patient (ratio = 1 in E.N.), but

somewhat less attention to the left in S.D. and C.W. (ratio < 1) and much more in J.B. (ratio > 1). Across the four patients, LVF/RVF ratios strongly correlated with the number of omissions in the cancellation test ($r^2 = 0.99$, $P = 0.04$; Kendall's rank test) (Fig. 6C) but not with deviation on line bisection ($r^2 = 0.18$). By contrast, target costs were substantial (close to 1) in both visual fields (Table 3) and not significantly different between the two sides [$t(3) = 0.82$, $P = 0.24$, one-tailed], with individual LVF/RVF ratios indicating a disadvantage of left targets only in S.D. (ratio ≥ 1). This suggests that the ability to attend to a second star once a first star had been detected was bilaterally impaired, though not particularly more in the contralesional than the ipsilesional hemifield. Further, LVF/RVF ratios of target costs showed no relation with omissions on letter cancellation ($r^2 = 0.45$) or deviation on line bisection ($r^2 = 0.07$).

These findings were replicated in an additional session of this task (two blocks) given to one patient (S.D.) with stimuli presented for 150 ms in order to improve her detection of one target (0 and 2% missed on right single and double displays, 17 and 23% missed on left single and double displays, respectively). In bilateral trials, a left-side star was extinguished in 67% of single and 55% of double displays with a right-side triangle, but in 91 and 100%, respectively, with another right-side star. In unilateral trials, a second star was missed in 67% of right and 83% of left double displays with two stars.

Comparison of between- and within-field performance. This comparison further demonstrates the different allocation of attention to targets and non-targets. The effect of distractors on performance showed a clear lateral bias between fields, such that a left star was missed much more often with a triangle in the opposite RVF (bilateral single displays) than in the same LVF (left double

left displays; mean increase in misses rate = 27.1%, range 4–42%). But the effect of a second target showed no consistent lateral bias: a second star on the left was missed as often with another star in the RVF (bilateral single displays) as with another star in the LVF (left double displays; mean difference in rate of misses = -1.6%, range -12% to +8%).

Vocal reaction time

Patients were much slower to report no star than one star (mean 1816 versus 1117 ms; $P < 0.001$ for the group). Since two stars were detected rarely, these trials are not analysed here. Correct 'one' responses (Fig. 6C) were slower in the LVF than in the RVF (mean 1245 versus 993 ms) and were delayed by distractors in the opposite field (mean 1079 versus 1145 ms), even in the case of RVF targets with LVF distractors. Overall, these four types of trial (left or right target, with or without opposite distractors) differed reliably [$\chi^2(3) = 16.7$, $P \leq 0.001$; Friedman's rank ANOVA], with a strong effect of target side ($P = 0.0005$, *post hoc* paired comparison) and a milder effect of opposite distractors ($P = 0.015$). Distractors in the LVF significantly delayed RTs compared with a single target in the RVF (mean 1081 versus 931 ms, $P = 0.036$) but not compared with distractors in the same RVF (mean 1018 ms, $P = 0.9$).

RTs were much slower on the few correct bilateral trials with two targets than with two different shapes (mean 1565 versus 1162 ms, $P = 0.011$). Bilateral trials with two targets but left extinction (mean 1276 ms) differed from trials with a right target (mean 931 ms; $P = 0.025$; Wilcoxon's test for the group) but not consistently from those with a right target and left distractors except for E.N. (mean 1066 ms, $P = 0.07$) (Fig. 4B).

Discussion

This study provides several important findings about visual extinction and impaired attentional mechanisms following right hemisphere damage. Simple changes in instructions produced a different pattern of performance across tasks in all patients, although stimuli and duration exposure remained the same. To sum up, patients extinguished many contralesional stimuli in bilateral displays when reporting their location (Experiment 1) but not when counting them regardless of location and shape (Experiment 2). In that condition, however, they often detected only one of two stimuli within the contralesional hemifield. Similarity of shapes across fields was not relevant in either task and did not affect extinction in Experiment 2, while it moderately improved performance in Experiment 1. In contrast, when counting and discriminating stars among other irrelevant shapes (Experiment 3), patients extinguished many contralesional targets, and similarity of shapes worsened performance: left extinction increased when there was a second star rather than irrelevant triangles on the right side. Moreover, a second star was often missed even in unilateral

displays with two targets within either the contralesional or the ipsilesional field. Symmetry of position of the stimuli across fields did not affect performance overall.

A disorder of attention modulated by task demand and stimulus relevance

These findings show that visual extinction can be strongly influenced by the task-defined perceptual set and relevance of stimuli. This clearly supports a deficit of attention rather than weakened sensory inputs to the contralesional field (Baylis *et al.*, 1993; Ward *et al.*, 1994) and appears to be consistent with other evidence showing little effect of the physical characteristics of contralesional stimuli (Di Pellegrino and De Renzi, 1995; Smania *et al.*, 1996).

First, contralesional extinction differed markedly between enumeration and localization (Experiments 1 and 2), being much more severe when patients reported stimuli on both sides compared with when they reported two or four stimuli in the same bilateral displays. This is difficult to reconcile with a primary sensory disorder because the stimuli were identical and both tasks required the detection and individuation of simultaneous visual events in the two fields. Fatigue or habituation effects are unlikely, as the task order was alternated across patients and sessions. Also, worse performance on unilateral double displays in the LVF for enumeration than for localization and differences in the pattern of RTs suggest that enumeration was not just an easier task.

Secondly, in the discrimination task (Experiment 3), extinction was influenced by the relevance of the stimuli: a left star was less likely to be missed when there was an irrelevant distractor (triangle) in the RVF rather than when there was another star drawing attention to that side. While this task presumably required a greater focusing of attention that is susceptible to exacerbate contralesional neglect (Rapcsak *et al.*, 1989; Kaplan *et al.*, 1991), the visual identification of a right-side star in itself should not be more demanding than that of a right-side triangle and should therefore not affect extinction of left-side targets. Indeed, star and triangle shapes were equally well detected in the two other experiments. Therefore, relevance to the task appeared to be critical and capable of modulating to some extent the allocation of attention between fields selectively to target stimuli as opposed to irrelevant ones. One notable exception to this, however, concerned patient J.B., who had a larger brain lesion (discussed below).

These findings are not entirely accounted for by current attentional theories that explain extinction by failure of the ability of the right hemisphere to control attention to both sides of space (Heilman *et al.*, 1993) or release of the left hemisphere contraversive orienting bias (Kinsbourne, 1987). It is unclear why these models would assume different residual capacity or different hemispheric bias for orienting to contralesional stimuli when a task requires the reporting

of location rather than number, or when there is a given shape (star) rather than another (triangle) in the right hemifield.

These findings demonstrate that spatial attention is not diverted to ipsilesional stimuli in a purely automatic bottom-up way, even in patients with extinction. A given task set may determine a different allocation of attention to physically similar stimuli both in subjects with neglect (Bisiach *et al.*, 1989; Baylis *et al.*, 1993; Smania *et al.*, 1996) and in normal subjects (Folk *et al.*, 1992; Baylis and Driver, 1993; Folk and Remington, 1998). For instance, extinction increases when contralesional stimuli are similar to ipsilesional ones on a dimension that must be attended (e.g. letters of the same colour regardless of their shape if reporting colours, or vice versa) while similarity on an irrelevant dimension has no effect (Baylis *et al.*, 1993). These observations and others (Volpe *et al.*, 1979; Berti *et al.*, 1992) imply that the visual processing of unattended stimuli may proceed to the point where shape and colour attributes, as well as categorical information, are extracted and interact across fields. Likewise, when patients extinguished a left stimulus in the location task, their latency to respond 'right' was longer than in true unilateral right trials, indicating that ignored stimuli were nonetheless processed by the visual system (Mijovic-Prelec *et al.*, 1994; Di Pellegrino and De Renzi, 1995). Some information from the left field remained unavailable for attention and conscious perception in the location task but was available in the enumeration task. RTs in the discrimination task also suggest that contralesional distractors were processed even in the presence of an ipsilesional target, so as to delay responses compared with a single ipsilesional target as much as distractors within the ipsilesional field. Attentional selection and extinction therefore appear to operate on the product of substantial processing in extrastriate visual areas (Rafal, 1994; Driver, 1995).

Localization and enumeration

At least three factors may contribute to the dissociation between localizing and enumerating. Note that we do not imply that enumeration cannot yield visual extinction under different experimental conditions, as this was actually found in other studies that required patients to report one versus two targets without explicit instructions to attend to the side of presentation (e.g. Gilchrist *et al.*, 1996), including a study with one of the patients (S.D.) reported here (Danziger *et al.*, 1998). However, location and enumeration response modes may be confounded in some studies because patients can rely on one or the other depending on the task, or report stimuli on both sides when in fact they detect two and infer their location, given that there is no alternative in a typical experiment with single targets in either one or both fields and no double targets on the same side, unlike in our experimental design. Our results suggest rather that localizing and counting visual stimuli differ in some critical ways in regard to attentional mechanisms (Vuilleumier and Rafal, 1999).

A first possible account of poorer performance in localization might be that patients misperceived left-side stimuli rightwards in bilateral trials, as in allaesthesia (Denny-Brown *et al.*, 1952; Di Pellegrino and De Renzi, 1995). This seems unsatisfactory, however, since they never transposed a single unilateral left stimuli to the right or reported a double unilateral left stimulus on both sides. Conversely, allaesthesia might result from a deficient spatial encoding of contralesional stimuli.

A second possibility is a specific impairment in attending to location. Attentional mechanisms depending on the right parietal lobe may operate on the basis of spatial coordinates and explicit location information might be crucial for selective vision and awareness (Rizzolatti and Berti, 1990; Friedman-Hill *et al.*, 1995). There is extensive evidence that attention can be directed to stimuli on the basis of their spatial location (Eriksen and Yeh, 1985; Posner and Petersen, 1990), though it can also be directed on the basis of object and feature representations such as shape, colour and motion (Duncan, 1984; Driver and Baylis, 1989). Although these two mechanisms must interact (Driver *et al.*, 1992; Vecera and Farah, 1994), spatial location might make a unique contribution to selective visual processing (Treisman and Gelade, 1980; Robertson *et al.*, 1997), as shown by the fact that attending to any property of a stimulus (e.g. its colour or shape) necessarily draws attention to its location in space (Tsal and Lavie, 1988, 1993; Cave and Pashler, 1995). Neurons in the posterior parietal lobe of monkeys show activity that is tuned to the location of salient or relevant stimuli (Andersen, 1995; Steinmetz and Constantinidis, 1995; Gottlieb *et al.*, 1998), and parietal areas might provide spatially based gating or binding mechanisms that are necessary for the selection of information processed in ventral visual areas (Luck *et al.*, 1997). Parietal damage could preclude the explicit encoding of location of contralesional stimuli for directing attention to them for access to awareness and related action (Rizzolatti and Berti, 1990; Andersen, 1995). However, locations could still be tagged implicitly outside attention after parietal damage (Robertson *et al.*, 1997; Danziger *et al.*, 1998), possibly through other subcortical representations of space.

A third possibility is that enumeration confers a specific advantage in detecting contralesional stimuli, perhaps without explicit location information. Findings in normal subjects suggest that the rapid enumeration of up to four visual elements [an ability called 'subitizing' (Kaufman *et al.*, 1949)] may not require spatial attention, unlike the enumeration of more elements (called 'counting'), which requires serial attentive scanning (Mandler and Shebo, 1982; Trick and Pylyshyn, 1993, 1994). Thus, enumeration accuracy and response latency are relatively independent of the number of stimuli for one to three items and increase linearly for more than four (Atkinson *et al.*, 1976; Mandler and Shebo, 1982). Because subitizing occurs when stimuli do not call for spatial attention (e.g. pop-out targets in a search task, such as Os among Xs) but not otherwise (e.g. conjunction targets, such

as Os among Qs) (Trick and Pylyshyn, 1993, 1994), it may rely on mechanisms of visual parsing and grouping that operate automatically independently of spatial attention (Sagi and Julesz, 1984; Trick and Pylyshyn, 1993, 1994), as well as on the recognition of familiar configurational patterns (Mandler and Shebo, 1982; but see Aktinson *et al.*, 1976). Preattentive parsing and grouping mechanisms occur at early stages of visual processing in extrastriate areas (Spillman and Werner, 1996) and can still operate in the neglected field of patients with parietal damage (Driver *et al.*, 1992; Driver, 1995; Mattingley *et al.*, 1997; Vuilleumier and Landis, 1998). Further, patients with bilateral parietal damage and Balint syndrome, who usually fail to perceive more than one object (simultanagnosia), may show relatively good subitizing ability for one, two and sometimes three items in the face of a severe counting deficit when there are more than three items (Dehaene and Cohen, 1994). Therefore, subitizing mechanisms based on parallel processes that can individuate and group a small set of candidate objects prior to spatially directed attention could explain the preserved enumeration of bilateral items in our patients. In this task, bilateral stimuli might have been preattentively grouped together in a numerable set and thus survive extinction. In support of this, enumeration RTs were as fast for bilateral as for unilateral right stimuli even though they were clearly slower for unilateral left stimuli, indicating facilitated rather than inhibited detection of contralesional stimuli by ipsilesional ones. By contrast, localization responses were as slow for bilateral as for unilateral left stimuli compared with unilateral right stimuli, indicating that contralesional and ipsilesional stimuli were attended to individually. Our findings are therefore consistent with a role of preattentive visual processes in subitizing (Dehaene and Cohen, 1994; Trick and Pylyshyn, 1993, 1994) and converge with the recent demonstration that extinction is reduced when bilateral stimuli form a good perceptual group on the basis of Gestalt principles, such as symmetry, closure and good continuity (Driver *et al.*, 1992; Ward *et al.*, 1994; Driver, 1995; Gilchrist *et al.*, 1996). Similarly, neglect patients tend to miss more left-sided letters in a word when they must process the letters separately in order to count them, compared with when they automatically process the letters as a single group to read the word aloud (Humphreys, 1998). Overall, these findings are consistent with the existence of distinct, task-dependent forms of spatial coding which can use between-object or within-object representations, the former being impaired but the latter still intact after parietal damage (Humphreys, 1998).

However, our patients were impaired in enumerating more than one stimulus in the contralesional hemifield. Extinction on double stimulation within a field has been reported previously, but only for the leftmost of horizontal pairs of stimuli (Kinsbourne, 1987; Smania *et al.*, 1996). This deficit seems problematical for the traditional view that subitizing involves only automatic and parallel mechanisms that are entirely independent of spatial attention and the coding of location, because enumeration of two items should then

be preserved both across and within hemifields. Worse enumeration within the contralesional field than across fields might be consistent with a lack of explicit encoding of spatial location on this side, precluding the individuation of two distinct stimuli when both fall on the left. Alternatively, it might indicate a limitation in preattentive parsing mechanisms for individuating more than one candidate object on this side or a limited serial component in these processes, including subitizing (Folk *et al.*, 1988). Although most investigators have emphasized a flat slope in RTs and errors when enumerating small quantities relative to a steeper linear increase with greater numbers, others have pointed out that the slope value is not zero and enumeration time not constant over the subitizing range, suggesting the existence of at least partly serial processing in numerosity judgements even for fewer than three items (Folk *et al.*, 1988; Balakrishnan and Ashby, 1991). Further studies should investigate whether such a deficit of individuation on the left side may stem from impaired spatial attention within the contralesional field (Baynes *et al.*, 1986) or contribute to defective orienting towards contralesional stimuli. Indeed, difficulty in individuating more than one object and encoding their location on both sides is the hallmark of bilateral attentional defect in Balint syndrome (Robertson *et al.*, 1997). Even though Dehaene and Cohen showed that subitizing ability is relatively preserved in these patients compared with counting, this held mostly for detecting 1 versus 2 brief simultaneous stimuli, and their study did not compare within- and between-field presentations (Dehaene and Cohen, 1994).

Discrimination and attention selectivity

In the discrimination task, the relevance of a specific feature (e.g. shape) modulated contralesional extinction and favoured attention to targets over distractors, suggesting that top-down influences based on current goals were preserved. One exception to this concerned patient J.B., whose lesion was larger than in other patients and included the entire frontal lobe. He also had a visual field defect and more severe neglect. Notably, we found that a measure of ipsilesional capture of attention by distractors, reflecting poorer top-down influence on attentional selection, correlated reliably with neglect severity on a cancellation test in each patient (whereas the total rate of extinction of left stimuli did not). Differential allocation of attention to targets and non-targets was also observed when both shapes were within the same hemifield. One star was almost as likely to be detected with a triangle on the same side as when it was alone, even though the capacity to identify two simultaneous stars was impaired, suggesting that less attention is drawn to the rejection of a distractor than to the recognition of a second target, irrespective of hemifield. Here too, the only exception was patient J.B., who showed a higher cost of distractors, i.e. poorer selectivity, in his contralesional field. As for ipsilesional capture by distractors, we found that the left-right asymmetry in distractor costs, reflecting weaker selectivity in

the left than in the right hemifield, correlated reliably with neglect severity on cancellation in each patient. This finding supports the view that extinction participates in impaired attentional mechanisms of spatial neglect, and further suggests that a deficit in top-down control may contribute to this complex syndrome in some patients. By contrast, target costs showed no significant left–right asymmetry and no relation to neglect severity, producing as much competition between as within fields.

We speculate that the pervasive lack of top-down influence in J.B. reflects his extensive right prefrontal damage. Neglect on the cancellation task is more sensitive to distractors in patients with frontal rather than parietal lesions (Husain and Kennard, 1997), and Ladavas and colleagues noted a dissociation between impaired voluntary and automatic orienting of attention after frontal and parietal damage, respectively (Ladavas *et al.*, 1994). Several accounts of normal visual searching postulate that top-down control over attentional orienting might be subserved by prefrontal functions related to working memory (Duncan and Humphreys, 1989; Bundesen, 1990; Folk *et al.*, 1992; Desimone and Duncan, 1995). Neurophysiological findings in monkeys suggest that frontal neurons carry signals indicating current relevant information that can enhance the response to the target and suppress the response to irrelevant stimuli in extrastriate visual areas (Chelazzi *et al.*, 1993; Rainer *et al.*, 1998).

Stimulus repetition and attention capacity

Our study helps to clarify contradictory findings about the role of stimulus similarity in extinction and further extends them. Ward and colleagues suggested that similarity of contralesional and ipsilesional stimuli may reduce extinction because of grouping mechanisms in a task that requires detection and localization, but not identification (Ward *et al.*, 1994). By contrast, using a task that required both localization and identification, Baylis and colleagues suggested that similarity increases extinction because of an abnormal difficulty in creating distinct representations for objects that share the same features (Baylis *et al.*, 1993). Here, we found that when shape identity was not relevant to the task, similarity decreased extinction in the location condition or had no effect in the enumeration condition. But in the discrimination task, similarity exacerbated extinction, suggesting that a repetition effect arises only when features (e.g. shape) must be identified. Further, difficulty in individuating two identical objects occurred not only across fields but equally within the same field, contralesionally or ipsilesionally. All patients failed to detect two concurrent stars whatever their location in space. In this task, the effect of stimulus similarity corresponded to target–distractor assignment, suggesting a problem in selecting multiple targets, which arises only when target stimuli must be discriminated from distractor stimuli based on their features, and not because of feature similarity *per se*, as shown by the

lack of effects in our other tasks or even beneficial grouping effects in other studies.

Given that our patients had relatively little difficulty in detecting a target presented with a distractor, this ‘double target cost’ suggests a limitation of attention that cannot be attributed to processes that discriminate targets from distractors (Duncan, 1980; Pashler, 1998). Although a deficit in explicit spatial coding might prevent individuation of identical objects that differ only in their location (Dehaene and Cohen, 1994; Ward *et al.*, 1994), this seems an unsatisfactory account for misses of a second target in the ipsilesional hemifield, since location tags should be preserved on that side. These findings suggest rather a capacity limit similar to that in normal attention, albeit to a much more severe degree. It is known that (i) dividing attention between two concurrent targets produces substantial costs in performance, while non-targets produce much less interference (Duncan, 1980; Treisman and Gelade, 1980), and (ii) identifying a visual target impairs detection of another for several hundred milliseconds (‘dwell time’) even at the same location (Duncan *et al.*, 1994). Although the underlying mechanisms of these effects are still unclear (Pashler, 1998), recent studies suggest that neglect patients have non-lateralized impairments in the capacity (Karnath, 1988; Robertson, 1989) and the temporal dynamics of attention, including an abnormally protracted dwell time (Husain *et al.*, 1997). In keeping with this, bilateral deficits are common in neglect on tasks that require fine visual discrimination, such as search or cancellation tests (Weintraub and Mesulam, 1987; Robertson, 1989; Kaplan *et al.*, 1991; Chatterjee *et al.*, 1992; Cassidy *et al.*, 1998). A bilateral deficit in the processing rate of visual stimuli has also been demonstrated in patients with unilateral neglect by the use of a partial report paradigm with multiple-element displays similar to our discrimination task (Duncan *et al.*, 2000). Parietal function may play a critical role in shifting the focus of attention once it is engaged on a visual object, not only towards contralateral locations in space (Posner *et al.*, 1984, 1987; Posner and Petersen, 1990) but also towards other object representations that compete for selective visual processing and awareness (Husain *et al.*, 1997; Lumer *et al.*, 1998). Therefore, in addition to causing spatial bias towards objects in the ipsilesional field, parietal damage might impair the efficient coordination of gating or binding influences on ventral extrastriate visual areas which mediate object representations (Chelazzi *et al.*, 1993; Desimone and Duncan, 1995) and impair flexible switching of attention between concurrent objects irrespective of their locations.

Conclusion

Our study shows that the spatial allocation of attention is modulated by the goals of the task and the relevance of the stimuli. While preattentive visual processes may allow the individuation, grouping and enumeration of a small set of items across fields without attending to individual stimuli, location information may play a critical role in the parietal

mechanisms of attention that affect visual processing in extrastriate areas and in the pathological competition for awareness encountered in extinction. Extinction also entails a non-lateralized deficit in attending to two concurrent objects when their features must be identified. Loss of frontal top-down control might further contribute to neglect in search behaviour. In keeping with other findings (Karnath, 1988; Robertson, 1989; Rafal, 1994; Husain *et al.*, 1997), these results show that visual extinction and neglect involve a multicomponent breakdown in attentional mechanisms.

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