 Patients with spatial neglect following unilateral brain damage are impaired at reporting objects in contralesional hemispace. Recent research suggests there may be several components underlying the neglect syndrome (Vallar, 1998; Mesulam, 1985). Understandably, much interest has focused on spatial mechanisms. For example, there is evidence for distortion of the mental representation of space as well as abnormal deployment of spatial attention in neglect patients (Heilman et al., 1993; Bisiach and Vallar, 2000).

Neglect is most commonly observed following damage to the right parietal or parieto-temporal lobes (Vallar and Perani, 1986). Several groups have used Posner’s cuing paradigm to provide evidence for a specific impairment in disengaging and shifting attention leftward in patients with right hemisphere damage (Posner et al., 1984, 1987; Morrow and Ratcliff, 1988; Friedrich et al., 1998; Losier and Klein, 2001). Others have demonstrated a spatial gradient of response performance, with worst performance in the left field and best performance on the right side, on tasks such as speeded responses to visual stimuli presented at different locations (De Renzi et al., 1989; Gainotti et al., 1991; Ladavas et al., 1990; Smania et al., 1998). Indeed, these studies have suggested that left neglect may actually be associated with ‘hyperattention’ towards stimuli on the right, in addition to impaired attention to objects on the left.

More recently, several investigators have also demonstrated deficits of disengaging attention that are not spatially lateralized. For example, a temporal deficit in allocating attention has been reported using the attentional blink protocol (Husain et al., 1997). In that study, patients were asked to report two targets embedded in a stream of letters that were presented rapidly and sequentially, entirely at fixation in the midsagittal plane. The time between targets was manipulated by varying the number of interposed nontargets in the stream. Young and healthy observers require about 400 msec between targets to be able to reliably report both targets accurately (Raymond et al., 1992; Shapiro et al., 1997). This ‘attentional blink’ (AB) is usually attributed to an inability to retain a usable representation of the second target while completing attentive processing of the first target. The neglect patients in the Husain et al. study had a severe and protracted AB, lasting nearly three times as long as for healthy observers, demonstrating abnormal temporal dynamics of attentional deployment even when stimuli were presented at the same spatial location. In addition, reduced visual short-term memory capacity in both left and right hemispace and impaired sustained attention have also been demonstrated in patients with neglect (Duncan et al., 1999; Robertson et al., 1997).

Although these studies provide evidence of non-spatial deficits in neglect, a critical outstanding question is how such deficits relate to the lateralized spatial bias in neglect (see also Husain, 2001). Very few previous investigations have addressed this issue. Duncan and colleagues examined the visual processing abilities of left neglect patients using the framework of Bundesen’s theory of visual attention (Duncan et al., 1999; Bundesen, 1990). In addition to the non-lateralized capacity deficit, they found evidence of a spatially
lateralized bias in attentional weighting, which they suggested could account for the spatial disengage-and-shift type deficit (Posner et al., 1984; Morrow and Ratcliff, 1988; Friedrich et al., 1998; Losier and Klein, 2001). Robertson and co-workers asked left neglect patients to judge whether a left visual stimulus preceded a right one, or vice versa, and found that patients became aware of the left stimulus half a second later than the right one. This rightward bias was reversed when patients heard a central warning sound, and the authors concluded that a tonic deficit in alertness contributes to the spatial bias in the neglect syndrome (Robertson et al., 1998).

While there is little previous research examining the relationship of spatial and non-spatial deficits with neglect patients, Di Pellegrino and colleagues have conducted pioneering research with a patient with extinction. Unlike patients with neglect, patients with extinction typically explore contralesional space. While these patients are able to accurately detect single items presented in either side of space, they reliably miss the contralesional item when two items are presented simultaneously and briefly. Di Pellegrino et al. (1997, 1998) have compared spatial and nonspatial shifts of attention, in a patient with left-sided extinction. Their patient was instructed to report the identity of two letters that appeared at a single location (in either left or right hemifield) or to report two letters that appeared in opposite hemifields, with either left or right letter appearing first. In both studies, stimulus onset asynchrony (SOA) varied. When the two letters appeared in opposite hemifields, report of the right letter was always accurate, but report of the left letter suffered when SOA was brief, regardless of whether it was presented first or second. When the two letters were successively presented at the same location in right space, the patient reported both letters accurately if the SOA was of the order of 400 msec or more, consistent with a normal AB. But when the two letters were sequentially presented at the mirror-symmetrical location in left space, a much longer SOA was needed for accurate report of both letters, consistent with the Husain et al. (1997) result of a prolonged attentional blink (AB) in neglect.

The studies by Di Pellegrino and his colleagues suggest that in extinction there may be a spatiotemporal gradient of attention, with impaired temporal dynamics of visual processing on the left and normal processing on the right. Recent investigations of visual processing in healthy individuals have suggested that visual stimuli compete for selection by a limited-capacity system (Desimone and Duncan, 1995). In left-sided extinction, the speed or capacity of visual processing may be reduced on the left as compared to the right. When two objects are simultaneously presented, the right one may win in the competition for selection while the left one may be ‘extinguished’ from awareness - even if it is presented just before the right one. Thus the spatial and temporal deficit may be very closely linked: slower processing on the left may contribute to the bias against a stimulus presented on that side if an object is simultaneously presented on the right.

Does a similar spatiotemporal gradient exist also in neglect? In this study, we used the AB protocol to examine the temporal dynamics of attention in a patient with left-sided neglect, when he had to allocate attention at fixation and report stimuli that appeared subsequently in either left or right hemispace. In addition, we also examined performance when attention was allocated only at fixation. In this way, we were able to examine the temporal dynamics of attention at the three, rather than only two, locations in space.

**Method**

*Participants.* The patient participant, SR, was a 68-year-old male tested 7 months after suffering a large right hemisphere, middle cerebral artery territory infarction involving the inferior parietal, inferior frontal and temporal lobes, as well as white matter underlying these regions and the putamen (see Figure 1). At initial presentation, his line bisection deviated by a mean of 4 cm to the right of the true midline on the Behavioural Inattention Test (Wilson et al., 1987). On the Mesulam shape-cancellation test (Mesulam, 1985), he found only 10 out of 60 targets, all on the right.

By the time he performed the experimental study described here, his neglect had improved considerably but was still clearly present. For example, on the Mesulam shape-cancellation test he now marked 36 of 60 targets. All the targets he missed were on the left. He had intact visual fields, left tactile extinction and a moderate left hemiparesis. He scored 28/30 on the Mini Mental State Exam. On BIT Star Cancellation, he missed only 4 targets, all on the left; and on the BIT line cancellation task he found all the targets. Copying figures was generally good, although he did tend to miss some details from the left. He had no evidence of visual extinction to clinical confrontation, even when both stimuli were presented in the ipsilesional hemifield.

Four healthy control participants (aged 65, 67, 68, and 70 years), recruited from the community participant panel of the University of Wales at Bangor, were also tested. Their data are included. Four more persons diagnosed with right hemisphere based visual neglect were tested, but their data are not included because they were unable to master the task, as evidenced by poor and inconsistent performance at identifying targets on the left and to some degree at fixation, regardless of whether they were performing the single- or dual-report tasks (see below).
**Apparatus and Stimuli.** Visual stimuli were presented at the center of a monitor of an Apple powerbook. Participants were seated so that the viewing distance was approximately 60 cm, and fixation was positioned at the observer’s midsaggital plane. Two successive target letters (which we shall refer to as T1 and T2) were presented, each followed by a mask. T1 was a white letter, chosen randomly from the 24 letters of the alphabet, excluding ‘X’ and ‘Y’. T2 was a black letter, either ‘X’ or ‘Y’. T1 and T2 were masked by randomly chosen black letters other than ‘X’ or ‘Y’. The background was a uniform gray field.

Each trial began with a plus sign at fixation, which was replaced after 1100-2300 msec by T1, which was always presented at fixation. The SOA between the two targets was 304, 456, 608, 912, 1216, 1520, or 1824 msec, and the display duration of all letters was 111 msec. A masking letter was presented at fixation 152 msec after T1 onset, and another masking letter appeared 152 msec after T2 onset, at the T2 location. T2 appeared either at fixation or 4° to the left or right of fixation. In some blocks, T2 was always at fixation; in others, T2 was always peripheral, varying side unpredictably from trial to trial. This unpredictability of T2 location within blocks and the use of masks are important differences distinguishing our study from the di Pellegrino et al. (1997, 1998) studies. All letters presented at fixation were approximately 1.6° high and 1° wide. When T2 and its mask were peripheral, they were 1.5 times that size: 2.4° high and 1.5° wide. Figure 2 is a schematic representation of a trial.

**Procedures.** SR was tested in a quiet room of his home and the control participants in a quiet office. The experimenter initiated each trial and, in blocks in which T2 was peripheral, watched the participant’s eyes to ensure that no eye movements were made during the trials. Responses were verbal.

The first session for each participant began with instructions to keep eyes directed at fixation even when peripheral stimuli were presented, to emphasize responding correctly to T1 if it was difficult to identify both T1 and T2, and to guess if not confident of the identity of targets. To verify that the participant had adequate peripheral vision, before the experiment began 28 masked peripheral Xs or Ys were presented, which the observer was to identify. The criterion for adequate performance was accuracy greater than 75% on each side. For SR, the mean accuracies were 85.7% and 92.9% for targets presented on the left and right, respectively. For the control participants, accuracy was 91.2% and 92.9% for targets on the left and right, respectively.

Once the experiment began, the participant reported both T1 and T2 in some blocks (dual-report condition) and only T2 in others (single-report). T1 always appeared at fixation. In some blocks of the experiment T2 was also always presented at fixation (just as in Husain et al., 1997), but in the remaining blocks T2 location was peripheral. Altogether, for SR there were 3 blocks in which T2 was at fixation and only T2 was reported, 4 blocks in which T2 was at fixation and both T1 and T2 were reported, 6 blocks in which
T2 was peripheral and only T2 was reported, and 7 blocks in which T2 was peripheral and both T1 and T2 were reported. Control participants took part in 4-6 blocks of each of the above. The blocks were ordered differently for each participant; for SR all the blocks in which T2 was at fixation were presented before any of the blocks in which T2 was peripheral.

In each block, the trials were evenly distributed among the 7 T1-T2 SOAs. In blocks in which T2 was peripheral, it was on the left half the time and on the right half the time. Since T2 position, SOA, and T2 identity were fully crossed, each block in which T2 was peripheral consisted of one trial for each combination of those factors, whereas each block in which T2 was at fixation consisted of two trials for each combination.

**RESULTS**

Figure 3 presents SR’s response accuracies for reporting T2 under various conditions. When both T1 and T2 were reported, T2 accuracy was calculated only for trials in which T1 was correctly reported. After all, if T1 were not reported correctly, it may not have been attended, in which case there would be no reason to expect an AB to occur. When only T2 was reported, T2 accuracy was slightly lower overall when T2 appeared to the left (contralesional, 95.2%) rather than at fixation (100%) or to the right (ipsilesional, 100%). However SOA had no systematic influence on T2 accuracy. But when both targets were reported, there was a profound effect of SOA on T2 performance when T2 was on the left (70.6%), but significantly less so when T2 was at the center location (93.3%) or on the right (97.6%).

A repeated measures ANOVA was run on arcsine transforms of T2 accuracy, looking at the effect of number of targets reported (single-report or dual-report), SOA (7 levels), and T2 spatial position (center, left, or right). A significance criterion of \( p < .05 \) was used for all tests. See Table 1 for F-ratios and \( p \)-values from the ANOVA. Simple effects tests showed that when T2 was central, T2 accuracy was significantly reduced in dual report (69.5%) compared to single report (100%) at the 304 msec SOA, \( F(1,5) = 9.7 \), but not at any longer SOAs. This is evidence for an AB of approximately normal duration when T1 and T2 were presented successively at fixation. When T2 was on the right, the number of targets reported did not reliably influence T2 response accuracy at any SOA. Thus there was no evidence of an AB when T2 was on the right. When T2 was on the left, however, T2 accuracy was significantly reduced in dual report at the 456 (33.3% for dual report vs 95.8% for single report) and 608 msec (50.0% vs. 100%) SOAs, \( F(1,5) = 16.0 \) and 15.0, respectively, but not at SOAs of 912 msec or greater. At 304 msec SOA, the difference (44.5% vs. 91.7%) approached significance. Thus, when T2 was on the left, the AB lasted for over 600 msec, which is longer than normal (400 msec). Overall the prolongation of the AB showed a spatial gradient, with a prolonged AB when T2 was on the left, a moderate AB when T2 was at fixation, and no significant AB when T2 was on the right.

Figure 3 also shows T1 accuracy across all
trials in which both T1 and T2 were reported. Overall T1 accuracy was 97.0%, 93.7%, and 89.9% when T2 appeared to the left, at fixation, and to the right, respectively. Note that there is a suggestion that (central) T1 accuracy suffers when it appears left relative to T2. A repeated-measures ANOVA on an arcsine transform of T1 performance with factors of SOA (7 levels) and T2 spatial position (center, left, or right) found that the effect of T2 spatial position approached significance, $F(2,5) = 3.2$, $p < .1$, but the effect of T2 temporal position and the interaction between spatial and temporal position did not, $Fs < 1$. Furthermore, because there appeared to be a data trend towards a difference in T1 accuracy depending on T2 position, a follow up ANOVA was run in which trials in which T2 was central were omitted. This, too, did not statistically support the trend that seems to appear in the data.

Compare this to the performance of the control participants, presented in Figure 4. For ANOVA results, see Table 1. An AB is seen at all T2 spatial locations (as evidenced by an interaction between SOA and number of targets) and there is no statistical evidence that T2 spatial location affected the magnitude of the AB (as evidenced by no significant 3-way interaction between T2 location, SOA and number of targets). The duration of the AB approximates that of young and healthy observers. T1 accuracy in dual-report trials is equivalent across T2 spatial location.

**Discussion**

A patient with neglect for objects on the left who always saw T1 (the first stimulus) at fixation showed a prolonged AB in identifying T2 (the second stimulus) when T2 appeared contralesionally, an AB of normal duration when T2 appeared at fixation, and no significant AB when T2 appeared ipsilesionally. Thus a spatial gradient in the temporal dynamics of attention was demonstrated in this patient with left neglect.

This study joins a growing body of evidence that demonstrates that spatial neglect may be associated with a non-spatial temporal deficit. Both impaired sustained attention and reduced visual short-term memory capacity have recently been implicated in the neglect syndrome (Duncan et al., 1999; Robertson et al., 1997, 1998). The AB paradigm has also been used to probe the temporal dynamics of visual processing in patients with neglect. Husain and colleagues examined the AB at one central location and found that neglect patients had a deeper and more protracted AB than healthy
individuals or control stroke patients without neglect (Husain et al., 1997).

The results of the present study demonstrate an interacting spatial and temporal gradient of difficulty in shifting attention from one stimulus to another in neglect. Patient SR had a longer and deeper AB when T2 appeared to the left, compared to when T2 appeared at the center. When T2 appeared on the right, there was no significant AB. This suggestion of atypically good performance on the right is consistent with results of previous investigations of the spatial deficit in neglect, which demonstrated ‘hyperattention’ towards stimuli on the right at the expense of stimuli to the left (De Renzi et al., 1989; Gainotti et al., 1991; Ladavas et al., 1990; Smania et al., 1998). Our results suggest that the temporal dynamics of visual processing may be enhanced compared to normal performance when T2 appears to the right, whereas it is significantly more sluggish when T2 appears to the left.

There was also a non-significant trend towards a decrease in T1 accuracy when the central T1 was contralateral to T2 (i.e. T2 presented on the right), relative to trials where T2 was presented at the center or left side. This trend might be followed up in a study designed to determine whether this reflects a redundant target effect (Marzi et al., 1996) or faster processing of ipsilesional stimuli (Baylis et al., 2002; Rorden et al., 1997). According to the redundant target model, T1 performance may benefit from an item presented toward the contralesional side of space. On the other hand, according to the speed of processing account, a central T1 may be perceived as occurring later than an ipsilateral T2, leading to reduced processing of the objectively earlier T1.

Could the pattern of results we obtained be due to a representational neglect? Although we cannot rule out a role for representational bias, it is difficult to see how it could account for the entire pattern of results. Although there is a small spatial asymmetry in T2 report in the single-report task (when the letters that appeared at fixation were not attended), the asymmetry was far more pronounced when a target (T1) was attended at fixation. Thus, attention appears to play a key role in this effect.

Could the hyperattention be merely an overall bias to attend towards the right, rather than true neglect? SR definitely had neglect, according to a number of standard diagnostic tests. However, it would be useful to correlate the spatiotemporal asymmetry we found in our task with the severity of neglect, across a group of patients (cf. Husain et al., 1997). We tested four other neglect patients but found they had severe difficulty in reporting stimuli to the left, regardless of whether they were performing single- or dual-report. Nevertheless, they were able to report stimuli to the right quite well, and so we attempted to correlate their Mesulam shape cancellation scores, which ranged from 36-57 out of 60, with T2 performance on the dual-report task (i.e. when T1 had also to be reported). Neglect as measured by the Mesulam shape cancellation test correlated with T2 performance when T2 was on the right ($r(3) = -0.925$, $p < .05$; Pearson product-moment correlation), suggesting that there is a relationship between performance on our task and degree of neglect. Namely, the more severe the neglect, the better the report of T2 (second target) on the right in our task. But, neglect as measured on the Mesulam task did not correlate significantly with report of leftward or central T2s, $r(3) = 0.150$ and –0.793, respectively, nor with (left-right)/(left+right), $r(3) = -0.519$ and –0.445, respectively. Future studies using this type of paradigm may need to make the task easier, to improve report of leftward stimuli.

The lack of a prolonged AB when both T1 and T2 were at fixation might be construed as inconsistent with previous results (Husain et al.,

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**Fig. 4 - Accuracy of the control participants' responses to the targets as a function of the relative position of the targets and whether both targets or only T2 were reported**
The difference between that result and the present finding may have been caused by a number of task differences that made the present judgments easier. First, stimuli at fixation were slightly larger in this experiment. Second, instead of the steady stream of letters used by Husain et al. (1997), there were only two letters and two masks in this study, which would change the vigilance characteristics of the task, perhaps rendering the disengagement process easier, since the display contained no stimuli while disengagement was occurring (but see evidence from Losier and Klein, 2001, that this does not impact disengagement deficits in cuing paradigms). Third, in this study the T2 judgment was a two alternative forced-choice judgment rather than a presence/absence judgment, which obviates observers’ conservative reporting of target detection when targets are not clearly seen. Finally, and perhaps the most important reason for the lack of a present finding may have been caused by a number of task differences that made the present judgments easier, since the display contained no stimuli while disengagement was occurring (but see evidence from Losier and Klein, 2001, that this does not impact disengagement deficits in cuing paradigms). Third, in this study the T2 judgment was a two alternative forced-choice judgment rather than a presence/absence judgment, which obviates observers’ conservative reporting of target detection when targets are not clearly seen. Finally, and perhaps the most important reason for the lack of a prolonged AB at fixation in the present study, was that SR had milder neglect than the patients tested by Husain et al. (1997): they found, on average, 24 targets on the Mesulam shape-cancellation task (range 6-36), in contrast to SR who found 36. In that study, the degree of spatial neglect correlated with the magnitude of the AB.

The only previous investigations of the spatial and temporal dynamics of visual attention in focal brain damage has been performed by Di Pellegrino et al. (1997, 1998) in a patient with left-sided extinction. Their data also suggested there may be a spatiotemporal gradient of attention in extinction, with impaired temporal dynamics of visual processing on the left and normal processing on the right. Recent investigations of visual processing in healthy individuals have led to the proposal that visual stimuli normally compete for selection by a limited-capacity system (Desimone and Duncan, 1995). In left-sided extinction, the capacity or speed of visual processing may be reduced on the left compared to the right. Thus, when two objects are presented simultaneously, the right one may win in the competition for selection and the left stimulus may be ‘extinguished’ from awareness. Di Pellegrino and his colleagues suggested that in extinction the spatial and temporal deficit may be very closely linked: slower processing on the left may actually contribute to the bias against a stimulus presented on that side if an object is simultaneously presented on the right.

The results of our investigation would be compatible with a similar proposal for neglect (see also Husain 2001), although they do not allow us to distinguish between such a biased-competition account or a disengagement model (Posner et al., 1984, 1987; Morrow and Ratcliff, 1988; Friedrich et al. 1998; Losier and Klein, 2001). Nor do they allow us to discriminate between models ascribing neglect to damage to hemispheric competition (Kinsbourne, 1987; Losier and Klein, 2001) or to damage to competition between all regions of space (Cohen et al., 1994; Di Pellegrino et al., 1997, 1998).

Nevertheless, our findings clearly demonstrate a spatiotemporal gradient in the allocation of attention in visual neglect, supporting the growing view that non-spatial mechanisms may combine with spatial deficits to contribute to the neglect syndrome.

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