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Increased attentional demands impair contralesional space awareness following stroke

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ABSTRACT

Rate and severity of contralesional loss of awareness following stroke is highly variable across patients and assessment methods. We studied whether the degree of impairment for contralesional space awareness depends on the quantity of attentional resources that are available for task performance. A new computer-based paradigm was used to assess visual extinction and single-target detection rate in four right hemisphere stroke patients. In the single-task condition, they had to report only the position of the target(s) ("right", "left", or "both" sides). In the dual-task conditions, patients also performed a second task, visual or auditory, that recruited additional attentional resources. The same tasks were also performed by healthy controls and by a left hemisphere stroke patient. Patients' performance was apparently unimpaired in the single-task condition. In contrast, dramatic failures to report the left-sided target emerged in the dual-task conditions. The performance of control participants was unaffected by the dual-task manipulation, whereas the left stroke patient showed the opposite pattern (i.e., unawareness of right-sided targets). Severe contralesional space unawareness under dual-task conditions reveals that visuospatial deficits can dramatically emerge when attentional resources are consumed by a concurrent task. Apparently spared contralesional awareness may simply reflect the availability of resources that are just sufficient to perform a single-task. This finding has important implications for the assessment of contralesional space awareness following stroke, because everyday life activities are often more demanding than most of the tests adopted for diagnosing space awareness disorders.

1. Introduction

Deficits of contralesional space awareness (neglect and extinction) frequently follow right hemisphere stroke and result in the disruption of the neural and cognitive systems subserving the orienting of spatial attention (Driver & Vuilleumier, 2001). Extinction patients are typically unaware of a contralesional stimulus when simultaneously presented with another stimulus in the ipsilesional hemispace, whereas neglect patients are unaware even of a single contralesional stimulus. Both extinction and neglect index a failure in attending to the contralesional space and are an important source of information about the competitive processes underlying orienting of spatial attention and, thus, of contralesional space awareness (Karnath, 1988; Làdavas, Menghini, & Umiltà, 1994; Làdavas, 1990; Mattingley, Davis, & Driver, 1997).

Rate and severity of contralesional space unawareness following stroke is highly variable across patients and assessment methods. Also the higher incidence of contralesional space unawareness following right with respect to left hemisphere stroke is somehow controversial (Becker & Karnath, 2007; Stone, Halligan, & Greenwood, 1993). This variability might be particularly high because the performance of extinction and neglect patients depends on the "attentional requirements" of the task adopted for the assessment (Sarri, Greenwood, Kalra, & Driver, 2009). For example, simply requiring to erase instead of marking targets in visual search tasks ameliorates patients' performance (Mark, Kooistra, & Heilman, 1988, see also Làdavas, Umiltà, Ziani, Brogi, & Minarini, 1993).

Contralesional space awareness, as measured by a primary task (e.g., cancellation, bisection, detection, etc.), might also be affected by means of a different experimental manipulation: the deployment of attentional resources for performing a second resource-consuming task. This has been shown, for instance, by increasing perceptual demands at fixation (Russell, Malhotra, & Husain 2004). Crucially for our study, Robertson and Frasca (1992) showed that the performance of left neglect patients in cancellation and reaction time tasks declines when patients are required to execute, in parallel to the primary tasks, a concurrent-task recruiting working memory resources (e.g., counting forward, gen-

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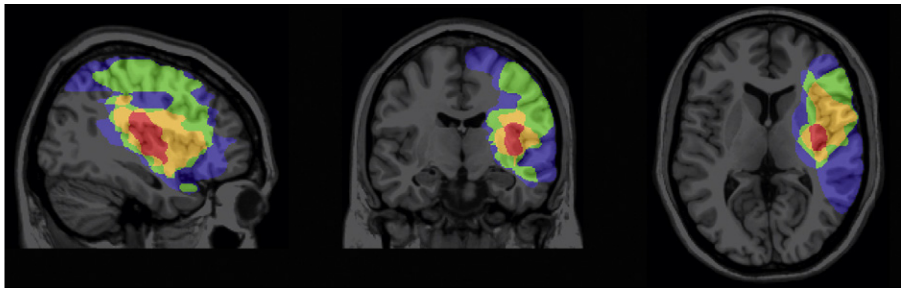

Fig. 1. Overlay plots of the right hemisphere stroke patients' lesions. The number of overlapping lesions is illustrated by four different colours, each coding increasing frequencies of anatomical regions: blue (one patient), green (two patients), yellow (three patients), and red (four patients). The sagittal (left), coronal (center), and transverse (right) sections correspond to MNI coordinates *X*:38, *Y*:−10, and *Z*:7, respectively. Lesions of each patient were mapped using the MRIcro and MRIcron (Rorden & Brett, 2000) softwares and were drawn manually on slices of a T1-weighted template MRI scan from the Montreal Neurological Institute.

erating random numbers, or counting backward in threes from 100). Importantly, Robertson and Frasca described one patient who had symmetric response latencies to stimuli presented to the left or right of fixation when performing a single reaction time task, but showed a left–right asymmetry (i.e., increased reaction times to contralesional stimuli with respect to ipsilesional stimuli) when performed also an attentionally demanding concurrent task (i.e., counting backward in threes from 100). This important finding might induce to think that patients with apparently recovered neglect can, instead, use compensatory recourses to overcome their difficulties, unless a concurrent and resource-consuming task is performed. However, further studies on the clinical relevance of this issue, and aimed at a better specification of what is "task difficulty" are, to our knowledge, overall missing. The idea that performance in dual-task conditions decreases with reference to that in single-task conditions might seem rather obvious, but the issue at stake is whether a second task would specifically disrupt contralesional space awareness.

Moreover, there are no studies on this issue employing a more sensitive measure of contralesional space awareness as, for example, the extinction rate which involves detection not only of single stimuli (i.e., left-sided or right-sided) but also of bilateral stimuli (i.e., left- and right-sided).

We were interested in studying whether the reported variability in the results of different tasks aiming to assess contralesional space awareness might be linked to the possibility for the patients to recruit sufficient attentional resources in order to perform the task at hand. This possibility might also explain the occasional mismatch between normal patients' performance on standard clinical testing of visuospatial disorders, based on paper-and-pencil tests, and impaired patients' performance in everyday life activities (Azouvi et al., 2002). We studied, thus, whether increased demands of attentional resources, generated by a dual-task, could modulate contralesional space awareness as it is indexed by the rates of extinguished or missed contralesional stimuli. The new and crucial issues we addressed here were (a) whether contralesional space awareness could be hindered by a second task that, independently of its nature (i.e., visual vs. auditory), would limit the availability of attentional resources, and (b) whether the effects of a second task on contralesional space awareness might provide useful clinical clues concerning diagnosis and treatment of the above described disorders.

2. Methods

2.1. Participants

The study was approved by an agreement between the University of Padova and the Rehabilitation Centre of Padova Hospital. All participants gave their informed consent to take part in the study, according to the Declaration of Helsinki. Four right hemisphere stroke patients with intact visual fields and time since lesion less than 6 months participated in the study. The first patient we tested, Case 1 (71-year-old female), had left neglect and visual extinction on double simultaneous stimulation. Cases 2–4 were consecutively selected with the same criteria as those of Case 1 (right hemisphere lesion, onset time < 6 months), but with the presence of neglect as exclusion criterion in order to recruit only patients who had mild or no deficits of contralesional space awareness according to standard clinical assessment. Case 2 (61-year-old male) had only mild visual extinction on double simultaneous stimulation, whereas Case 3 (50-year-old female) and Case 4 (56-year-old male) had not visual extinction.

Lesion mapping (see Fig. 1) showed that right hemisphere stroke patients had cortical-subcortical ischemic areas within the territory of the right middle cerebral artery. Maximal overlap was found over the insula and the surrounding white matter. Indeed, focal insular damage to the right hemisphere has been associated with extinction on double simultaneous stimulation (Manes, Paradiso, Springer, Lamberty, & Robinson, 1999). However, our patients presented with very large lesions and, thus, more specific claims regarding anatomic localisation of function may be inappropriate.

The patients were administered a version of the Mini Mental State Examination (MMSE, Magni et al., 1996), a standardised neuropsychological battery (ENB, Mondini, Mapelli, Vestri, & Bisiacchi, 2003), and the conventional part of the Behavioural Inattention Test (BIT, Wilson, Cockburn, & Halligan, 1987). Scores at the MMSE, on each subtest of the BIT, and on each test of the ENB are shown in Table 1. Patients were diagnosed as having neglect according to the BIT score (cutoff ≤ 129). The absence of neglect for Cases 2–5, indexed by BIT scores that were well above the cutoff point (range 138–145; note that 146 is the maximum score), was further confirmed by their symmetric performance on the clock drawing and copy of a picture tests included in the ENB, which was always administered on a different day from that of the BIT.

In order to establish that our dual-task paradigm could exacerbate a deficit of contralesional spatial awareness and, thus, that it did not simply reflect an exaggerated rightward bias induced by increased task demands (Peers, Cusack, & Duncan, 2006), we also tested three neurologically intact control participants with the same procedure and task order as that of Case 1 (control 1, 70-year-old female), of Case 2 (control 2, 62-year-old male), and of Cases 3 and 4 (control 3, 61-year-old female). Finally, we also examined the performance of one more patient who had left hemisphere stroke (see Section 3.3).

2.2. Apparatus, stimuli, and procedure

Participants sat at a distance of about 60 cm from a 15 in. computer monitor. A head-and-chin rest was adopted to prevent head movements of the participants. There were two experimental conditions: the single-task condition and the dual-task condition (visual vs. auditory). The paradigm was programmed and administered using E-Prime (Psychology Software Tools, Pennsylvania, USA, http://www.pstnet.com/).

In the single-task condition, each trial started with a blank screen (1000 ms), followed by a black fixation point (1000 ms) that was presented in the centre of the screen against a white background. Thereafter, either a single target (left-sided or right-sided) or bilateral targets (left- and right-sided) were presented equiprobably in the periphery, each at a lateral distance of 135 mm from the centre of the screen. The target was a black disk (diameter: 8 mm) presented against a white background. Target duration (reported for each patient in Table 1) was obtained by applying an automatic calibration procedure (see below for details) to achieve optimal sensitivity (i.e., to avoid ceiling effects). For control participants, target duration was set at the lower bound (50 ms) to maximize the probability to detect any spatial bias. Simultaneously with target(s) presentation, a symbol (letter or digit) was shown at fixation for the same duration as that of the target. The symbol was either a letter for Cases 1 and 2 (randomly chosen among: a, s, d, f, for Case 1, and among: a, b, v, z, for Case 2) or an Arabic digit for Cases 3 and 4 (randomly chosen among: 1, 2, 8, and 9). Because patients were tested within a multiple-single-case approach, different symbols (letters and digits) were presented to the participants to ensure that the observed effects were independent from the symbols' type and identity. After the

Table 1
Patients' data.

Case number	1	2	3	4	5
Age (years)	71	61	50	56	42
Education (years)	5	13	5	13	8
Sex (Male–Female)	F	M	F	M	M
Lesion side	Right	Right	Right	Right	Left
Lesion site	F,P,I	I	F,P,T,I	BG, C	F, P
Lesion volume (cm^3)	192	47	247	23	
Etiology	I	I	I	H	I + H
MMSE total score	20	28	26	30	25
Days since lesion	57	31	39	56	113
Contralesional stimuli extinguished on double finger confrontation (in %)	100%	35%	0%	0%	10%
BIT total score (max 146, pathological if ≤129)	104	145	144	14 4	138
BIT subtests:					
Line cancellation (18–18)[a]	18–18	18–18	18–18	18–18	18–18
Letter cancellation (20–20)[a]	4–16	20–19	20–20	20–20	17–19
Star cancellation (27–27)[a]	18–21	27–27	27–25	27–27	27–27
Copying (4)[b]	4	4	4	4	4
Line bisection (9)[c]	3	9	9	9	7
Drawing (3)[b]	2	3	3	1	3
ENB tests:					
Digit Span	4	7	5	5	3[d]
Memory: immediate recall	13	16	10	12	7
Memory: delayed recall	7[d]	16	15	12	7[d]
Memory with interference (10 s)	3	9	7	9	2[d]
Memory with interference (30 s)	4	8	6	9	1[d]
TMT[e] version A (s)	NE	68	49	34	125[d]
TMT[e] version B (s)	NA	233[d]	145	152[d]	360[d]
Token Test	2.5[d]	4.5[d]	4.5[d]	5	5
Fluency (phonemic)	6.7[d]	11	6.7[d]	NA	3.7[d]
Abstract reasoning	3	6	5	6	4
Cognitive estimation	2[d]	5	3[d]	5	5
Overlapping figures	17[d]	24[d]	26[d]	33	22[d]
Copy of drawing	0[d]	2	2	1[d]	2
Spontaneous drawing	1[d]	2	2	2	2
Clock drawing	1[d]	9.5	5.5[d]	10	9.5
Ideomotor praxis	6	5[d]	6	6	6
Target duration (ms)	100	50	650	50	50
Omitted unilateral targets (%)[f]					
Single-task: Left target	20.8	0	0	6.3	0
Single-task: Right target	4.2	0	0	0	15.6
Visual dual-task: Left target	0	6.5	0	20.7	3.2
Visual dual-task: Right target	0	0	0	0	45.2
Auditory dual-task: Left target	NA	34.5	6.9	82.8	3.1
Auditory dual-task: Right target	NA	0	0	3.1	84.4

Lesion site: F = frontal; P = parietal; T = temporal; I = insula; BG = basal ganglia; C = capsula. Etiology: I = ischemic; H = hemorrhagic. BIT (Behavioral Inattention Test) subtests: maximum scores are shown in brackets. NE: Not Executed; NA: Not Administered.

[a] The two numbers refer to the scores (items marked) on each cancellation task for left and right hemispace, respectively (i.e., left–right).
[b] One point is given for each task (four copying and three drawing tasks) if performance does not reveal important asymmetries.
[c] Bisection of each of the three lines in the subtest is scored from 0 to 3 according to the accuracy of performance.
[d] Altered performance (score below the 5th percentile with respect to the performance of matched controls).
[e] TMT: Trail Making Test.
[f] Calculated on "zero" responses.

offset of the target(s) and the symbols, a noisy screenshot was presented until the participant responded. Participants had to report the position of the target(s) (i.e., "right", "left", or "both" sides), but to ignore the centrally presented symbol. The experimenter coded participants' oral responses to the position of the target ("left", "right", "both" sides, no response) by means of a second keyboard. Participants were allowed to stop and take a short rest at the end of any trial. A camcorder zoomed on patients' eyes was centrally placed above and behind the computer screen. The experimenter detected and coded eye movements first online (on the camcorder display) and then offline by reviewing the entire recording session.

In the visual dual-task condition, the display and the sequence of events were identical to that of the single-task condition. The only difference was that participants had to name the centrally presented symbol, before reporting the position of the lateral visual target(s) (but see Section 2.2.2). The experimenter coded participants' oral responses to the position of the target ("left", "right", "both" sides, no response) and to the identity of the centrally presented symbol (letter or digit).

In the auditory dual-task condition, the display and the sequence of events were identical to that of the single-task condition. The only difference was that participants (i.e., Cases 2, 3, and 4 and their controls) had to pay attention to an auditorily presented digit and to count forward twice by two starting from the heard number, before reporting the position of the lateral visual target(s) (but see Section 2.2.2). The auditorily presented digit was randomly chosen among: one, two, eight, and nine, and it was simultaneously presented along with the target and a task-irrelevant, randomly chosen letter (a, b, v, z). The experimenter coded patients' oral responses to the position of the target ("left", "right", "both" sides, no response) and to counting accuracy.

2.2.1. Calibration procedure

Duration of the target was determined by means of an automated calibration procedure in which a target (diameter 8 mm) was presented on the left (4 trials), on the right (4 trials), or bilaterally (16 trials). The initial target duration was set to 200 ms. For each bilateral trial with duration X the accuracy was calculated online and determined the duration of the subsequent trial. If the patient extinguished the contralesional target, the subsequent trial had a duration $X + (2 \times \text{screen refresh rate})$ (i.e., 2×17 ms), whereas if the patient reported both targets, the subsequent trial had a duration of $X - (2 \times \text{screen refresh rate})$. Upper and lower bounds for duration were set at 700 and 50 ms, respectively. Target duration for the experimental session was set at the duration of the last calibration trial rounded down to the closest multiple of 50 ms. The calibration procedure yielded target durations of 50 ms for Cases 2 and 4, and 650 ms for Case 3. Calibration for the first patient (Case 1) was achieved by pre-testing several target durations and a different disk diameter (4 mm), yielding an optimal duration of 100 ms. For control participants, target duration was set to the lower bound allowed by the paradigm

(50 ms) in order to maximize its sensitivity (i.e., to detect any potential asymmetry in performance).

2.2.2. Counterbalancing

This occurred as follows: Case 1 performed the single-task first and then the visual dual-task. Case 2 performed the auditory dual-task first, then the visual dual-task and, finally, the single-task. Cases 3 and 4 performed the single-task first, then the visual dual-task and, finally, the auditory dual-task. In addition, Case 3 was also tested by inverting task order (i.e., report the position of the target before reading the symbol). For each condition, Case 1 was presented with a single block of 72 trials, whereas Cases 2, 3, and 4 were presented with two blocks of 48 trials each. Each neurologically intact control participant performed the same tasks – and in the same order – as those of his/her matched patient.

3. Results

Trials affected by eye movements were discarded from analysis.

3.1. Right hemisphere stroke patients

3.1.1. Contralesional omissions (extinction) for bilateral targets

For each task, extinction rate was calculated for trials with bilateral targets, as the ratio between the number of targets reported as ipsilesional only and the total number of (bilateral) trials to which a response occurred. The rate of left extinction dramatically increased from the single-task condition to both dual-task conditions. The extinction rate of Case 1 (Fig. 2, panel A) raised from 8.7% in the single-task condition to 87% in the visual dual-task condition, χ^2 (1, N = 46) = 28.23, p < .001, Fisher's Exact Test. For Case 2, the extinction rate (Fig. 2, panel A) increased from 6.3% in the single-task condition to 81.3% in the visual dual-task condition, χ^2 (1, N = 64) = 36.6, p < .001 and to 80.6% in the auditory dual-task condition, χ^2 (1, N = 63) = 35.6, p < .001. The extinction rate of Case 3 (Fig. 2, panel A) increased from 14.8% to 100% in the visual dual-task condition, χ^2 (1, N = 59) = 44.7, p < .001, and to 80.6% in the auditory dual-task condition, χ^2 (1, N = 58) = 25.02, p < .001. Extinction rate remained at ceiling (100% of extinguished stimuli) when Case 3 was asked to report target position before cue identity. Finally, the extinction rate of Case 4 (Fig. 2, panel A) increased from 43.8% (single-task) to 90.6% in both the visual dual-task condition and the auditory dual-task condition, χ^2 (1, N = 64) = 15.95, p < .001.

Case 4, at the end of the testing session, was re-administered the auditory dual-task condition but this time he was asked to ignore the auditory presented digits and to respond only to target(s) position (i.e., a single-task condition). The extinction rate in this variant of the task was 18.75% which was significantly less than 90.63% in the "real" auditory dual-task condition where numbers had to be explicitly processed, χ^2 (1, N = 64) = 33.36, p < .001. This finding confirmed that contralesional space unawareness was related to the allocation of attentional resources for stimulus processing and not to the mere passive listening to numbers.

3.1.2. Contralesional omissions for single targets

Omissions on unilateral trials for Cases 1 and 3 did not increase in the dual-task conditions (see Table 1 and Fig. 2, panel B). However, Cases 2 and 4 who had no clinical signs of neglect and were presented with the shortest stimuli duration (50 ms) showed neglect-like performance (missed contralesional single targets) in the auditory dual-task condition. For Case 2 (Fig. 2, panel B) the rate of missed responses to single left-sided targets increased from 0% in the single-task condition to 34.5% in the auditory dual-task condition, χ^2 (1, N = 60) = 12.8, p < .001. The comparison between the single-task condition and the visual dual-task condition was, instead, not significant: 0% vs. 6.5%, respectively, χ^2 (1, N = 62) = 2.1, p = .492.

For Case 4 (Fig. 2, panel B), the rate of missed responses to single left-sided targets increased from 6.3% in the single-task condition to 82.8% in the auditory dual-task condition, χ^2 (1, N = 59) = 40.57, p < .001. The difference between the single-task condition and the visual dual-task condition was not significant: 6.3% vs. 20.7%, respectively, χ^2 (1, N = 59) = 3.19, p = .13. Finally, contralesional single target detection was significantly better in the additional control condition for the auditory dual-task, where the auditorily presented digit become task-irrelevant: 6.25% (task-irrelevant) vs. 82.8% (task-relevant), χ^2 (1, N = 59) = 40.58, p < .001.[1]

3.2. Neurologically intact control participants

Neurologically intact control participants' error rate was low for both unilateral (left-sided target: 1.3% vs. right-sided targets: 1.7%) and bilateral (2.5%) trials. Furthermore, none of the controls presented an extinction pattern (no "right" response to bilateral trials). This suggested that the deficit observed in right hemisphere stroke patients was a consequence of their neurological condition and it did not relate to pre-morbid rightward spatial biases (Peers et al., 2006).

3.3. Left hemisphere stroke patient

Although our neurologically intact controls did not show a rightward bias in the dual-task condition, one possible caveat is that the contralesional space unawareness found in our right hemisphere stroke patients might be due to a general consequence of brain damage rather than to a specific deficit of contralesional space awareness. In contrast, if performing a concurrent task affects contralesional space awareness, one should expect that damage to the left hemisphere should result in the pattern opposite to that observed in right hemisphere damaged patients (i.e., unawareness of right-sided targets). We therefore tested one left hemisphere stroke patient (Case 5, 42-year-old male). He sustained a subcortical ischemic stroke 11 months before testing and a hemorrhagic stroke 3 months before testing. Because of his second stroke, he underwent neurosurgery (see Fig. 3 for the CT scans). Case 5 had a non-fluent aphasia but good oral comprehension (see Table 1).

Case 5 was presented with the same sequence of paradigms and target duration (50 ms) as those of Case 2. To circumvent his linguistic deficits in oral production, he was asked to point at target position and his accuracy for central symbol reading and counting was not further considered. His performance for single ipsilesional targets was near-perfect (maximum of 3% of missed left-sided stimuli) and it was not affected by the experimental manipulation (see Table 1). In contrast, contralesional (i.e., "right") omissions in the single-task (15.6%) increased in the visual dual-task condition (45.2%), χ^2 (1, N = 52) = 12.08, p < .01 and in the auditory dual-task condition (84%), χ^2 (1, N = 60) = 32.41, p < .001 (see Fig. 4, panel B). For bilateral targets, contralesional omissions (i.e., "left" rather than "both") increased from 0% in the single-task condition to 16.1% in the visual dual-task condition, χ^2 (1, N = 61) = 5.63, p < .05, and to 21.9% in the auditory dual-task condition, χ^2 (1, N = 60) = 8.47, p < .01 (see Fig. 4, panel A). Thus, also Case 5 presented a deficit for contralesional (in this case: right) space awareness that was

[1] The fact that the performance of Case 4 returned to baseline immediately after performing a dual-task condition runs against the hypothesis that the spatial bias is partly due to fatigue/sustained attention deficit. Nevertheless, to further investigate this potential confound we compared the temporal distribution of errors between the first half and the second half of trials for each task (collapsing the data across different sessions of the same task). Cases 1, 2, and 5 did not present any significant difference. Case 3 showed an *improvement* in performance in the auditory dual task (i.e., a lower extinction rate in the second half; χ^2 (1, N = 31) = 6.13, p < .05). Case 4 showed an inconsistent pattern, with more missed single contralesional targets in the first half of trials for the visual dual-task condition (χ^2 (1, N = 27) = 8.31, p < .05) on the one hand, and an increased extinction rate in the second half during the single-task condition (χ^2 (1, N = 32) = 5.72, p < .05) on the other hand.

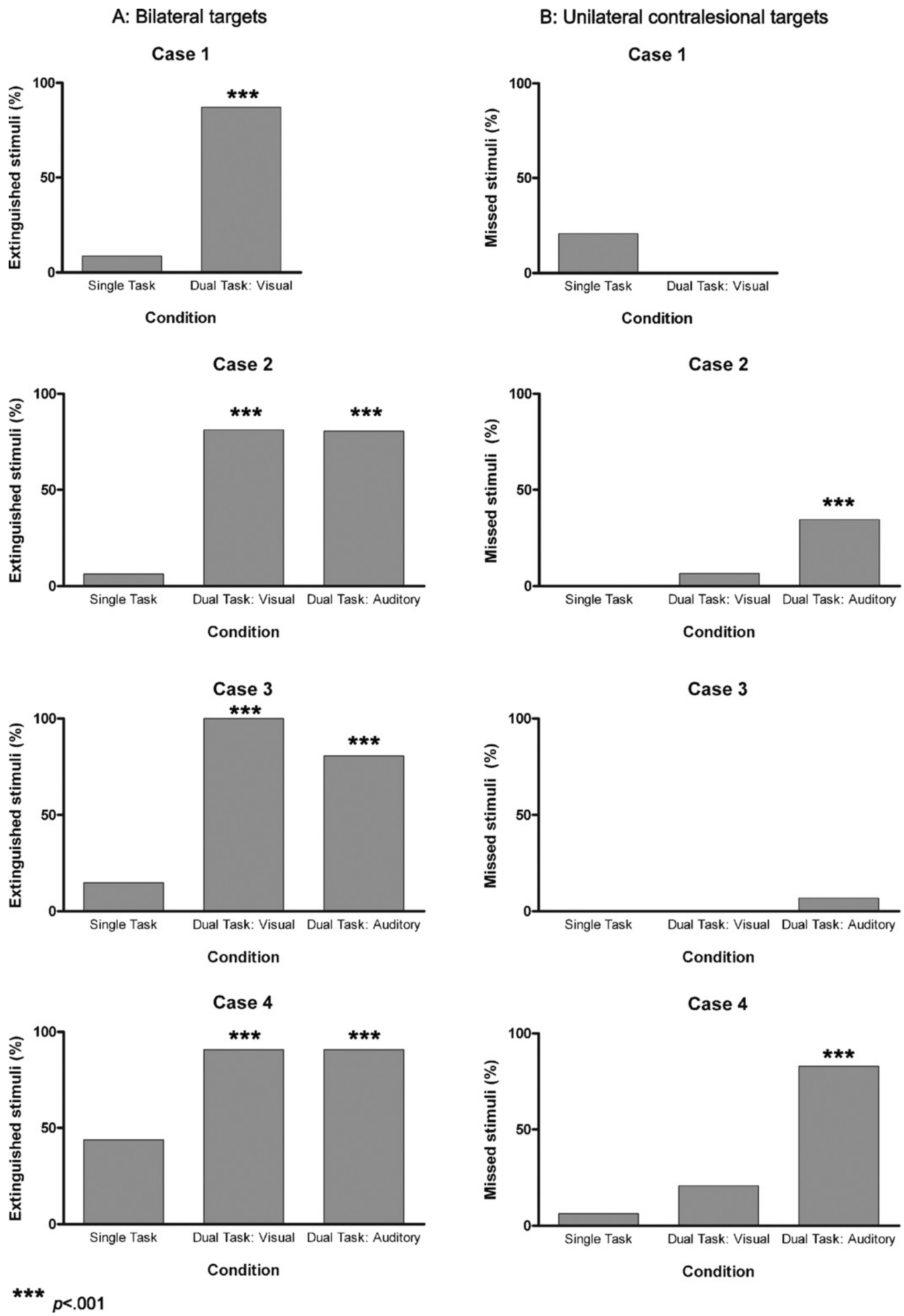

Fig. 2. Cases 1–4: The left panels (A) show the percentage of bilateral targets reported as ipsilesional (extinguished), separately for the different conditions. The right panels (B) show the percentage of unilateral contralesional (left-sided) targets missed, separately for the different conditions. Asterisks above the bars index a significant difference with respect to the single-task condition.

modulated by attentional demands. Right neglect and extinction emerged, indeed, in both the visual and the auditory dual-task conditions.

4. Discussion

Increased attentional demands, generated by a concurrent task, can induce unawareness for the left hemispace in right hemisphere stroke patients (and for the right hemispace in a left hemisphere stroke patient). The multiple–single-case approach adopted in the present study allows us to conclude that a dramatic loss of contralesional awareness emerges when available attentional resources are consumed by a second task, independently of its nature (visual vs. auditory). Indeed, three patients (Cases 3, 4, and 5) who had no neglect or extinction according to standard clinical test, showed a dramatic decrease in contralesional space awareness as soon as

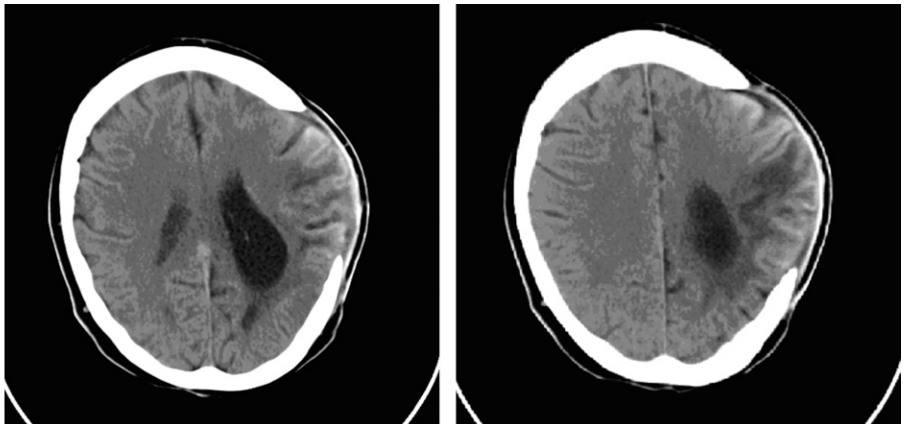

Fig. 3. Two CT scans of Case 5 are shown. The scans were performed 1 day after the data collection. A large left frontoparietal ischemic area is visible, altogether with the sequelae of a left decompressive craniectomy.

they were engaged in the second task. Although assessment based on double simultaneous stimulation is a sensitive task for detecting extinction (Maravita et al., 2007), our findings show that apparently spared contralesional awareness may reflect the general availability of attentional resources that are just sufficient for patients in order to perform single-tasks. It has been suggested that a restricted general attentional capacity, which is a common finding following a large neurological insult, might be a prerequisite for contralesional extinction (Marzi, Girelli, Natale, & Miniussi, 2001). Accordingly, our paradigm highlights a deficit of contralesional spatial awareness that emerges within a context of limited attentional resources (Husain & Rorden, 2003).

The present results extend those of studies showing that increased visual and auditory load in healthy participants hampers processing at peripheral locations (Lavie, 2005; Webster & Haslerud, 1964). An increase of attentional resources deployed at fixation has been shown to interfere with the orienting of spatial attention in healthy participants and to asymmetrically limit the visual field of right hemisphere damaged patients (Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Russell et al., 2004). A selective bias in disengaging attention from fixation has also been reported in right hemisphere damaged patients (Ptak, Schinder, Golay, & Muri, 2007). Thus, as noted by different authors (Bartolomeo & Chockron, 2002; Bonato, Priftis, Marenzi, & Zorzi, 2009; di Pellegrino et al., 1997; Husain & Rorden, 2003; Lavie & Robertson, 2001; Robertson, Mattingley, Rorden, & Driver, 1998; Snow & Mattingley, 2006), attentional deficits in neglect and extinction are far more complex phenomena than those expected by a selective failure limited to contralesional processing. For instance, patients' performance reflects not only a failure of contralesional orienting mechanisms but also a reduction of resources (e.g., alertness) which has been shown to be crucial in modulating patients' contralesional space awareness (Robertson et al., 1998). Indeed, our study highlights that both spatial and non-spatial attentional resources can contribute to contralesional awareness (see also Robertson & Frasca, 1992).

A relation between a spatial bias and concurrent-task performance was also suggested by a previous study by Peers et al. (2006). In contrast to our findings of ipsilesional spatial bias under dual-task, they observed a generalized rightward bias when patients performed a concurrent task, regardless of lesion side. This discrepancy might be due to important differences between paradigms, especially for what concerns the primary (spatial) task. Indeed, the task used by Peers et al. required participants to report the identity of six letters presented in a circular array. This implies that their measure of bias reflects a difficulty in identifying the targets on one side of space rather than lack of awareness for the stimuli. It is also worth noting that the etiology of patients' lesions in their study was mainly non-vascular, making the comparison with our study more difficult.

Importantly, our study shows that a concurrent task can disrupt even the mere detection (i.e., awareness) of a contralesional target in stroke patients. The fact that neurologically intact controls did not show any rightward bias in our paradigm, together with unawareness for the right hemispace in a left brain damaged patient, suggests that our findings reflect a deficit for contralesional space awareness that is uncovered only in the dual-task manipulation. One possible caveat is that the observed deficit would reflect

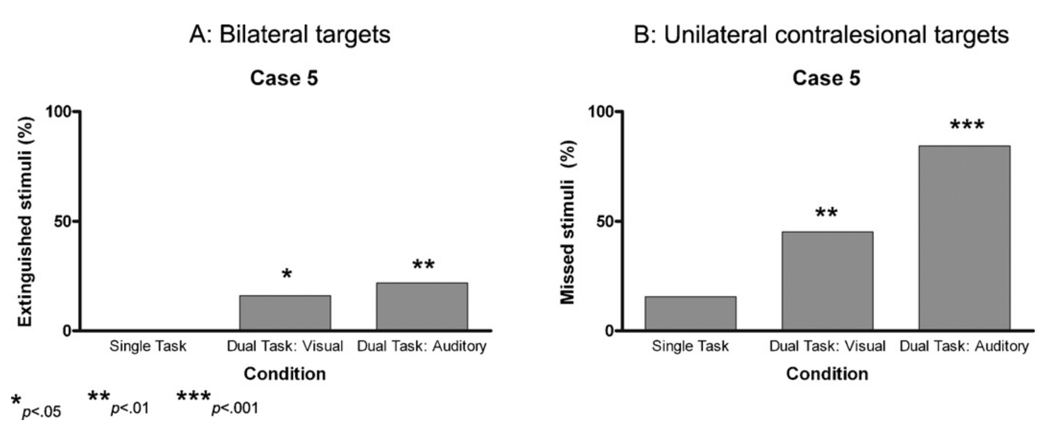

Fig. 4. Case 5: The left panel (A) shows the percentage of bilateral targets reported as ipsilesional (extinguished), separately for the different conditions. The right panel (B) shows the percentage of unilateral contralesional (right-sided) targets missed, separately for the different conditions. Asterisks above the bars index a significant difference with respect to the single-task condition.

a general dual-task interference rather than a true spatial bias. This alternative interpretation cannot be entirely dismissed, because control subjects (across conditions) and patients on trials with ipsilesional targets performed essentially at ceiling. The data about single contralesional targets, however, run counter this interpretation. Indeed, the spatial bias under dual-task did not only emerge on bilateral trials (i.e., the most difficult condition) but it also emerged, at least for some patients, on trials with unilateral contralesional targets. Three out of five patients showed a significant deficit in processing unilateral contralesional targets under dual-task even though their performance in the single-task condition was at or near ceiling.

The present findings, if confirmed in a larger sample of patients, might have crucial implications for the assessment of the disorders of contralesional space awareness. Simple clinical tests are often adopted to infer patients' performance in everyday life situations. We suggest that this inference might be misleading because everyday life situations are typically more demanding than these tests are and often require visuospatial orienting to occur in parallel with other tasks. Accordingly, stroke patients may perform within normal limits on paper-and-pencil tests, while showing deficits in everyday activities (Azouvi et al., 2002), where distracters are numerous (e.g., driving) and parallel processing in often required (e.g., driving and conversating).

Indeed, neglect recovery has been described to be sometimes only apparent (Mattingley, Bradshaw, Bradshaw, & Nettleton, 1994) and neglect re-emerges when more sensitive measures, such as kinematics, are used (Goodale, Milner, Jakobson, & Carey, 1990). In this sense, dual-task paradigms might also be effective for a more sensitive assessment of any potential change in patients' performance following rehabilitation of contralesional spatial awareness. In turn, rehabilitation of contralesional space unawareness should encompass not only spatial but also non-spatial concurrent exercises, to be effective for patients behaving in everyday life settings. Within our sample, for instance, apparently unimpaired patients might have only compensated for their deficits using spared resources until the dual-task consumed them, with consequent re-appearance of contralesional space unawareness.

It is plausible, however, that not all neurological insults determine a deficit for contralesional awareness. Indeed, only the adoption of spatial and non-spatial dual-tasks in a larger sample would indicate whether deficits of contralesional space awareness occur with similar frequency following left and right hemisphere damage, whether these deficits are more related to damage to some brain areas with respect to others and, finally, whether they might spontaneously resolve in chronic stages following stroke.

In conclusion, the use of resource-demanding paradigms (e.g., employing both spatial and non-spatial tasks) can play a key role in evaluating disorders of contralesional space awareness and in understanding why some patients who perform reasonably well on bedside testing show, nonetheless, contralesional space unawareness in everyday life.

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