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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.

Keywords: Bias; Dual task; Patients; Arousal

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, & Chang 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 contralesional 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, Boucart, 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

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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 contralesional 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 examines 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 Kinsbourne & Hicks, 1978) 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 eight 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 (Baddeley, Emsley, & 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, 1981). 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 bisection

Table 1
Participant details: demographic data, medical history and performance on standard tests of word recognition and unilateral neglect

Participant	Age (years)	Sex	Aetiology[a]	Time from onset to first testing (months)	Spot-the-word (correct/60)	Line bisection error (mm)[b]	Cancellation (omissions/60) (left/right)[c]
Control							
AB	55	M			51	1.3	0 (*0/0*)
AJ	57	F			55	−3.0	0 (*0/0*)
BBD	47	F			56	−3.5	0 (*0/0*)
BR	65	M			50	−2.3	0 (*0/0*)
CH	58	M			48	3.0	0 (*0/0*)
CS	59	F			45	−0.3	0 (*0/0*)
HG	48	M			52	−6.8	0 (*0/0*)
JAM	40	F			54	−0.2	0 (*0/0*)
RB	50	M			54	−14.8	0 (*0/0*)
RO	50	M			47	3.8	0 (*0/0*)
WE	63	F			55	−3.5	4 (*0/4*)
Mean	**54**				**52**	**−2.4**	**0.4**
Left parietal							
AMO	37	F	Meningioma	20	50	−1.0	0 (*0/0*)
BT	70	M	Infarct	61	48	−3.5	2 (*2/0*)
IH	50	F	Meningioma	113	56	0.8	0 (*0/0*)
JAL	52	M	Infarct	59	47	−3.0	0 (*0/0*)
JEL	51	F	Meningioma	42	54	−2.0	2 (*1/1*)
KM	67	M	Meningioma	9	59	−7.7	4 (*1/3*)
PD	49	M	Meningioma	26	47	−3.8	0 (*0/0*)
SB	45	M	Infarct	84	45	3.2	0 (*0/0*)
Mean	**53**			**52**	**51**	**−2.1**	**1.0**
Right parietal							
BER	63	F	Aneurysm	6	51	5.8	4 (*4/0*)
EO	62	M	Aneurysm	52	41	11.0	10 (*4/6*)
MB	43	F	Infantile CVA	504	46	10.2	0 (*0/0*)
MIB	54	M	Infarct	8	57	−9.8	0 (*0/0*)
RC	69	M	Infarct	18	56	−1.8	1 (*1/0*)
Mean	**58**			**118**	**50**	**3.1**	**3.0**

[a] All tumor patients had undergone surgical resection; patients with aneurysms had undergone surgery following vessel rupture.
[b] Mean error from true mid-point in three bisections of lines 205 mm in length (−ve left, +ve right).
[c] The numbers in italics indicate the distribution of cancellation errors to the left and right sides of space.

task is shown in Table 1, with negative scores indicating bisection to the left of the mid-point. Two out of three bisections over 12.75 mm from the mid-point form the usual clinical cut-off for this test; only one patient (EO) and one control (RB) were found to be within the clinically significant range. Performance on the cancellation task is also shown in Table 1. Weintraub and Mesulam (1985) report the clinical cut-off on this task to be more than two errors. One control (WE), one left parietal patient (KM) and two right parietal patients (BER, EO) were within the clinical range. Based on these assessments, neglect was weak or absent in our patients.

2.1.2. *Lesion analysis*

Structural MRI scans of all patients' brains were acquired on a 1.5 T scanner (T1-weighted SPGR, 3D, resolution 0.98mm × 2 mm × 0.98 mm, whole brain coverage). Lesions were traced on contiguous slices by a neurologist using MRIcro (Rorden & Brett, 2000). Brains were normalized to the space of the Montreal Neurological Institute (MNI) template using SPM99 (http://www.fil.ion.ucl.ac.uk/spm), with affine plus nonlinear transforms and cost function masking as described by Brett, Leff, Rorden, and Ashburner (2001). Normalized brains and lesions are shown in Fig. 1.

2.1.3. *Tasks*

Subjects completed three conditions in separate blocks of trials; the visual task alone (single task), the visual task plus the non-spatial auditory task (non-spatial dual task) and the visual task plus the spatial auditory task (spatial dual task). 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 BCDFGHJKLNPQRSTVXYZ.

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 centre 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

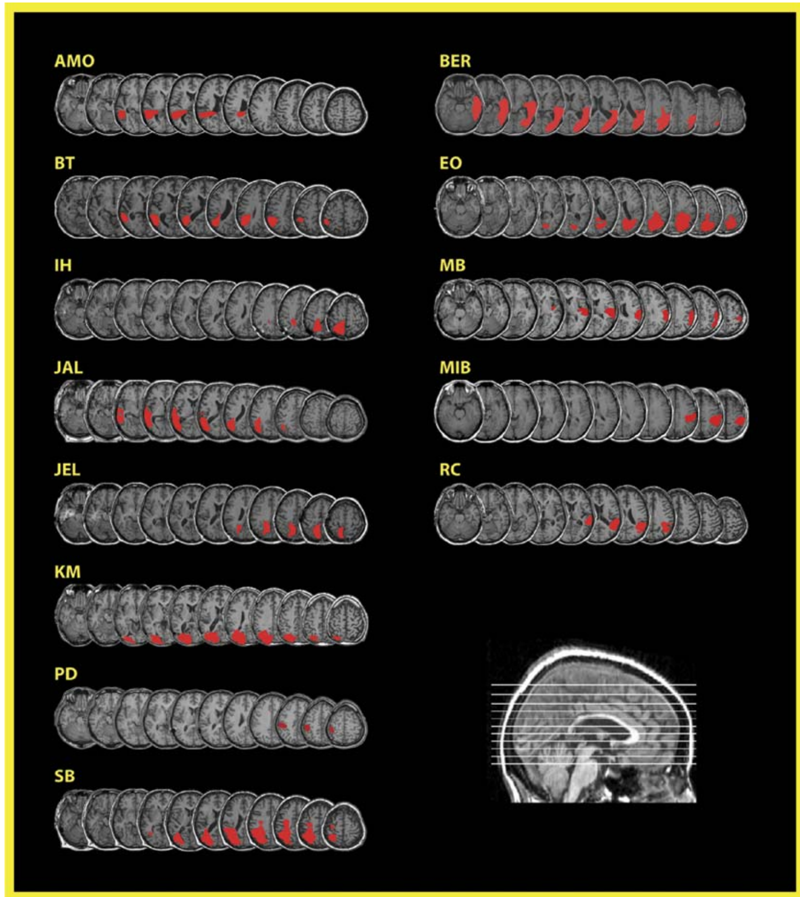

Fig. 1. Patient lesion drawings. Each patient's lesion is shown in red on a structural MRI of their own brain which has been normalized in to MNI space. The patients with left lesions are shown in the left column, whilst those with right lesions are shown in the right column. Axial slices are shown at 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.)

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

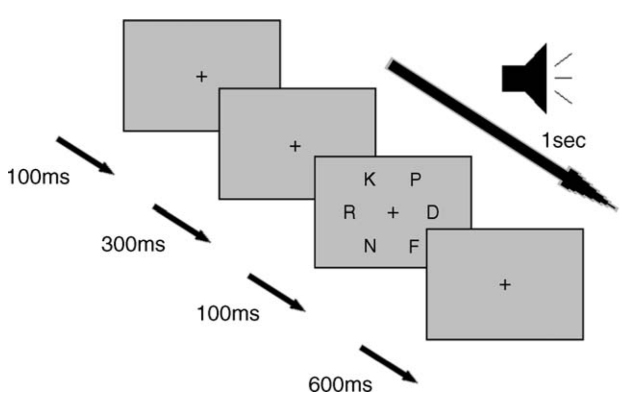

Fig. 2. A diagrammatic representation of the dual task. Participants were requested to fixate on the cross. In dual task conditions the sounds were presented across headphones with the letters presented on the screen 300 ms after the onset of the sound. Participants requested to respond to the sound, using a mouse before reporting any of the letters they had seen.

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 but with a mean, start point and end point in the centre). Previous data from both neuroimaging (Pavani, Macaluso, Warren, Driver, & Griffiths, 2002; Smith, Okada, Saberi, & Hickok, 2004) and patient work (Adriani et al., 2003) suggests overlapping brain regions underlying location perception and motion perception, with motion perception recruiting these regions more extensively.

As in the non-spatial dual task condition, all sounds comprised band passed noise within the frequency range 1000–1500 Hz, with a mean level of 60 dB SPL. To generate the shifts in perceived location for the moving sounds, we made the sound delivered to one ear louder and those to the other ear quieter (generating an "interaural level difference"). This was again done sinusoidally, at a rate of 1 Hz. Difficulty was adjusted by varying the size of the maximal interaural level difference. Again the block was split into two halves with the interaural level differences for 'moving' sounds being set at 7 dB for the first half and 4 dB for the second half. These values corresponded to accuracy in the pilot sample of 90 and 70%, respectively.

To ensure that the task involved a spatial judgement, rather than detection of level modulations in one ear, a random additional modulation in level at the same rate as the spatial modulation was added to both ears. The amplitude of this was randomly chosen from the range 0–14 dB in 2 dB steps, and the phase randomly chosen to be the same as the interaural level difference manipulation in either the left or the right ear.

The procedure was identical to that of the non-spatial dual task, with the 'still' and 'moving' sounds replacing the 'constant' and 'varying' sounds.

3. Results

3.1. Sound tasks

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, $F(1,21) = 7.17$, $p < 0.05$. A near significant group by difficulty interaction, $F(2,21) = 3.53$, $p = 0.05$ 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.

3.1.2. Spatial dual task

Average d' values on the spatial task were 1.51, 0.66 and 0.64 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. 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:

$$\frac{P_{(\text{Left})}}{P_{(\text{Left})} + P_{(\text{Right})}} \tag{1}$$

where $P_{(\text{Left})}$ and $P_{(\text{Right})}$ denote the proportion of left and right side targets identified correctly, respectively (for group mean values of $P_{(\text{Left})}$ and $P_{(\text{Right})}$ 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 parietals 0.61 and right parietals 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 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
Mean proportion of targets correctly identified from the left and right sides of the display calculated for each group separately, for each of the manipulations, visual only, non-spatial, spatial, left hand, right hand, verbal and pitch. The mean bias score in each group for each condition is also provided

		Controls	Left parietals	Right parietals
Experiment 1				
Visual only	Left	0.62	0.55	0.44
	Right	0.59	0.36	0.59
	Bias score	0.51	0.61	0.41
Non-spatial	Left	0.41	0.40	0.30
	Right	0.51	0.32	0.47
	Bias score	0.45	0.57	0.36
Spatial	Left	0.42	0.32	0.29
	Right	0.47	0.32	0.51
	Bias score	0.47	0.53	0.33
Experiment 2				
Left hand	Left	0.42	0.29	0.27
	Right	0.42	0.32	0.47
	Bias score	0.49	0.52	0.34
Right hand	Left	0.41	0.29	0.27
	Right	0.41	0.30	0.45
	Bias score	0.49	0.51	0.36
Verbal	Left	0.42	0.29	0.28
	Right	0.41	0.28	0.42
	Bias score	0.50	0.54	0.38
Pitch	Left	0.41	0.30	0.26
	Right	0.43	0.35	0.50
	Bias score	0.48	0.49	0.31

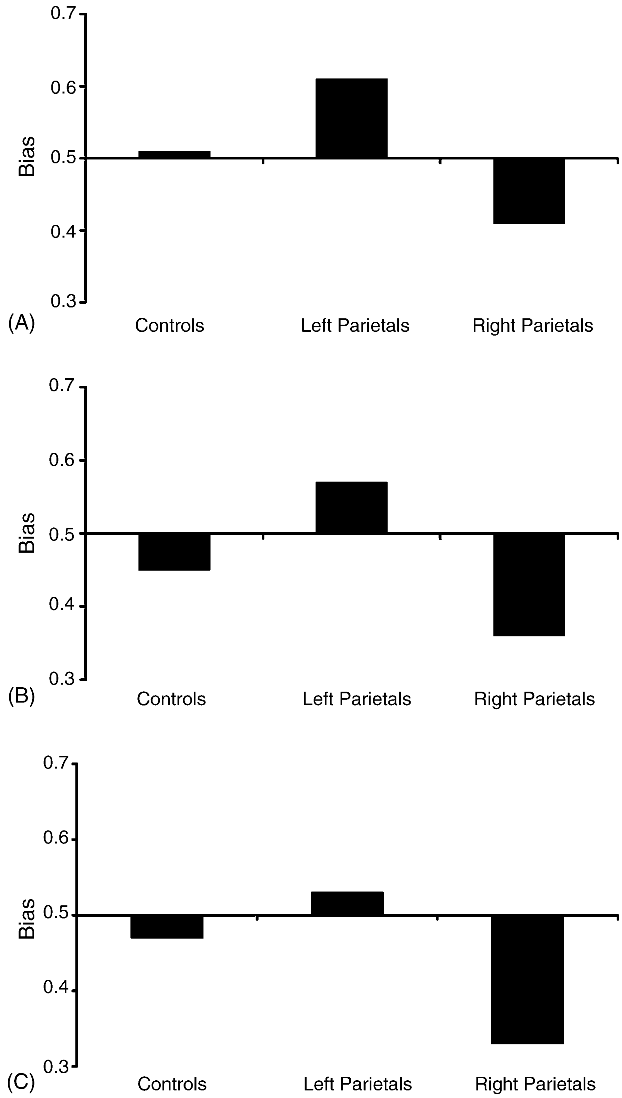

Fig. 3. Mean bias scores on the visual task for controls, left parietals and right parietals for (A) the 'single task', (B) the non-spatial dual task and (C) the spatial dual task. Values >0.5 indicate a bias to the left, while values <0.5 indicate a bias to the right.

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 0.36 for controls, left parietals and right parietals, respectively (Fig. 3B; see Table 2 for group mean values of $P_{(\text{Left})}$ and $P_{(\text{Right})}$). An ANOVA comparing bias on the single task with the non-spatial dual task showed a significant effect of task $F(1,21) = 5.00$, $p < 0.05$, but no task by group interaction ($F(2,21) = 0.03$) suggesting that the addition of the non-spatial task caused a shift in bias to the right across all groups.

3.2.3. Spatial dual task

With the spatial concurrent task, proportion correct on the visual task was 0.45 in controls, 0.32 in left parietals and 0.40 in right parietals. Again the addition of the auditory task led to reductions in performance compared to the single task, $F(1,21) = 99.135$, $p < 0.01$, with no task by group interaction, $F(2,21) = 0.93$.

Average bias scores, calculated using Eq. (1), were 0.47, 0.53, and 0.33 for controls, left parietals and right parietals, respectively (Fig. 3C, 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 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. A comparison of bias on the spatial versus non-spatial dual tasks revealed no significant effect of task type, $F(1,21) = 0.60$, and no task by group interaction, $F(2,21) = 1.83$.

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 could be performed accurately by pilot subjects the patients appeared to find these particular discriminations very demanding. The addition of the sound task had the desired effect in reducing performance on the visual task, the spatial versus non-spatial manipulation would have been more convincing if there was stronger evidence to suggest that the patients were able to carry out the sound discriminations as successfully as controls. The use of easier, more intuitive auditory tasks in Experiment 2 may address this.

Finally, the third hypothesis discussed in Section 1 suggested that direction of spatial bias would be strongly dependent upon the exact nature of a concurrent task (Kinsbourne & Hicks, 1978). In the present study patients with right hemisphere lesions performed worst on both the non-spatial and spatial 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, resulting in the bias shifting to the right. Whilst most auditory discriminations, such as location (Anourova et al., 2001; Griffiths et al., 1997), prosody (Grimshaw, 1998) and pitch (Sidtis, 1980, 1981; Zatorre, 1998) are primarily associated with the right hemisphere, verbal tasks show preferential processing by the left hemisphere (Grimshaw, 1998; Hugdahl et al., 1999). In Experiment 2 we compare the effect on bias of concurrent verbal and pitch discrimination tasks.

5. Experiment 2

5.1. Methods

5.1.1. Participants

All the participants from Experiment 1 took part in Experiment 2.

5.1.2. Methods

The methods were broadly similar to those from Experiment 1. On this occasion just two blocks of trials were run, the visual task plus an auditory verbal task and the visual task plus a pitch judgement task. The order of completing the two tasks was counterbalanced across participants. Subjects completed 10 trials of practice on the visual task and were presented with examples of each of the sound tasks prior to data collection.

5.1.2.1. Verbal dual task. This task required participants to make 'same'/ 'different' judgements about pairs of words that were played to them at 60 dB SPL whilst the visual task was being carried out. Recordings of a single individual were made whilst he repeated a series of 16 monosyllabic words eight times. The 16 words comprised four different onsets (/b/, /d/, /p/, or /t/) each paired with four different rimes (/an/, /en/, /in/, /un/). Each utterance lasted approximately 400–450 ms, with a gap of 100 ms between utterances. On 'same' trials two different instances of the same word (e.g., bin, bin) were played to the participant, whilst on 'different' trials the two words played rhymed but had different onsets (e.g. bin, pin). Participants were informed that on 'same' trials they would not hear the exact utterance repeated and so they must use verbal cues rather than tonal ones to make their decision.

The procedure was much the same as that described for the dual task conditions in Experiment 1. Some changes were made, however, in order to incorporate the manipulation of hand use. The block of 50 trials was separated into two blocks of 25 trials. In one of these blocks participants made their auditory response using the mouse in their left hand, in left space, in the other block participants responded with their right hand in right space. The order of response hand was counterbalanced across participants.

5.1.2.2. Pitch dual task. Like the verbal task, the pitch task also required participant's to make 'same'/'different' judgments 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 central 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. Participants were informed that on 'different' trials the higher in pitch of the tones could either be first or second.

The procedure was identical to that of the verbal dual task with the pitch tones replacing the verbal utterances.

6. Results

6.1. Sound tasks

6.1.1. Verbal dual task

Mean d' values for controls, left parietals and right parietals 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 significant, $F(2,21) = 1.95$.

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 $F(1,21) = 0.03$, and no task by hand by group $F(1,21) = 1.48$, 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

Collapsing across the verbal and pitch tasks, overall proportion correct using the left hand was 0.42 for controls, 0.31 for left parietals and 0.37 for right parietals. Equivalent scores for the right hand were 0.41, 0.30 and 0.36, respectively. Overall performance on the visual task was not affected by response hand, $F(1,21) = 0.77$, nor was there a group by response hand interaction, $F(2,21) = 0.00$. There was, however, a main effect of group, $F(2,21) = 4.67$, $p < 0.05$, with left parietal patients performing significantly worse than controls ($p < 0.01$).

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.

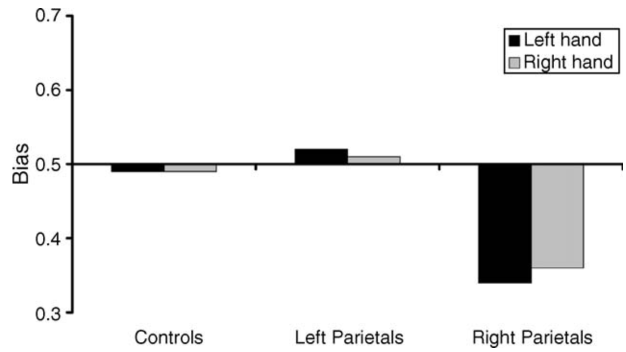

Fig. 4. Mean bias scores on the visual task for controls, left parietals and right parietals trials when participants responded with their left hand vs. their right hand in Experiment 2. Here trials are collapsed across the 'verbal' and 'pitch' dual task conditions. Values >0.5 indicate a bias to the 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 significant difference was observed between groups, $F(2,21) = 5.33$, $p < 0.05$, with left patients performing significantly worse than controls ($p < 0.05$). 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 $F(1,21) = 0.88$. 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, $F(1,21) = 102.86.4$, $p < 0.01$, 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 task by group 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.

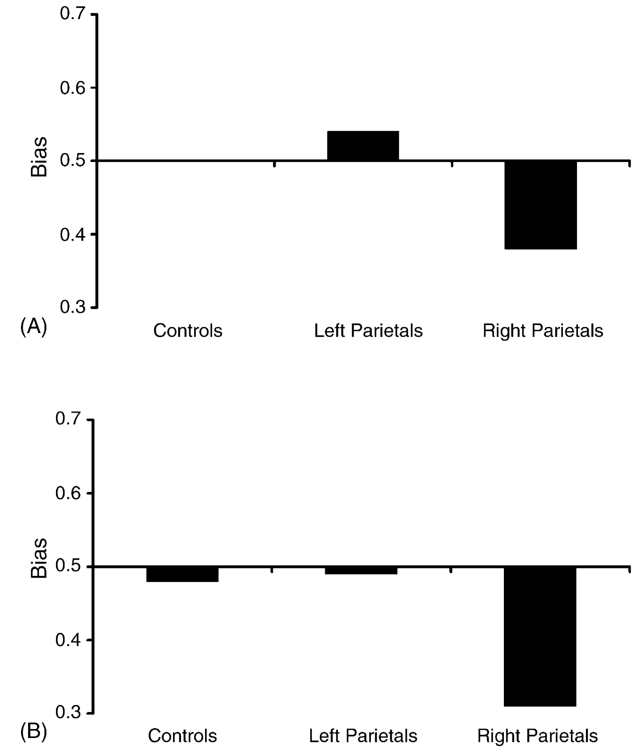

Fig. 5. Mean bias scores on the visual task for controls, left parietals and right parietals for (A) the verbal and (B) the pitch dual task conditions. Values <0.5 indicate a bias to the left, while values >0.5 indicate a bias to the right.

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 comparison 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 identical 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. Additionally, 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 after they had identified the visual stimuli.

This experiment also attempted to distinguish between the hypothesis that dual task conditions produce a general rightward 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 hemisphere) 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 condition. Caution must be adopted when comparing data obtained from the same individuals in different experimental sessions. However, this result may provide some indication that hemispheric lateralization of the auditory task may have small influences 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 processing, 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 processing, 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 similarly why the right lesioned patients were unimpaired on the pitch discrimination task. For the future, a broader range of secondary tasks would be useful for more extensive investigation of the functional distance theory.

In our experiments there was just one visual task, requiring letter identification in a brief display, which may preferentially 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 rightward shift in attention. One hypothesis is suggested by a large body of evidence linking the right hemisphere to sustained attention or arousal. Neuroimaging studies have uncovered a right hemispheric network of regions associated with sustained attention (Manly et al., 2003; Pardo, Fox, & Raichle, 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 lateralization 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 attention 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 evidence 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, Hofle, & 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

Adriani, M., Maeder, P., Meuli, R., Bellmann Thiran, A., Frischknecht, R., Villemure, J.-G., et al. (2003). Sound recognition and localization in man: Specialized cortical networks and effects of acute circumscribed lesions. *Experimental Brain Research*, *153*, 591–604.

Anourova, I., Nikouline, V. V., Ilmoniemi, R. J., Hotta, J., Aronen, H. J., & Carlson, S. (2001). Evidence for dissociation of spatial and nonspatial auditory information processing. *NeuroImage*, *14*, 1268–1277.

Baddeley, A., Emslie, H., & Nimmo-Smith, I. (1993). The Spot-the-Word test: A robust estimate of verbal intelligence based on lexical decision. *British Journal of Clinical Psychology*, *32*, 55–65.

Ballard, J. C. (1996). Computerised assessment of sustained attention: A review of the factors affecting vigilance performance. *Journal of Clinical and Experimental Neuropsychology*, *18*, 843–863.

Bartolomeo, P. (2000). Inhibitory processes and compensation for spatial bias after right hemisphere damage. *Neuropyschological Rehabilitation*, *10*, 511–526.

Battersby, W. S., Bender, M. B., Pollack, M., & Kahn, R. L. (1956). Unilateral "spatial agnosia" ("inattention") in patients with cerebral lesions. *Brain*, *113*, 1163–1183.

Bellgrove, M. A., Dockree, P. M., Aimola, L., & Robertson, I. H. (2004). Attenuation of spatial attentional asymmetries with poor sustained attention. *NeuroReport*, *15*, 1065–1069.

Brett, M., Leff, A. P., Rorden, C., & Ashburner, J. (2001). Spatial normalization of brain images with focal lesions using cost function masking. *NeuroImage*, *14*, 486–500.

British Society of Audiology. (1981). Recommended procedures for pure-tone audiometry using a manually operated instrument. *British Journal of Audiology*, *15*, 213–216.

Cocchini, G., Cubelli, R., Della Sala, S., & Beschin, N. (1999). Neglect without extinction. *Cortex*, *35*, 285–313.

Critchley, M. (1949). The phenomenon of tactile inattention with special reference to parietal lesions. *Brain*, *72*, 538–561.

Critchley, M. (1953). *The parietal lobes*. New York: Hafner.

Damasio, A. R., Damasio, H., & Chang Chui, H. (1980). Neglect following damage to frontal lobe or basal ganglia. *Neuropsychologia*, *18*, 123–132.

Dobler, V. B., Manly, T., Verity, C., Woolrych, J., & Robertson, I. H. (2003). Modulation of spatial attention in a child with developmental unilateral neglect. *Developmental Medicine and Child Neurology*, *45*, 282–288.

Driver, J., & Mattingley, J. B. (1998). Parietal neglect and visual awareness. *Nature Neuroscience*, *1*, 17–22.

Griffiths, T. D., Rees, A., Witton, C., Cross, P. M., Shakir, R. A., & Green, G. G. R. (1997). Spatial and temporal auditory processing deficits following right hemisphere infarction. A psychophysical study. *Brain*, *120*, 785–794.

Grimshaw, G. M. (1998). Integration and interference in the cerebral hemispheres: Relations with hemispheric specialization. *Brain and Cognition*, *36*, 108–127.

Heilman, K. M., Watson, R. T., & Valenstein, E. (1993). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (pp. 279–336). New York: Oxford University Press.

Hugdahl, K., Bronnick, K., Kyllingsbæk, S., Law, I., Gade, A., & Paulson, O. B. (1999). Brain activation during dichotic presentations of consonant-vowel and musical instrument stimuli: A 15O-PET study. *Neuropsychologia*, *37*, 431–440.

Humphreys, G. W., Boucart, M., Datar, V., & Riddoch, M. J. (1996). Processing fragmented forms and strategic control of orienting in visual neglect. *Cognitive Neuropsychology*, *13*, 177–203.

Karnath, H.-O., Himmelbach, M., & Rorden, C. (2002). The subcortical anatomy of human spatial neglect: Putamen, caudate nucleus and pulvinar. *Brain*, *125*, 350–360.

Kinsbourne, M., & Cook, J. (1971). Generalized and lateralized effects of concurrent verbalization on a unimanual task. *Quarterly Journal of Experimental Psychology*, *3*, 341–345.

Kinsbourne, M., & Hicks, R. E. (1978). Functional cerebral space: A model for overflow, transfer and interference effects in human performance: A tutorial review. In J. Requin (Ed.), *Attention and performance VII* (pp. 345–362). Hillsdale, NJ: Lawrence Erlbaum Associates.

LoCasto, P. C., Krebs-Noble, D., Gullapalli, R. P., & Burton, M. W. (2004). An fMRI investigation of speech and tone segmentation. *Journal of Cognitive Neuroscience*, *16*, 1612–1624.

Mackworth, J. F. (1969). *Vigilance and habituation: A neuropsychological approach*. Harmondsworth: Penguin Books.

Manly, T., Dobler, V. B., Dodds, C. M., & George, M. A. (2005). Rightward shift in spatial awareness with declining alertness. *Neuropsychologia*, *43*, 1721–1728.

Manly, T., Owen, A. M., McAvenue, L., Datta, A., Lewis, G. H., Scott, S. K., et al. (2003). Enhancing the sensitivity of a sustained attention task to frontal damage: Convergent clinical and functional imaging evidence. *Neurocase*, *9*, 340–349.

Pardo, J. V., Fox, P. T., & Raichle, M. E. (1991). Localization of a human system for sustained attention by positron emission tomography. *Nature*, *349*, 61–64.

Paus, T., Zatorre, R. J., Hofle, N., & Caramanos, Z. (1997). Time-related changes in neural systems underlying attention and arousal during the performance of an auditory vigilance task. *Journal of Cognitive Neuroscience*, *9*, 392–408.

Pavani, F., Macaluso, E., Warren, J. D., Driver, J., & Griffiths, T. D. (2002). A common cortical substrate activated by horizontal and vertical sound movement in the human brain. *Current Biology*, *12*, 1584–1590.

Peers, P. V., Ludwig, C. J. H., Rorden, C., Cusack, R., Bonfiglioli, C., Bundesen, C., et al. (2005). Attentional functions of parietal and frontal cortex. *Cerebral Cortex*, *15*, 1469–1484.

Posner, M. I., Walker, J. A., Friedrich, F. A., & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience*, *4*, 1863–1874.

Rizzolatti, G., Riggio, L., Dascola, I., & Umilta, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia*, *25*, 31–40.

Robertson, I. H. (1993). The relationship between lateralised and non-lateralised attentional deficits in unilateral neglect. In I. H. Robertson & J. C. Marshall (Eds.), *Unilateral neglect: Clinical and experimental studies* (pp. 257–275). Cambridge, MA: MIT Press.

Robertson, I. H. (2001). Do we need 'lateral' in unilateral neglect? Spatially non-selective attention deficits in unilateral neglect and their implications for rehabilitation. *NeuroImage*, *14*, S85–S90.

Robertson, I. H., Manly, T., Beschin, N., Daini, R., Haeske-Derwick, H., Homberg, V., et al. (1997). Auditory sustained attention is a marker of unilateral spatial neglect. *Neuropsychologia*, *35*, 1527–1532.

Robertson, I. H., Mattingly, J. B., Rorden, C., & Driver, J. (1998). Phasic alerting of neglect patients overcomes their spatial deficit in visual awareness. *Nature*, *395*, 169–172.

Robertson, I. H., & North, N. (1992). Spatio-motor cueing in unilateral left neglect: The role of hemispace, hand and motor activation. *Neuropsychologia*, *30*, 553–563.

Robertson, I. H., & North, N. (1993). Active and passive activation of left limbs: Influence on visual and sensory neglect. *Neuropsychologia*, *31*, 293–300.

Robertson, I. H., Tegner, R., Tham, K., Lo, A., & Nimmo-Smith, I. (1995). Sustained attention training for unilateral neglect: Theoretical and rehabilitation implications. *Journal of Clinical and Experimental Neuropsychology*, *17*, 416–430.

Rorden, C., & Brett, M. (2000). Stereotaxic display of brain lesions. *Behavioral Neurology*, *12*, 191–200.

Sidtis, J. J. (1980). On the nature of the cortical function underlying right hemisphere auditory perception. *Neuropsychologia*, *18*, 321–330.

Sidtis, J. J. (1981). The complex tone test: Implications for the assessment of auditory laterality effects. *Neuropsychologia*, *19*, 103–111.

Smit, A. S., Eling, P. A. T. M., & Coenen, A. M. L. (2004a). Mental effort causes vigilance decrease due to resource depletion. *Acta Pyschologia*, *115*, 35–42.

Smit, A. S., Eling, P. A. T. M., & Coenen, A. M. L. (2004b). Mental effort affects vigilance enduringly: After-effects in EEG and behaviour. *International Journal of Psychophysiology*, *53*, 239–243.

Smith, K. R., Okada, K., Saberi, K., & Hickok, G. (2004). Human cortical auditory motion areas are not motion selective. *NeuroReport*, *15*, 1523–1526.

Stone, S. P., Patel, P., Greenwood, R. J., & Halligan, P. W. (1992). Measuring visual neglect in acute stroke and predicting its recovery: The visual neglect recovery index. *Journal of Neurology, Neurosurgery and Psychiatry*, *55*, 431–436.

Stone, S. P., Wilson, B., Wroot, A., Halligan, P. W., Lange, L. S., Marshall, J. C., et al. (1991). The assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery and Psychiatry*, *54*, 345–350.

Sturm, W., de Simone, A., Krause, B. J., Specht, K., Hesselmann, V., Radermacher, I., et al. (1999). Functional anatomy of intrinsic alertness: Evidence for a fronto-parietal-thalamic-brainstem network in the right hemisphere. *Neuropsychologia*, *37*, 797–805.

Vuilleumier, P., & Rafal, R. (1999). Both means more than "two": Localizing and counting in patients with visuospatial neglect. *Nature Neuroscience*, *2*, 783–784.

Weintraub, S., & Mesulam, M. M. (1985). Mental state assessment of young and elderly adults in behavioral neurology. In M. M. Mesulam (Ed.), *Principles of behavioral neurology* (pp. 71–123). Philadelphia: Davis, FA.

Wilkins, A. J., Shallice, T., & McCarthy, R. (1987). Frontal lesions and sustained attention. *Neuropsychologia*, *25*, 359–365.

Wilson, B. A., Cockburn, J., & Halligan, P. W. (1987). *Behavioural inattention test*. Fareham, UK: Thames Valley Test Company.

Zatorre, R. J. (1998). Functional specialization of human auditory cortex for musical processing. *Brain*, *121*, 1817–1818.

Zatorre, R. J., Evans, A. C., Meyer, E., & Gjedde, A. (1992). Lateralization of phonetic and pitch discrimination in speech processing. *Science*, *256*, 846–848.