

"Both" means more than "two": localizing and counting in patients with visuospatial neglect

P. Vuilleumier and R. Rafal

Department of Neurology, University of California, Davis and Veterans Administration Medical Center, VANCHS, 150 Muir Road, Martinez, California 94553, USA

Correspondence should be addressed to P.V. (patrick@ebire.org)

We report that in patients with hemispatial neglect after parietal damage, visual awareness critically depends on different attentional demands for enumeration or localization. Neglect patients usually fail to attend to stimuli in the hemifield contralateral to the lesion (contralesional) and 'extinguish' them when simultaneously presented with competing stimuli ipsilateral to the lesion (ipsilesional), even though primary visual pathways are intact, and a contralesional stimulus presented alone is detected. Here we show that contralesional extinction differed when patients enumerated or located stimuli in space. Enumerating only a few (≤ 4) visual elements may exploit 'subitizing' mechanisms independent from spatial attention (unlike 'counting' of more elements), as is the case in normal people¹.

Three patients (SD, EN and CW) with chronic right parietal lesions due to stroke, intact visual fields and mild signs of left neglect (for instance, in line bisection and cancellation tasks) were given two different tasks using the same stimuli and exposure duration in each case. Shapes were briefly presented in one, two or four possible locations (Fig. 1a). In single displays, one shape appeared unilaterally (in right or left hemifield) or bilaterally (in both fields); in double displays, two shapes appeared unilaterally or bilaterally. The location task required the patients to report where shapes appeared (on "right", "left" or "both" sides). The enumeration task required reporting how many shapes appeared ("one", "two" or "four") without having to localize them. The response set was thus similar (three correct answers or "none" for occasional misses). Only instructions differed, and all other conditions remained unchanged. Shape (star or triangle) was irrelevant in both tasks. The subjects signed informed consent statements approved by the Institutional Review Board of the Martinez Department of Veterans Affairs and the University of California, Davis.

In the location task (Fig. 1b), patients extinguished many left-side stimuli in both single (45–67%) and double (27–52%)

bilateral displays, but missed only a few more unilateral stimuli in the left visual field (LVF; 6–11%) than in the right (RVF; 0–3%; $t_2 = 2.8$, $p = 0.052$, one-tailed). All performed better on double than single unilateral left displays (0–3% versus 9–21% missed). Bilateral and unilateral left trials significantly differed for both display types ($t_2 = 3.8$ and 5.4 , respectively, $p = 0.031$ and 0.016 , one-tailed). By contrast, in the enumeration task (Fig. 1c), although the exact same stimuli were shown (and although saying "two" for a bilateral display, for example, may intuitively seem not different from saying "both"), the patients extinguished very few left stimuli in bilateral trials with single (5–16%) or double (0–5%) displays. They detected "two" shapes across fields as well as "one" on the left in single displays ($t_2 = 0.25$, $p = 0.41$, one-tailed), and "four" even better than "two" on the left in double displays ($t_2 = 6.9$, $p = 0.021$, two-tailed), perhaps because they sometimes inferred "four" when they actually saw three.

Direct comparison of the two tasks clearly demonstrated that contralesional extinction was worse for the same displays when reporting stimuli on "both sides" rather than "two" or "four" stimuli ($t_5 = 6.4$, $p = 0.001$, two-tailed). A 2×2 ANOVA on the number of left misses showed a reliable effect of the task

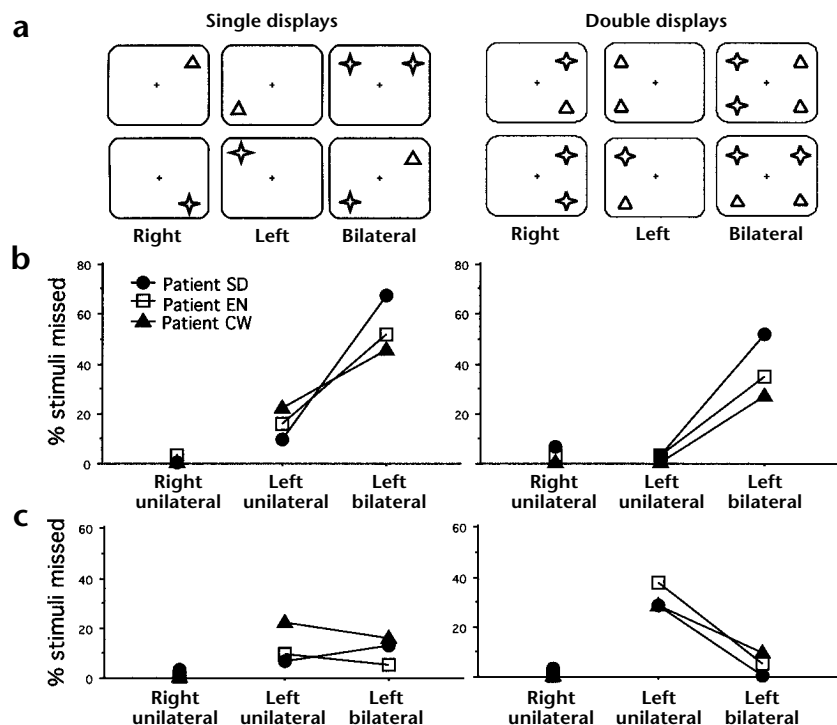


Fig. 1. Stimuli and results in both tasks. **(a)** Black shapes (1.7°) were presented $\sim 8^\circ$ away from fixation on a blank computer screen. Display types (single versus double; unilateral versus bilateral) and shape arrangements (upper versus lower position; same versus different shapes) were equiprobable. Each task was given in two blocks of 128 trials (randomized) in a counterbalanced order in two sessions. Stimuli duration was set during a practice phase so as to obtain a reliable rate of extinction while avoiding floor and ceiling effects, and then kept constant in each patient across tasks and sessions (50 ms in SD; 25 ms in EN; 100 ms in CW). **(b)** Localization. More left stimuli were missed in bilateral than unilateral left trials, indicating marked extinction in all cases. Extinction slightly worsened with different rather than same shapes on the right and left sides in single (50–78% versus 41–56%) but not double displays (25–56% versus 21–50%). In bilateral single displays, extinction was not affected by the shapes' arrangement (horizontal versus diagonal) but was slightly worse for lower than upper left stimuli (not shown). **(c)** Enumeration. Left stimuli were reported on bilateral trials as well as on unilateral left trials in single displays and detected even better in double displays, indicating no extinction by competing ipsilesional stimuli. Symmetry, arrangement or position of the shapes had no effect (not shown). In all patients, extinction rate differed between tasks ($p < 0.0005$ and $p < 0.01$ by Fisher's exact test for single and double displays, respectively).

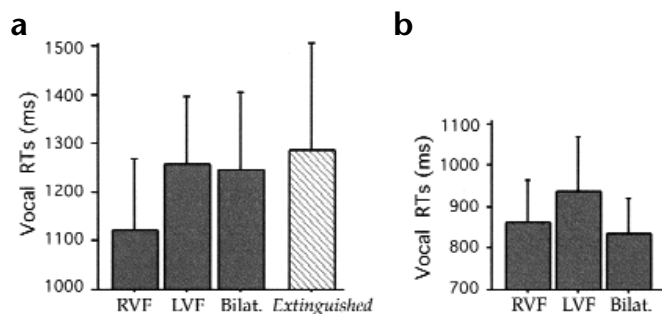


Fig. 2. Vocal response latencies across patients and displays (mean \pm s.e.). **(a)** Localization. Correct responses were slower on bilateral (580–1689 ms) and unilateral left (690–1573 ms) trials compared to unilateral right trials (520–1548 ms; $\chi^2_2 = 9.6$, $p = 0.022$, Friedman's rank analysis of variance; left and bilateral versus right, $Z \geq 2.2$, $p \leq 0.028$, paired Wilcoxon's rank test). Extinction responses were also slowed (575–1751 ms), indicating implicit processing of contralesional stimuli unavailable to awareness. **(b)** Enumeration. Correct responses were slower on unilateral left (596–1315 ms) but not bilateral trials (558–1046 ms) compared to unilateral right trials (540–1164 ms; $\chi^2_2 = 4$, $p = 0.13$; left versus right, $Z = 1.8$, $p = 0.058$; bilateral versus right, $Z = 0.3$, $p = 0.75$).

($F_{1,8} = 15.2$, $p = 0.001$) but little effect of the display size (single versus double targets; $F_{1,8} = 4.7$, $p = 0.06$) and no interaction ($F_{1,8} = 1.0$). The difference between tasks was found in each patient and was unlikely to have resulted from fatigue or habituation because the task order was alternated across sessions. It is also unlikely to have resulted from enumeration being easier or patients adopting different guessing bias. In both tasks, they admitted seeing "none" on a similar number of single left targets ($t_2 = 1.7$, $p = 0.23$).

Voice response latencies also suggest qualitative differences between tasks, whereby enumeration facilitated rather than disadvantaged perception of contralesional stimuli in bilateral displays. Although correct responses were slower for left than for right unilateral trials in both tasks, responses on bilateral trials were delayed for localization but not for enumeration (Fig. 2). Moreover, in contrast to localization, enumeration deteriorated in the LVF for double displays in all three patients, who missed more stimuli in these displays (28–37%) than single targets (6–22%) and often reported "one" instead of "two" shapes ($t_2 = 2.9$, $p = 0.050$). Whether shapes were identical (two triangles or two stars) or different (one triangle and one star) had no effect. Enumerating two shapes was thus better across fields than within the LVF (Fig. 1c). There was no difference between "one" or "two" shapes in the RVF (0–9% versus 0–6% missed).

These findings demonstrate that counting or localizing a small set of objects made different demands on visual attention, although this does not imply that extinction cannot occur in other experimental tasks requiring subjects to enumerate "one" versus "two" lateral targets (see refs. 2, 3). As both tasks required detecting simultaneous events in each field, why did contralesional stimuli receive less weight in competing for attention when patients reported their location and said "both" as compared to when they reported their number and said "two" or "four"? Was localizing or counting—or both—the special task? Response times suggest that enumeration allowed linkage rather than competition between bilateral stimuli, whereas localization emphasized differentiation and attention to individual items. Changing the task goals could thus facilitate the detection of contralesional items in bilateral displays, somehow grouped with ipsilesional ones in a single numerable percept. Seeing "two" items may not mean seeing "one" twice but "one set of two", whereas "both" indeed means "one on the right and one the left". Accordingly, subitizing abilities for the enumeration of small quantities may not require spatial attention but may instead rely on parallel visual mechanisms of

parsing and grouping^{1,4} that still operate in the neglected field^{2,5,6}. However, classic models of attentional competition and subitizing do not entirely explain impaired enumeration of two stimuli in the contralesional field⁷. Why should attention to a contralesional item suffer more from another contralesional item than from a stronger ipsilesional competitor? There may be a limited or serial component contributing to preattentive subitizing mechanisms⁸. Alternatively, loss of location information on the contralesional side might preclude awareness of two distinct stimuli when both fall within the left field but not when only one does. Although location can be registered implicitly outside attention after parietal damage^{3,9}, explicit spatial encoding of stimuli may be critical in parietal-lobe mechanisms directing attention for conscious awareness and subsequent action¹⁰.

Attentional mechanisms allow the brain to regulate sensory inputs and select, or exclude, information reaching awareness. Our findings demonstrate that, in addition to the nature of stimuli and gestalt principles^{2,11–13}, competition or linkage for spatial attention can be determined by the nature of the task^{14,15}, and these influences seem intact in parietal-lesion patients.

ACKNOWLEDGEMENTS

This work was supported by a Swiss National Science Foundation grant to PV (81-GE-50080) and a US PHS grant to RR (RO1 MH 41544).

RECEIVED 20 JANUARY; ACCEPTED 20 JULY 1999

- Trick, L. M. & Pylyshyn, Z. W. *J. Exp. Psychol. Hum. Percept. Perform.* **19**, 331–351 (1993).
- Gilchrist, I. D., Humphreys, G. W. & Riddoch, M. J. *Cognit. Psychol.* **13**, 1223–1249 (1996).
- Danziger, S., Kingstone, A. & Rafal, R. D. *Psychol. Sci.* **9**, 119–123 (1998).
- Dehaene, S. & Cohen, L. *J. Exp. Psychol. Hum. Percept. Perform.* **20**, 958–975 (1994).
- Mattingley, J. B., Davis, G. & Driver, J. *Science* **275**, 671–674 (1997).
- Vuilleumier, P. & Landis, T. *Neuroreport* **9**, 2481–2484 (1998).
- Bundesen, C. *Psychol. Rev.* **97**, 523–547 (1990).
- Folk, C. L., Egeth, H. & Kwak, H. *Percept. Psychophys.* **44**, 313–320 (1988).
- Robertson, L., Treisman, A., Friedman-Hill, S. & Grabowecy, M. *J. Cognit. Neurosci.* **9**, 295–317 (1997).
- Rizzolatti, G. & Berti, A. *Rev. Neurol. (Paris)* **146**, 626–634 (1990).
- Fryklund, I. *Percept. Psychophys.* **17**, 375–386 (1975).
- Ward, R., Goodrich, S. & Driver, J. *Vis. Cognit.* **1**, 101–129 (1994).
- Baylis, G. C. & Driver, J. *J. Exp. Psychol. Hum. Percept. Perform.* **19**, 451–470 (1993).
- Vuilleumier, P., Valenza, N., Perrig, S., Mayer, E. & Landis, T. *J. Int. Neuropsychol. Soc.* **5**, 75–82 (1999).
- Baylis, G., Rafal, R. & Driver, J. *J. Cognit. Neurosci.* **5**, 453–466 (1993).