Modulation of spatial bias in the dual task paradigm: Evidence from patients with unilateral parietal lesions and controls

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Abstract
Lateral attentional bias is common after unilateral brain damage. It has sometimes been proposed that lateral bias is increased by concurrent cognitive demands, perhaps because of lost top-down compensation. However, an important limitation of previous studies is the sole use of right hemisphere patients. Here we employed a dual task paradigm to measure spatial bias on a visual task while manipulating demands of a concurrent auditory task. Bias was examined in patients with left or right parietal lesions and controls. In Experiment 1 the addition of either a non-spatial or spatial auditory task led to a rightward shift in visual bias. This same rightward shift occurred in controls, left parietals and right parietals. Experiment 2 examined whether the participant’s response hand affected their bias. In addition, it attempted to distinguish between the hypothesis that modulatory effects are strongly dependent on lateralization of the concurrent task, and the hypothesis that dual tasks cause a general rightward shift. Response hand was found to have no effect on spatial bias. In addition, bias did not differ between left hemisphere (verbal) and right hemisphere (pitch) concurrent tasks, though the trend was for a smaller rightward shift with the verbal task. Our results show that dual tasks do not exacerbate patients’ underlying deficits; instead they cause a global shift in attention to the right. This shift may resemble general rightward shifts that have previously been linked to reduced arousal.

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1. Introduction
Attentional bias is a common consequence of unilateral damage to many cortical and subcortical brain regions (e.g. Battersby, Bender, Pollack, & Kahn, 1956; Damasio, Damasio, & Chiang Chui, 1980; Karnath, Himmelbach, & Rorden, 2002). In unilateral neglect, there is a severe tendency to ignore objects appearing on the contralesional side. Manifestations include failure to eat food on the contralesional side of the plate, failure to groom the contralesional side of the body, and bumping into objects in the environment due to misjudgements of space. Unilateral neglect has been commonly reported following damage to the parietal lobes (Battersby et al., 1956; Critchley, 1949, 1953; Driver & Mattingley, 1998; Posner, Walker, Friedrich, & Rafal, 1984).

Although there are a significant number of patients exhibiting these gross deficits, particularly in the acute phase (Stone et al., 1991), many patients with unilateral lesions exhibit much milder deficits, for example visual extinction. Visual extinction is characterised by normal recognition and report of contralateral items when they appear alone. If, however, contralesional and ipsilesional items are presented simultaneously for short exposures, and are thus in direct competition for attentional resources, patients exhibit a failure to see, or an ‘extinction’ of, items on the contralesional side. Here we examine attentional bias in patients with chronic lesions, selected on anatomical rather than behavioural criteria and showing no strong signs of neglect.

Previous studies have shed light on several potential factors which may influence spatial bias. One interesting suggestion concerns the relationship between spatial bias and general cognitive resources (Bartolomeo, 2000; Humphreys, Bounca, Datar, & Riddoch, 1996). Humphreys et al. (1996) reported a case, ARH, who showed chronic contralesional neglect on tasks such as target cancellation whilst showing a paradoxical bias to the contralesional side on extinction tasks. The authors postulate that when task demands are low (in the extinction paradigm) ARH is able to use top-down attentional control mechanisms
to consciously compensate for the spatial deficit, thus forcing attention towards the poor field. However, when task demands are increased in the target cancellation task, the patient has fewer resources available and as a result is no longer able to compensate for their underlying deficit. A similar suggestion was made by Bartolomeo (2000). In his study subjects made speeded responses to stimuli appearing in either the left or right field. Subjects were right hemisphere patients with and without neglect and controls. In the baseline condition subjects made the same response to all target stimuli as soon as they appeared. In a second condition a small number of ‘catch trials’, on which a cue informed subjects to withhold responding, was added. As expected, neglect patients were slower to respond to targets appearing in the left field than non-neglecting patients and controls. Interestingly, when catch trials were added, the patients without neglect started to respond like the neglecting patients, with much slower reaction times for left stimuli. Bartolomeo suggested that, in the absence of catch trials, non-neglecting patients were able to inhibit a tendency to orient to the right. However, the addition of the catch trials acted to increase the task demands and reduce the resources available for such inhibition.

Other evidence suggests that attentional bias may be specifically influenced by a task’s spatial demands (Cocchini, Cubelli, Della Sala, & Beschin, 1999; Vuilleumier & Rafal, 1999). Vuilleumier and Rafal (1999), for example, showed that spatial versus non-spatial task instructions could modulate awareness of identical stimuli in patients with right lesions. When the task was one of enumeration subjects appeared aware of contralateral stimuli, but when the task was to indicate the locations of items in the same stimulus array, items in the contralesional field were extinguished.

An important limitation of previous studies is the sole use of right hemisphere patients. The greater incidence of chronic neglect following lesions to the right hemisphere (Stone et al., 1991; Stone, Patel, Greenwood, & Halligan, 1992), has suggested that the right hemisphere may be especially important in spatial attention (Heilman, Watson, & Valenstein, 1993). At the same time, significant attentional biases can also follow left hemisphere lesions (Peers et al., 2005). In the present study we examine bias in right parietal patients, left parietal patients and controls. We employ a dual task paradigm to investigate how bias is affected by concurrent task demands. In all conditions the bias is measured by the ability to report targets in a visual task, whilst task demands are varied by changing a concurrent auditory task. The comparison of bias on the visual task alone with bias when the task is paired with a concurrent auditory task, allows examination of general effects of increasing task demands. A comparison of bias with spatial and non-spatial auditory tasks examines the specific influence of spatial demands.

Previous data from right hemisphere patients suggest that increasing task demands may simply exaggerate an underlying spatial bias. If this is the case, the addition of a concurrent auditory task in our group (regardless of whether that task is spatial or non-spatial) should increase bias to the right in right hemisphere patients, increase bias to the left in left hemisphere patients and produce no effect in healthy controls. If spatial demands are especially important, then these effects should be particularly marked with the spatial concurrent task.

It is, however, possible to imagine two further scenarios which would predict different patterns of results. Firstly, the effect of a concurrent task may be highly dependent upon its exact nature. The ‘functional distance model’ (see Vuilleumier & Rafal, 1999) suggests that the amount of interference in a dual task situation is dependent upon the distance between the control centres involved in the two tasks. Thus, tasks which are processed by the same or anatomically close regions of the brain (such as speaking and the use of the right hand) are harder to perform together than those which are processed by anatomically distant areas of the brain (such as speaking and the use of the left hand) (Kinsbourne & Cook, 1971). In the present experiment, therefore, if the auditory task recruits the left hemisphere we may expect to see a bias to the left (weaker attention to the right), whilst an auditory task that requires right hemisphere processing would be expected to shift the bias on the visual task to the right (weaker attention to the left). If this is the case then any concurrent task might produce similar effects in all our groups, but the effects would depend on the exact content of the concurrent task.

The final possibility is that dual tasks cause a global bias to the right. As only right hemisphere patients have been tested in previous studies (Bartolomeo, 2000; Humphreys et al., 1996), it is logically possible that rightward shift produced by concurrent tasks could be a general finding, not restricted to this patient group. The use of patients with left hemisphere damage is crucial to test this hypothesis. To anticipate, it is this final possibility that our results support. In Section 4 we suggest a possible analogy to general rightward shifts produced by low arousal (Manly, Dobler, Dodds, & George, 2005).

2. Experiment 1

2.1 Methods

2.1.1 Participants

The total study sample comprised 24 participants, 13 with parietal lesions and 11 controls (Table 1). Participants were paid a small honorarium and gave full written informed consent prior to each testing session. The study was approved by the Cambridge local research ethics committee. The patient group comprised right patients with left lesions and five with right lesions, all with lesions centred on the parietal lobe. In some patients lesions extended into temporal and occipital regions (see Fig. 1). Groups were approximately matched (Table 1) for age and premorbid IQ, assessed with the Spot-the-Word sub-test of the SCOLP (Heilman, Emmst, & Nimmo-Smith, 1993). Patients were recruited from lesion records, without regard for behavioural impairment. Selection criteria were: (i) non-traumatic unilateral lesion, (ii) age between 18 and 70 years, (iii) absence of significant current medication or psychiatric history, (iv) normal or corrected-to-normal visual acuity (Lighthouse Near Visual Acuity Test, Lighthouse Low Vision Products, New York) and auditory acuity (assessed using a standard audiological procedure, British Society of Audiology, 1983). In addition, visual field cuts were tested using brief unilateral presentations of letter stimuli under conditions in which eye movements were controlled. No patient showed global sensory loss in either visual field. All patients were tested in the chronic stage (at least 6 months post insult).

Both controls and patients were tested for clinical signs of neglect using two standard tests, the line bisection task from the BIT (Wilson, Cockburn, & Halligan, 1987) and the Weintraub and Mesulam cancellation test (Weintraub & Mesulam, 1985). Mean deviation from the true mid-point on the bissection
2.1.3. Lesion analysis

Structural MRI scans of all patients’ brains were acquired on a 1.5 T scanner (T1-weighted SPGR, 3D, resolution 0.98 mm x 0.98 mm, whole brain coverage). Lesions were traced on contiguous slices by a neurologist, who entered them before initiating the next trial. Participants were seated 40 cm from the screen. As a head restraint was not used distances and visual angles are approximate. Each block comprised 50 trials. Block ordering was fully counterbalanced across participants.

The experiment was run on a Dell Inspiron 3700 lap-top computer, with 17 in. Dell trinitron monitor and serial mouse. Sounds were presented on Sennheiser HD 250 linear II headphones.

Before data collection participants were given 10 practice trials of the visual task. They were also taught each auditory discrimination with gradually increasing difficulty.

2.1.3.1. Single task

The single task required participants to verbally report the identities of six black letters presented to them in a circular arrangement about a central fixation point. The letters used in each trial were chosen at random (without replacement) from the letter set BCDGJEKLMNOPQRSTUVWXYZ.

Participants were sat 40 cm from the screen. As a head restraint was not used distances and visual angles are approximate. Each trial commenced with a red fixation cross (2.4° by 2.4° visual angle) presented in the center of a grey screen which marked the appropriate place to fixate. A button press by the experimenter initiated the trial (see Fig. 2). The cross remained on the screen for 300 ms before the presentation of the letters. Six letters (2.1° by 2.8°) were displayed in a circular configuration, radius 8.5°, in positions 0°, –60° and 60° from the horizontal to both the left and right of fixation for 100 ms. The letters were replaced with the fixation cross alone for 600 ms, before subjects were requested to report any letters they had seen to the experimenter, who entered them before initiating the next trial. Participants were
Fig. 1. Patient lesion drawings. Each patient’s lesion is shown in red on a structural MRI of their own brain which has been normalized in to MNI space. The patients with left lesions are shown in the left column, whilst those with right lesions are shown in the right column. Axial slices are shown at MNI z-levels of −24, −16, −8, 0, 8, 16, 24, 32, 40, 50, and 60 mm, their positions indicated on a sagittal section in the bottom right corner. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

Fig. 2. A diagrammatic representation of the dual task. Participants were requested to report any letter that they were reasonably confident they had seen.

2.1.3.2. Non-spatial dual task. In this condition a simultaneous sound discrimination task was carried out in addition to the visual task. To avoid unintentional mediation of the task with a spatial cue, we avoided pitch discriminations (higher-pitched sounds are associated with higher elevation) or changes in loudness (which are associated with changes in depth). Instead, we required discrimination between sounds of constant and varying timbre. Each sound was one second in length with 15 ms linear onset and offset ramps to avoid clicks. They were played at a level of 60 dB SPL. The constant timbre sounds comprised digitally generated band passed noise, with a constant spectrum level across the frequency range 1000–1500 Hz. They sounded like hissing on an untuned radio. The dimension of timbre that was changed to create the varying sounds was the frequency range, or bandwidth. Sounds with a narrower bandwidth sound more tonal, while those with a wider bandwidth, more like white noise. The bandwidth was varied sinusoidally over time at a rate of 1 Hz. The depth of the modulation was adjusted to change the difficulty of the task. The experimental block was split into two, with sound discriminations in the first half of the task made easier than in the second half of the task. Modulations of bandwidth of 130 Hz were used for the varying sound in the first half, reducing to 90 Hz in the second half. These levels represented the mean modulation a pilot sample required in order to perform with an accuracy of 90 and 70%, respectively.

At the beginning of the block participants were provided with a pair of headphones and a serial mouse to make their response to the auditory stimuli. Participants were at liberty to position and use the mouse as they preferred. The trial followed the same procedure outlined in the single task, with the addition of the sound task (see Fig. 2). The experimenter’s button press initiated the onset of the sound. Three hundred milliseconds after the start of the sound the letters appeared for 100 ms, with the auditory presentation continuing for a further 600 ms following the offset of the letters. When the sound presentation was
complete participants were requested to respond firstly to the sound, using a mouse press (depressing the left button for ‘constant’ sounds and the right one for ‘varying’ sounds), and then verbally report any letters they had seen. They were requested to attend primarily to the sounds.

2.1.3.3. Spatial dual task. In this condition the visual task was accompanied by a spatial auditory task. To avoid spatial bias directly induced by stimulus position to left or right, sounds were designed so that their mean location was in the centre of the head. Participants were asked to discriminate between ‘still’ sounds (static in the centre of head) and ‘moving’ sounds (oscillating from ear to ear) at a rate of 1 Hz. Difficulty was adjusted by varying the size of the maximal interaural level difference. This was again done sinusoidally, making the sound delivered to one ear louder and those to the other ear quieter (generating an “interaural level difference”). This was again done sinusoidally, with post hoc analyses indicating that left parietal patients were significantly worse than controls, "p < 0.01". Spatial bias for each individual was calculated using the following equation:

\[
P_{\text{left}}(\text{left}) = \frac{P_{\text{left}}(\text{left}) + P_{\text{right}}(\text{right})}{2}
\]

where \(P_{\text{left}}(\text{left})\) and \(P_{\text{right}}(\text{right})\) denote the proportion of left and right side targets identified correctly, respectively (for group mean values of \(P_{\text{left}}(\text{left})\) and \(P_{\text{right}}(\text{right})\) see Table 2). According to this formula, a value of 0.5 indicates identical performance on the two sides, whilst scores tending towards zero indicate a bias to the right, and scores tending towards one indicate a bias to the left. Mean bias in the control sample was 0.51, for left parietal 0.61 and right parietal 0.41 (see Fig. 3A). A significant difference between groups was observed, \(F(2,21) = 7.36, \ p < 0.01\), with post hoc analyses indicating that left parietal patients were significantly more biased to the left than controls (\(p < 0.05\)) and right patients marginally more biased to the right than controls (\(p = 0.06\)).

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>Left parietals</th>
<th>Right parietals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment 1</strong></td>
<td></td>
<td></td>
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<tr>
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<td>0.55</td>
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<tr>
<td></td>
<td></td>
<td>0.59</td>
<td>0.36</td>
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<tr>
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<td>Bias score 0.51</td>
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<tr>
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<tr>
<td></td>
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<tr>
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<td>0.47</td>
<td>0.32</td>
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<tr>
<td></td>
<td></td>
<td>Bias score 0.47</td>
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<tr>
<td><strong>Experiment 2</strong></td>
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<tr>
<td></td>
<td></td>
<td>0.42</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bias score 0.49</td>
<td>0.52</td>
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<tr>
<td>Right hand</td>
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<td></td>
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<td>0.30</td>
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<tr>
<td></td>
<td></td>
<td>Bias score 0.49</td>
<td>0.51</td>
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<tr>
<td>Verbal Left</td>
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<td>0.29</td>
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<td></td>
<td>0.41</td>
<td>0.28</td>
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<tr>
<td></td>
<td></td>
<td>Bias score 0.50</td>
<td>0.54</td>
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<tr>
<td>Pitch Left</td>
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<td>0.30</td>
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<tr>
<td></td>
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<td>0.43</td>
<td>0.35</td>
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<tr>
<td></td>
<td></td>
<td>Bias score 0.48</td>
<td>0.49</td>
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</table>

3.2. Visual task

3.2.1. Single task

Average proportion correct on the single task was 0.61, 0.45 and 0.51, for controls, left parietals and right parietals, respectively. An ANOVA revealed a significant effect of group, \(F(2,21) = 6.23, \ p < 0.01\). Post hoc analyses indicated that left parietal patients were significantly worse than controls, \(p < 0.01\), with right parietal patients showing a similar trend (\(p = 0.09\)). Spatial bias for each individual was calculated using the following equation:

\[
P_{\text{left}}(\text{left}) = \frac{P_{\text{left}}(\text{left}) + P_{\text{right}}(\text{right})}{2}
\]

3.3. Results

3.3.1. Sound tasks

3.3.1.1. Non-spatial dual task

Accuracy on the sound tasks was measured with \(d'\). For the non-spatial task, average \(d'\) values for controls, left parietals and right parietals were 2.18, 1.92 and 0.74, respectively. An analysis of variance (ANOVA) showed a significant main effect of group \(F(1,21) = 10.93, \ p < 0.01\), with only right parietals significantly impaired compared to both controls \(p < 0.01\) and left parietals \(p < 0.01\). The difficulty manipulation on the sound task had the desired effect, with reduced accuracy on the harder discrimination, \(F(1,21) = 7.17, \ p < 0.01\). A near significant group by difficulty interaction, \(F(1,21) = 3.35, \ p = 0.07\) suggested that the effect of difficulty was not as great in right patients as in the other groups, presumably due to their lower performance on the easier discriminations.

3.3.1.2. Spatial dual task

Average \(d'\) values on the spatial task were 1.51, 0.66 and 0.62 for controls, left parietals and right parietals, respectively. The difference between groups was of borderline significance \(F(2,21) = 3.46, \ p = 0.05\). There was a near significant effect of difficulty on performance, \(F(1,21) = 3.35, \ p = 0.08\) but no difficulty by group interaction \(F(2,21) = 1.59\).
3.2.2. Non-spatial dual task

With the non-spatial concurrent task, proportion correct on the visual task dropped to 0.46 in controls, 0.36 in left parietals and 0.39 right parietals. An ANOVA comparing performance on the single task to the non-spatial dual task showed a significant effect of task, $F(1,21) = 49.54, p < 0.01$, but no task by group interaction, $F(2,21) = 0.90$.

Average bias scores, calculated using Eq. (1), were 0.45, 0.57, and 0.33 for controls, left parietals and right parietals, respectively (Fig. 3B; see Table 2 for group mean values of $P_{\text{Left}}$ and $P_{\text{Right}}$). A repeated measures ANOVA comparing bias on the single task with the non-spatial dual task showed a significant effect of task, $F(1,21) = 6.00, p < 0.05$, but no task by group interaction, $F(2,21) = 0.34$. Again, the addition of the spatial task caused a shift in bias to the right across all groups.

4. Discussion

Experiment 1 aimed to examine the effects of the addition of a concurrent non-spatial or spatial task on spatial bias in controls, and patients with either left or right parietal lesions. Overall accuracy on both the visual and auditory tasks differed between the three groups. Interestingly, however, the addition of a concurrent task had the same effect in all three groups. Whilst patients with right hemisphere lesions showed the expected exacerbation of their spatial bias, both controls and left parietals also showed a shift in bias to right (which ameliorated the leftward bias seen in left patients in the single task condition). There was no strong evidence to suggest that the spatial task caused a greater shift in bias than the non-spatial task.

Data from the patients with left hemisphere lesions do not appear to support the hypothesis that dual tasks act to exacerbate existing spatial biases. Instead the data from the three groups appear most consistent with the notion that dual tasks cause some general biasing to the right. This conclusion should, however be treated with caution for a number of reasons.

Firstly, in dual task conditions participants were requested to make their sound judgements using a mouse key press (no mouse was present in the single task condition). They were free to use the mouse as they wished, with most participants opting to use their dominant hand (usually their right hand) positioned in their dominant side of space. The premotor theory of attention (Rizzolatti, Riggio, Dascola, & Umilta, 1987) suggests that attention and motor responses are strongly linked. Thus in the present study the rightward shift in bias seen in the dual task condition may be the result of lateralized motor activity shifting attention towards the dominant side. Indeed Robertson and North (1992, 1993) have demonstrated that activation of the limb on the contralesional side can reduce unilateral neglect. In Experiment 2 we split each dual task condition into two blocks, one where the patients make their motor response using the right hand in right space and the other using the left hand in left space. In addition, the sound tasks used in Experiment 1 may not have been optimal. Despite attempts to develop sound tasks that
5.1.2.1 Verbal dual task.

of the sound tasks prior to data collection. Trials of practice on the visual task and were presented with examples of each task was counterbalanced across participants. Subjects completed 10 trials in the verbal dual task and the visual task plus a pitch judgement task. The order of completing the right hemisphere, verbal tasks show preferential processing of the visual stimuli on the left, resulting in the bias shifting to the right. Whilst most auditory tasks, perhaps suggesting that both tasks are more associated with right hemisphere functions. Indeed previous work has suggested the auditory spatial tasks, at least, are processed preferentially by the right hemisphere (Anourova et al., 2001; Griffiths et al., 1997). If the auditory tasks used in Experiment 1 were processed predominantly by the right hemisphere, then this could have weakened processing of the visual stimuli on the left.

5.1.2. Methods

5.1.2.2 Pitch dual task.

This task required participants to make ‘same’/‘different’ judgements about pairs of tones played during the visual presentation. The pitch stimuli consisted of 450 ms long tones, missing the fundamental frequency. Twenty-one sound stimuli were created in half semitone steps with the control one of these tones having a frequency of 440 Hz (equivalent to middle A). Linear ramps 25 ms in length were added to the beginning and the end of each tone. Tones were played at a level of 60 dB SPL. The starting tone in each pair was selected at random, with the second tone being either the same or half a semitone higher, or lower than the first tone. Participants were informed that on ‘different’ trials the higher in pitch of the tones could either be first or second.

5.2. Visual task

Bias scores (Eq. (1)) were calculated for each response hand for each task for all individuals. Data were first examined with a repeated measures ANOVA, with response hand, task and group as factors. No task by hand interaction, F(1,21) = 0.03, and no task by hand by group interaction, F(1,21) = 1.48, interactions were seen. Accordingly, effects of response hand and task were examined separately, in each case collapsing across the other factor.

6. Results

6.1. Sound tasks

6.1.1. Verbal dual task

Mean $d'$ values for controls, left pari- tals and right pari- tals were 3.43, 3.10 and 2.59, respectively. An ANOVA showed no evidence of differences between the three groups, $F(2,21) = 1.31$.

6.1.2. Pitch dual task

Mean $d'$ values on the pitch task were 3.05, 2.84 and 2.15 for controls, left parietals and right parietals, respectively. As with the verbal task, the difference between groups was not signifi- cant, $F(2,21) = 1.95$.

6.2. Visual task

Bias scores (Eq. (1)) were calculated for each response hand for each task for all individuals. Data were first examined with a repeated measures ANOVA, with response hand, task and group as factors. No task by hand interaction, F(1,21) = 0.03, and no task by hand by group interaction, F(1,21) = 1.48, interactions were seen. Accordingly, effects of response hand and task were examined separately, in each case collapsing across the other factor.

6.2.1. Effect of response hand

To examine the effect of response hand on spatial bias, data for each hand were collapsed across verbal and pitch conditions (see Fig. 4). When participants were using their left hand in left space, spatial bias scores (Eq. (1)) were 0.49, 0.52 and 0.34 for controls, left parietals and right parietals, respectively.
Fig. 4. Mean bias scores on the visual task for controls, left parietals and right parietals trials when participants responded with their left hand vs. their right hand in Experiment 2. Here trials are collapsed across the ‘verbal’ and ‘pitch’ dual task conditions. Values >0.5 indicate a bias to the left, while values <0.5 indicate a bias to the right.

When participants were responding with their right hand in right space, spatial bias scores for controls, left parietals and right parietals were 0.49, 0.51 and 0.36, respectively. An ANOVA with group and response hand as factors showed no effect of response hand, $F(1,21) = 0.06$, no effect of group, $F(2,21) = 0.24$, and no group by response hand interaction, $F(2,21) = 0.54$. Group means for $P_{\text{Left}}$ and $P_{\text{Right}}$ can be seen separately for the left hand response trials and right hand response trials in Table 2.

6.2.2. Verbal dual task

With the verbal concurrent task, overall proportion correct on the visual task was 0.41, 0.28 and 0.35 for controls, left parietals and right parietals, respectively. A comparison with performance on the ‘single task’ from Experiment 1 indicates a reduction in performance in the dual task condition, $F(1,21) = 107.51$, $p < 0.01$, but no group by task interaction ($F(2,21) = 0.27$).

Bias scores (Eq. (1)) were 0.50, 0.54 and 0.38 for controls, left parietals and right parietals, respectively (Fig. 5A). A comparison with the bias scores obtained from the ‘single task’ in Experiment 1 shows no effect of task $F(1,21) = 2.13$, and no group by task interaction $F(2,21) = 0.88$. As in Experiment 1, however, the trend was for the concurrent task to increase rightward bias. Group means for $P_{\text{Left}}$ and $P_{\text{Right}}$ with the verbal concurrent task can be seen in Table 2.

6.2.3. Pitch dual task

With the pitch concurrent task, overall proportion correct on the visual task was 0.42 for controls, 0.32 for left parietals and 0.38 for right parietals. The difference between groups was significant, $F(2,21) = 3.51$, $p = 0.05$, with left parietal patients performing significantly worse than controls ($p < 0.05$). Comparison with performance on the ‘single task’ from Experiment 1 revealed a reduction in performance in the dual task condition, $F(1,21) = 102.86$, $p < 0.01$, but no group by task interaction, $F(2,21) = 1.80$.

Bias scores (Eq. (1)) were 0.48, 0.49 and 0.31 for controls, left parietals and right parietals, respectively (Fig. 5B). A comparison with the bias scores obtained from the ‘single task’ in Experiment 1, shows a significant effect of task $F(1,21) = 5.17$, $p < 0.05$, but no group by task interaction, $F(2,21) = 0.76$. Again the concurrent task increased bias to the right. Bias measures compared between the verbal and the pitch task show no effect of task $F(1,21) = 2.99$, and no group by task interaction $F(2,21) = 0.28$. Group means for $P_{\text{Left}}$ and $P_{\text{Right}}$ with the pitch concurrent task can be seen in Table 2.

As a rightward shift in bias was observed relative to the single task a further investigation of the effects of response hand was carried out. Bias scores were recalculated just for the left hand trial block, and compared as before with scores from the single task in Experiment 1. A significant effect of task was seen, $F(1,21) = 5.70$, $p < 0.05$, indicating that bias was shifted to the right in the dual task condition despite participants’ using their left hand.

6.2.4. Comparison of all dual task conditions

A comparison of bias scores for all the dual task conditions from the two experiments showed no effect of task, $F(3,63) = 1.54$.

7. Discussion

The aim of Experiment 2 was to examine the effects of lateralized motor responses and simpler lateralized auditory tasks on spatial bias in the three groups of participants. The manipulation of response hand had no significant effect on bias. Overall performance on the auditory tasks was much improved in com-
parson to the performance on the non-spatial and spatial tasks used in Experiment 1, and no significant differences were seen between groups. Spatial bias was seen to be significantly shifted to the right in all groups in pitch dual task condition, relative to performance on the single task in Experiment 1. However no difference in bias was seen between the verbal dual task condition and the single task. Despite this, no difference was seen in the extent of the bias to the right when the verbal and pitch conditions were compared. Indeed a comparison of the bias scores across all dual task conditions in Experiments 1 and 2 showed no significant differences between tasks.

The data from Experiment 2 strongly suggest that the rightward bias in the dual task conditions is not a result of attention being drawn towards the response hand. Fig. 4 shows near identi-
cical spatial bias for left hand and right hand use in all three groups. Indeed, in the pitch condition, a significant rightward bias was seen relative to the ‘single task’ even when participants were using their left hand to make their responses. This seems particularly striking when we consider that a number of patients had some sensory and motor loss in their contralesional limb, making responses difficult to initiate with this hand. Concurrent limb activation in neglect patients (Robertson & North, 1992; 1993) can sometimes have a strong effect on attention. It may be important that, in our study, all patients were tested in the chronic stage and showed few signs of clinical neglect. Addi-
tionally, participants made their motor response at least 600 ms after the offset of visual stimuli. It is possible, therefore, that they did not direct their attention to the response hand until then.

This experiment also attempted to distinguish between the hypothesis that dual task conditions produce a general right-
ward shift in attention, and the hypothesis that attentional bias would be dependent upon the exact nature of the secondary task. The degree of bias observed with a concurrent verbal (left hemi-
sphere) task did not differ from that with a concurrent pitch (right hemisphere) task. Kinsbourne’s functional distance theory would predict that the verbal task should have biased attention to the left whilst the pitch task should have biased attention to the right. The fact that we see no difference in the degree of right bias produced by the two tasks provides evidence against this theory. Indeed, no difference was seen in the bias scores across all dual task conditions, suggesting that different kinds of concurrent task produce essentially similar effects on bias.

Before dismissing the functional distance model, we must consider the fact that no significant difference in bias was observed between the verbal dual task and the single task con-
dition. Caution must be adopted when comparing data obtained from the same individuals in different experimental sessions. However, this result may provide some indication that hemi-
spheric lateralization of the auditory task may have small influ-
ences on visual bias. This effect appears relatively minor in comparison with the general rightward biasing of attention with increased task demands. Furthermore, whilst every attempt was made to select auditory tasks which were lateralized in their pro-
cessing, it should be acknowledged that neuroimaging (Hugdahl et al., 1999; LoCasto, Krebs-Noble, Gullapalli, & Burton, 2004) data do suggest that these types of task involve bilateral process-
ing, albeit with a bias to the right hemisphere for pitch processing (Hugdahl et al., 1999; Sidtis, 1981; Zatorre, Evans, Meyer, & Gjedde, 1992) and to the left hemisphere for language processing (Hugdahl et al., 1999; Zatorre et al., 1992). Bilateral involvement in these tasks may also explain why our left hemisphere lesioned patients were unimpaired on the verbal auditory task, and simi-
larly why the right lesioned patients were unimpaired on the pitch discrimination task. For the future, a broader range of sec-
ondary tasks would be useful for more extensive investigation of the functional distance theory.

In our experiments there was just one visual task, requir-
ing letter identification in a brief display, which may prefer-
hentially recruit left hemisphere functions, making a bias to the right more likely. Our results are consistent, however, with other work showing that, in right hemisphere patients, increased task demands exaggerate rightward bias in a variety of tasks (Bartolomeo, 2000; Cocchini et al., 1999; Humphreys et al., 1996). The most parsimonious summary of all these data is that dual tasks cause a general biasing of attention to the right.

The question remains as to why dual tasks may cause a right-
ward shift in attention. One hypothesis is suggested by a large body of evidence linking the right hemisphere to sustained atten-
tion or arousal. Neuroimaging studies have uncovered a right hemispheric network of regions associated with sustained atten-
tion (Manly et al., 2003; Pardo, Fox, & Rauchle, 1991; Sturm et al., 1999). Moreover patients with right hemisphere lesions have been shown to have deficits in sustained attention (Wilkins, Shallice, & McCarthy, 1987). Possibly, the apparent lateraliza-
tion of arousal means that there are links between levels of arousal and lateral attentional bias (Robertson, 1993, 2001). In support of this idea, Bellgrove, Dockree, Aimola, and Robertson (2004) demonstrated a link between performance on a sustained attention task and the degree of lateral bias in healthy adults. Whilst all participants were seen to show a bias to the left on a spatial judgement task, poor performance on the sustained atten-
tion task was associated with a reduction in this leftward bias (i.e. a shift in bias to the right). Along the same lines Robertson and colleagues, (Robertson et al., 1997) tested a large group of right hemisphere patients with a tone counting task, which required sustained attention in the absence of any spatial demands. They found that performance on this task was a better predictor of the persistence of neglect symptoms than some overtly spatial tests. Recent work in healthy controls (Manly et al., 2005) used a within subjects design, to provide the most compelling evi-
sence of some link. Manly and colleagues asked shift workers to judge which side of pre-bisected lines appeared shorter, both at times of sleep deprivation and times when they were well rested. Participants showed a rightward shift in attention on the sleep deprived session relative to the alert session. In the alert session they also showed a gradual rightward shift in bias as the session progressed, which corresponded with self report measures of increased sleepiness at the end of the test session. Alerting can also ameliorate pathological bias to the right in clinical samples, including unilateral neglect patients (Robertson, Tegner, Tham, Lo, & Nimmo-Smith, 1995; Robertson, Mattingley, Rorden, & Driver, 1998) and children with ADHD (Dobler, Manly, Verity, Woolrych, & Robertson, 2003).
These results suggest the hypothesis that the rightward shift produced by concurrent tasks may in some way be linked to arousal. Early studies of sustained attention used simple repetitive stimuli over extended periods of time (e.g. Mackworth, 1969), and suggested that the inability to sustain attention over long periods of time is due to a lack of stimulation needed to maintain arousal levels. This idea does not appear to fit happily with any suggestion that the dual task condition (with high cognitive demands) should be associated with a reduction in arousal, relative to the less demanding single task condition. Two recent studies (Smit, Eling, & Coenen, 2004a, 2004b), however, suggest that increased task demands or ‘mental effort’ lead to greater reductions in performance over time than less cognitively demanding tasks. In addition cognitively demanding tasks are associated with increased theta activity, which is associated with reductions in arousal (Ballard, 1996; Paus, Zatorre, Holle, & Caramanos, 1997). Smit et al. (2004a, 2004b) argue that, in high cognitive load conditions, resources are depleted resulting in reduction in arousal. Following the argument through, reductions in arousal may lead to rightward biasing of attention (e.g. Bellgrove et al., 2004; Manly et al., 2005). Alternatively, diverting attention to a concurrent task may produce an effect functionally similar to reduced arousal, without decreasing arousal itself.

In the present study we have observed a general shift in bias to the right side under dual task conditions. This shift occurs in control subjects and patients with left lesions as well as in patients with right hemisphere lesions. The data provide no strong evidence that underlying spatial biases are exacerbated by increasing task demands. There is also little suggestion that the degree of spatial bias is modulated by the exact nature of the secondary task. Rather, the data appear most consistent with the idea that reductions in arousal between the single and dual task conditions act to shift attention to the right side of space.

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References


