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Spatial Attention in the Mental Architecture: Evidence from Neuropsychology*

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ABSTRACT

Using neuropsychological evidence, this paper examines whether spatial attention functions as a domain-specific module or as a more general-purpose central processor. Data are presented from two spatial attention cuing tasks completed by subjects, with an acquired attentional deficit, and control subjects. In both tasks, an arrow indicated with high probability the side of response (response task) or the side of space on which the stimulus would appear (visuospatial task). In the response task, the stimuli appeared foveally and the response component was lateralized, and in the visuospatial task, the stimuli were lateralized and the response component remained constant in the midline. Only the neglect subjects showed a disproportionate increase in reaction time on both the response and visuospatial tasks when the arrow cued the subject to the ipsilateral side and the stimulus or response was on the side of space contralateral to the lesion. The substantial association across the two tasks suggests that a common underlying internal spatial representation subserves perception and action. While this finding is consistent with Fodor's view of a cross-domain processor, it does not meet all of his criteria of a central processor. We conclude, therefore, that the posterior attentional mechanism is strictly neither a module nor a central processor. Rather, these results suggest that a common attentional mechanism may subserve behavior in domains that are tightly coupled.

One of the ways in which psychologists have attempted to understand the architecture of the mental system has been to delineate functionally individuated faculties or isolable subsystems. This enterprise has been largely endorsed by proponents of a modular view of the mind, one of the best known of whom is Fodor (1983, 1985). Fodor divided the mental architecture into two main types of mental structures: modules and central processors. Modules are defined as domain specific, special purpose operators which are 'vertically arranged' and genetically determined and have hardwired connections that implement their privileged paths of information access and encapsulation. A prototypical example of a module that is thought to fulfil these criteria is that subserving face recognition. To obtain insight into the mental architecture, according to Fodor, one should 'divide and conquer' – study the intrinsic characteristics of modules and, only thereafter, examine the interactions between them. In the last decade, this approach to modularity has dominated theorizing in neuropsychology in

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which it has been argued that neurological damage can selectively affect a module, leaving the remainder of the system intact. Dissociations between performance on two tasks, specifically double dissociations (Teuber, 1955), are commonly considered to constitute evidence for the separability of the modules and to provide direct insight into the organization of the cognitive system (see Caramazza, 1984, 1986; also see Farah, 1994; Plaut, this volume; Shallice, 1988, 1991, for alternative interpretations).

In contrast to the well-demarcated and circumscribed modules, central processors, such as those for attention and memory, are general-purpose, integrated systems that are horizontally organized and cross multiple domains. They are global, have universal connectivity and have no explicit neuroarchitecture. Whereas Fodor explicitly encouraged the study of modules, his view of the study of central processors is considerably more pessimistic. In fact, he argues that no scientific study of central processors is possible, stating that "there is good reason why nothing is known about *it* (operation of central processes) – namely, that there is nothing to know about it ... " (Fodor, 1983, p.119).

Despite Fodor's negative assessment, decades of research in psychology have been devoted to understanding the nature and status of attention as a cognitive operation (see Posner, 1988 for overview). One recent attempt to address the status of attention within a modular view of brain organization is that of Moscovitch and Umiltà (1990) who assert that 'attention' cannot be classified simply as a central process according to Fodor's criteria (see also Umiltà, this volume). Whereas modular processing is typically rapid, and central processing is typically slow according to Fodor (1983, 1985), Moscovitch and Umiltà (1990) point out that attention can be rapid and automatic as well as being slow and under volitional control. Furthermore, according to Fodor, modules have fixed neural architecture and are vulnerable to local damage but central processes are not clearly neurally instantiated. However, it is well known that attention can be impaired after focal brain damage (see Vallar, 1993, for overview of underlying neuroanatomy). In an attempt to resolve these discrepancies, Moscovitch and Umiltà have proposed that attention is not a monolithic operation but rather that it can be differentiated into two components: (1) a central process encompassing multiple domains concerned with the voluntary allocation of attention or resources and affected following lesions to the prefrontal area and (2) a more narrow, restricted modular process concerned with the automatic deployment of attention and affected by lesions to the parietal lobe.

Spatial Attention and Neglect: Dissociations and Coupled Domains

In this paper, we examine the performance of patients with an attentional deficit acquired following brain damage and demonstrate that, contra Fodor, much can be learned about the organization of attention through studying the performance of such patients. The patients all demonstrate unilateral spatial neglect (neglect for short), an impairment in which they fail to report or respond to stimuli that appear on the side of space contralateral to the lesion. This neurobehavioral deficit is more common and usually more severe after right hemisphere lesions, and, although the parietal lobe is the most frequent neuroanatomic concomitant, it can also occur after damage to other sites such as the frontal lobe, cingulate cortex, basal ganglia, thalamus, and midbrain (Bisiach & Vallar, 1988; Heilman, Bowers, Valenstein, & Watson, 1987; Rafal & Robertson, in press; Vallar, 1993). Neglect is generally assumed to be a deficit in which attention is not distributed automatically and evenly across the visual field. Thus, these patients fail to detect targets or changes in the contralateral visual field while their attention is engaged at an ipsilateral location. They can, however, deploy their attention to the contralateral side volitionally and can benefit from a cue directing their attention to the probable location of a stimulus even when the location is on the neglected side (Riddoch & Humphreys, 1983; see also Humphreys & Riddoch, 1993). This pattern of behavior has been attributed to a failure to 'disengage' attention from its current location (Posner, Cohen, & Rafal, 1982; Posner, Walker, Friedrich, &

Rafal, 1984) although other possible interpretations have been proposed (Cohen, Romero, Servan-Schreiber, & Farah, 1994; see also Marshall, Halligan, & Robertson, 1993). This deficit, in which attention is deployed volitionally but not automatically, reflects the impairment to the more narrow, modular form of attention (Moscovitch & Umiltà, 1990).

Consistent with this modular view of attention, many studies have demonstrated that hemispatial neglect is not a unitary phenomenon and can fractionate into a number of dissociable components in terms of sensory modality (tactile vs. auditory), spatial domain (e.g., extrapersonal vs. peripersonal) and stimulus content (Bisiach, Geminiani, Berti, & Rusconi, 1990; Costello & Warrington, 1987; Halligan & Marshall, 1993; Riddoch, 1990; Umiltà, this volume; Young, de Haan, Newcombe, & Hay, 1990). That such dissociations are possible has been taken as evidence against a supramodal, common attentional system and in support of a theory of domain-specific attentional processes each of which may be selectively impaired following brain damage. It is possible, however, that not all activities are separable in this way, adhering to this decentralized organization. Dissociations between sensory modalities and content areas may occur because the modalities are not integrally related nor do they rely critically on the same representations. For example, detecting a visual stimulus on the contralateral side does not involve the tactile system and vice versa and double dissociations between visual and tactile neglect have been reported (Barbieri & De Renzi, 1989).

There are, however, some behaviors that are more integrally related and do require close coupling. Reaching to pick up a glass for example, requires that the shape of the glass and its location is processed visually and that the movement of the hand is then guided to the correct spatial location. Such organized behavior requires the coordination of perception and action, both inherently spatial operations which, together, provide the temporal and spatial constraints that allow for successful interaction with the environment (Von Hofsten, 1987). Even if dissociations are observable across sensory modalities or different spatial domains (e.g., extrapersonal vs. peripersonal), the question remains whether or not a common spatial attentional representation subserves behaviors in coupled domains like perception and action. The simple prediction is as follows: if a unitary spatial attentional mechanism mediates both behaviors, then, following brain damage, both visuospatial processing and spatial action should be impaired. If, however, there are distinct and separable representations for each of these tasks, then performance in these two domains should be independent and doubly dissociable. Although this dichotomy is coarse, it provides a first cut at the question of separation between the representations subserving these two domains.

In an attempt to understand better the organization of the attentional operation, we present data from a group of neglect patients on two versions of a spatial attentional cuing task, the one a visuospatial task and the other a spatial response or action task. The visuospatial task involves the processing of a stimulus which is presented laterally, to the left or right of space, but which requires a central motor response. The action task involves the converse: processing of a centrally presented visual stimulus for which the response has a lateralized left-right component. The open issue is whether patients who process left-sided visual stimuli more poorly than right-sided ones also perform more poorly on the action task, that is, show neglect for the contralateral side in response or action space.

Differentiating Response Neglect from Other Forms of Motor Deficits

Neglect for the contralateral side of action or response space must be distinguished from a number of other motoric or output deficits which have been observed and are already known to be dissociable from sensory or visuospatial neglect. To distinguish these from the neglect for response space and delineate the phenomenon of interest here, a short digression is necessary. One well-known motoric deficit, *motor neglect* (néglicence motrice), is the reduction in spontaneous movement of the contralateral limb in the absence of a motor deficit. In such cases, responses of the contralesional limb are slower, less accurate, and reduced in amplitude relative to the ipsilesional limb on tasks such as manual pointing, line bisection, and simple reaction time measures (Laplane & Degos, 1983; Meador, Watson, Bowers, & Heilman, 1986). Neglect for the left of action space is also to be differentiated from *hemispatial or directional hypokinesia* (directional motor neglect, Làdavas, Umiltà, Ziani, Brogi, & Minarini, 1993) in which action directed towards contralateral space is slower or less efficient than towards ipsilateral space, independent of the side of the responding or effector limb. Thus, patients with hypokinesia following a right hemisphere lesion perform more slowly (bradykinesia) and/or less accurately (hypometria) on goal-directed movements into left than right extracorporeal space even with the intact ipsilateral limb (Heilman, Bowers, Coslett, Whelan, & Watson, 1985; Mattingley, Bradshaw, & Phillips, 1992). This pattern of performance has been noted on tasks such as typing, putting pegs in a hole, or picking up objects from the left and right sides of space (Chedru, 1976; De Renzi, Faglioni, & Scotti, 1970; Heilman, Bowers, & Watson, 1983; also Duhamel & Brouchon, 1990; Joanette, Brouchon, Gauthier, & Samson, 1986). A similar directional motor neglect deficit has been observed for contralesional eye movements (Behrmann, Watt, Black, & Barton, in preparation; Butter, Rapscak, Watson, & Heilman, 1988).

Both motor neglect and directional hypokinesia have been doubly dissociated from sensory or visuospatial neglect (Bottini, Sterzi, & Vallar, 1992; Daffner, Ahern, Weintraub, & Mesulam, 1990; Làdavas et al., 1993; Liu, Bolton, Price & Weintraub, 1992; Tegnér & Levander, 1991; see Deuel & Farrar, 1993, and Mijovic, 1991, for different results) even when very similar experimental paradigms are used to tap these two phenomena (Bisiach, 1993; Bisiach, et al. , 1990; Coslett, Bowers, Fitzpatrick, Haws, & Heilman, 1990; Reuter-Lorenz & Posner, 1990). The distinction between the motor and sensory forms is assumed to be neuroanatomical: whereas the motor effects are generally associated with premotor deficits and arise from anterior lesions (usually frontal lobe), the perceptual effects are generally attributable to selective attention deficits and arise from posterior lesions (Heilman, Watson, & Valenstein, 1985; Mesulam, 1981). Putting these motor-type deficits aside, the question still remains whether, in patients with an attentional deficit resulting in visuospatial neglect, a comparable neglect deficit is seen for the contralesional side of action when action does not involve the use of the contralesional limb (as in motor neglect) nor movements in a contralateral direction (as in directional hypokinesia).

Neglect for the Contralateral Side of Response Space

Evidence supporting the phenomenon of response neglect comes from a recent study by Làdavas, Farnè, Carletti, and Zeloni (in press) who showed that patients with left-sided neglect are indeed slower to produce responses on the relative left where "left" is defined with respect to external spatial coordinates. In their task, subjects pressed one of two keys in response to a single stimulus ('1' or '2') which appeared with equal probability on either the left or right of a central fixation point. The stimuli were associated with a specific finger response, for example, '1' indicated a left (index finger) response while '2' indicated a right (middle finger) response, and two fingers of the intact, ipsilesional hand were used for responding (thereby circumventing any sensory deficit or hemiparesis of the contralateral limb). The results showed that, irrespective of the side of space on which the stimulus was presented, patients with left neglect responded more slowly with the relative left key than with the right key. Làdavas et al. interpreted this as indicating that spatial codes for response can be formed through an attentional mechanism and that, when this mechanism is damaged, response neglect is manifest on the contralesional side.

Although these findings demonstrate that response neglect does exist, the conclusion that it is the product of an underlying attentional deficit which affects response coding is indirect. It is also unclear whether this response form of neglect is related to visuospatial neglect or whether it is a distinct and separable impairment. The question to be addressed in the first experiment in this paper is whether, when an explicit attentional manipulation is used, neglect for the side of response space is observed. The hypothesis is that if a common mechanism underlies the coding of the stimulus in perceptual tasks and the response in action tasks, then in a group of patients with visuosensory neglect, one might also see a selective deficit for the contralateral response. Furthermore, to investigate whether the attentional deficit affects performance similarly across both stimulus and response processing, in the second experiment, we examine the performance of the same patients on a comparable visuospatial attentional task.

EXPERIMENT 1: NEGLECT FOR THE CONTRALATERAL SIDE OF RESPONSE IN A SPATIAL ATTENTION CUING TASK

To demonstrate that neglect for the left of the response arises from a deficit in attention, in this experiment, we have adopted the classic spatial precuing paradigm used for demonstrating a deficit in covert attention in patients with parietal lesions (Posner, 1980, 1988, 1990; Posner et al., 1982, 1984) and modified it for use in the response domain. In one version of the classic visuospatial task, the subject is instructed to press a key when a target that appears at a peripheral location is detected. The target is preceded by a cue (e.g., a central arrow) that directs attention to the ipsilateral or contralateral space. The target then appears either in the cued (valid) or in the uncued (invalid) location and detection time is measured as a function of side of target (left/right) and validity (valid/invalid). The critical result is that of an interaction between side and validity, referred to as the 'extinction-like reaction time pattern'. Reaction time (RT) to detect the target in the contralesional field is minimally but generally not significantly slower than in the ipsilesional field when attention is directed there by a valid cue. However, when the cue directs attention towards the ipsilesional field and the target subsequently appears in the contralesional field, detection is slowed relative to when the invalidly cued target appears in the ipsilesional field.

The hallmark feature then is of disproportionately slowed reaction times to contralateral invalid targets and this correlates with the severity of neglect (Morrow & Ratcliff, 1988). In this experiment, we use this selective attention task and adapt it to the response domain to see whether the same pattern holds for responses which are emitted on the ipsilesional and contralesional sides of space. In the adapted task, an arrow cue appears foveally indicating with high probability the finger (relative left or right of a single hand) which will be called upon to respond. Following the offset of the arrow, a stimulus appears indicating whether the response should be made with the left or right finger. On 80% of the trials, the arrow and the subsequent stimulus both indicate the same finger (valid) whereas on 20% of the trials, the arrow and stimulus do not correspond and the arrow invalidly cues the response. Importantly, in this response task, the stimuli occupy the identical foveal location whereas the response has a horizontal left-right spatial dimension. If attention underlies performance on this response task, in the same way as in the visuospatial task, we would expect to see an interaction between side of response and validity with an impairment on the contralesional side particularly in the invalid condition.

METHOD

Subjects

Three groups of subjects participated in this experiment, an experimental group consisting of patients with hemispatial neglect (**Neglect**), and two control groups, one of patients with brain damage but with no evidence of neglect (**Non-neglect**) and one of elderly, normal control subjects (**Control**). The diagnosis of neglect was made on the basis of a battery of neglect tests including line cancellation (modified Albert's line cancellation task, 1973), line bisection, copying of a daisy and a clockface, and the Bell's test

(Gauthier, Dehaut, & Joanette, 1989). In the line cancellation task, 21 lines, each 3.3 cm in length, appeared on a page, one in the middle and 10 scattered randomly on each of the left and right sides. The subjects were instructed to mark or check all the lines and the number of lines omitted per side was calculated. On the Bell's test, 5 target bells in black silhouette appeared intermixed with 40 distractors in each of 7 predefined vertical columns (3 left, 1 center, 3 right), making a total of 35 bells and 240 distractors. The subjects were required to circle the bells and the number of omission errors was counted for the left, center, and right sides (see Gauthier et al., 1989 for exact instructions). Finally, on the line bisection task, the subjects were instructed to put a mark through the midline of the presented horizontal line. Each patient bisected a total of four lines, two longer lines of 19.4 cm in length and two shorter lines of 15.2 cm in length. The mean percent deviation was calculated with a positive number reflecting rightward deviation and left-sided neglect. The line cancellation, copying, and line bisection tasks all form part of the Sunnybrook neglect battery (Black, Vu, Martin, & Szalai, 1990) on which performance has been standardized on normal control subjects. On the basis of these norms, points are assigned indicating the degree to which performance differs from the standard result (e.g., on line cancellation, 2 points are assigned for each omitted line). The Bells' test was recently added to the battery to replace the symbol detection task and, using the norms set out by Gauthier et al., a neglect score is also assigned. The total neglect score (across all the tests) is out of 85 points and normal is defined as performance of 7 points or less.

The **Control** group consisted of 15 right-handed adult subjects from the volunteer subject pool at the Rotman Research Institute of Baycrest Center, and all consented to participate in this study. These subjects (6 male, 9 female) had no previous history of neurological disease and a mean age and education level of 70.4 (*SD* = 4.4) and 14.1 (*SD* = 3.05) years, respectively. The mean cumulative neglect score on the tests described above is 4 and no single subject exceeded the normal cut-off score.

A second control group, the **Non-neglect** patients, consisted of 20 patients (14 male, 6 female) with cerebral lesions but with no evidence of neglect on the diagnostic tests. For 18 of the patients, the lesion was a result of infarction and for the remaining 2, the lesion followed an arterio-venous malformation. This group was included to demonstrate that the results obtained are specific to those patients with an attentional deficit and not a general consequence of brain damage. The mean age and education level for this group was 59.9 (*SD* = 15.2) and 14.5 (*SD* = 4.1) years, respectively. The mean neglect score for this group was 1.5 (*SD* = 1.7) and no subject exceeded the normal cut-off of 8 points. Of the group, 18 patients were right-handed, 1 was a switched right-hander, and 1 was a dominant left-hander. Demographic details, lesion parameters, and neglect scores for these patients are shown in Table 1 below.

The experimental or **Neglect** group consisted of 16 subjects with neglect (5 males, 11 females), 15 of whom were right-handed. Of the 15 right-handed patients, 13 had a right hemisphere lesion with left neglect and 2 had a left hemisphere lesion with right neglect. The single left-hander had a left CVA. All 16 subjects had sustained a cerebral infarction. The mean age and education level for this group was 72 (*SD* = 10.3) and 12.8 (*SD* = 2.9) years, respectively. To incorporate the data of both the left and right hemisphere lesions in a single group, data are collapsed into contralesional and ipsilesional side rather than 'left' and 'right'. The mean neglect score for the group was 35 although there was considerable individual variation (*SD* = 23). All subjects exceeded the normal cut-off of 7 points. The demographic details, lesion information, and neglect scores for this group are also listed in Table 2.

Stimuli

The stimuli consisted of two symbols ('@' and '#') which appeared in black in the center of a white computer screen following a foveal fixation point. The cue, an arrow which pointed either left or right, also appeared in the center of the screen. At a distance of 40 cm, the symbols and the arrow subtended 1^{o} and 1.4^{o} of visual angle, respectively.

Apparatus

The sequence of presentation was controlled using Psychlab software (Bub & Gum, 1988) on a Macintosh computer with a 12-inch monitor. Subjects made a forced choice response to the symbols using two keys of a single hand. For example, if the right hand was used, the subject was instructed to press the ',' key with the 'left', index finger in response to the '#' symbol and the '.' key with the 'right', middle finger in response to the '@' symbol. The key responses were made on the keyboard and symbols and keys were counter-balanced across subjects. The response keys were aligned with the midline of the screen and the subject's hand was placed along the same midline to avoid any stimulus-response incompatibility effects (see Verfaellie, Bowers, & Heilman, 1988 for a similar task in which stimulus-response incompatibility is exploited).

Procedure

Subjects sat in front of a computer at a distance of approximately 40 cm. A black fixation point appeared centrally on a white computer screen for 1 s followed by a 500-ms delay. Subjects were instructed to maintain fixation throughout the trial. Following the fixation point, an arrow appeared centrally for 250 ms and was immediately replaced by the target,

Table 1. Biographical and Lesion Data for the Non-neglect Patients.

NON-NEGLECT GROUP

No.	SEX	AGE	HANDED	HAND USED	LESION	EDUCATION	NEG. SCORE	LESION
1	M	59	R	R	R	19	4	Frontal
2	F	28	R	R	R	13	0	Occipital
3	F	77	R	R	R	11	0	Occipital
4	M	51	R	R	R	13	0	Frontal, parietal, temporal
5	F	73	R	L	L	?	0	Frontal
6	M	76	R	R	B	12	4	Frontal, parietal, temporal
7	M	63	R	R	R	10	0	Frontal, parietal, temporal, thalamus, basal ganglia
8	M	46	R	R	R	13	0	Basal ganglia
9	M	72	R	R	R	12	0	Parietal, white matter
10	F	45	R	R	R	9	3	Occipital parietal temporal
11	M	69	R	R	R	15	2	Basal ganglia, frontal
12	M	72	R	R	R	11	4	Parietal, temporal
13	M	58	R	L	R	10	0	Centrum semiovale
14	M	65	R	L	L	19	0	Parietal
15	M	77	SWITCH	R	R	15	2	Frontal, parietal, basal ganglia
16	M	46	R	R	R	25	4	Frontal, temporal, basal ganglia
17	M	83	L	L	L	15	4	Basal ganglia
18	F	41	R	R	L	17	2	Parietal, basal ganglia
19	F	56	R	R	R	18	1	Frontal parietal
20	M	41	R	L	L	19	0	Temporal parietal

Note. Age and Education reported in years.

Table 2. Biographical and Lesion Data for the Neglect Patients.

NEGLECT GROUP

No.	SEX	AGE	HANDED	HAND USED	LESION	EDUCATION	NEG. SCORE	LESION
1	M	73	R	R	R	9	49	Frontal, parietal, temporal
2	F	68	R	R	R	14	40	Frontal, parietal, temporal, basal ganglia, thalamus
3	F	76	R	R	R	15	9	Parietal, temporal, basal ganglia
4	F	75	R	R	R	9	15	Parietal infarct on R; small benign tumour on L
5	F	61	R	R	R	13	15	Occipital, thalamus
6	F	74	R	R	R	9	85	Temporal, occipital
7	F	73	R	R	R	11	37	Frontal, parietal, temporal, basal ganglia, thalamus
8	M	81	R	R	R	12	56	Temporal, occipital
9	M	65	R	L	L	13	8	Parietal, temporal
10	M	68	R	R	R	20	38	Temporal, occipital
11	F	82	R	R	R	11	37	Frontal, parietal, temporal, basal ganglia
12	M	66	L	L	L	12	11	Frontal, parietal, temporal, basal ganglia, thalamus
13	F	88	R	L	L	?	14	Frontal
14	F	85	R	R	R	14	69	Frontal, parietal, temporal, occipital
15	F	45	R	R	R	14	32	Frontal, parietal, temporal
16	F	72	R	R	R	16	41	Frontal, parietal

one of the two symbols, which remained on the screen until a response was made. The duration of the arrow was chosen to be relatively short as the strongest effect of cuing on target detection occurs at relatively short intervals (Posner et al., 1984). The intertrial interval (measured from response offset) was 1 s. The subject's task was to press the key corresponding to the symbol as quickly as possible. Both accuracy of key response and reaction time (RT) were measured. The control group (all right-handed) used the index and middle finger of the right hand. Sixteen of the 20 non-neglect subjects used their dominant hand for responding (15 right-handed including the switched hander and 1 left-handed). The remaining 4 subjects, all of whom had sustained a left hemisphere lesion and suffered a right-sided hemiparesis affecting their dominant hand, used their nondominant hand for responding (see Table 1 for details). Fourteen of the 16 neglect patients used their dominant hand (13 right hand, 1 left hand; see Table 2 for details) while the remaining 2 patients, who were hemiparetic on their dominant side, used their nondominant hand. Subjects were first trained on the stimulus-response mapping on 24 trials. Once this was mastered, the arrow cue was introduced and they received 24 practice trials with the arrows and targets, reflecting the same distribution of conditions as in the experiment.

Design

There were two conditions in the experiment: (1) *valid trials*, in which the arrow reliably indicated the side of the response, making up 80% of the trials, and (2) *invalid trials*, in which the arrow did not reliably indicate the side of the response, making up the remaining 20% of the trials. The invalid left trial, which is the critical condition for the majority of the patients, that is, those with left neglect, involved the appearance of a rightward-pointing arrow but the target required the left (index finger) response. The validity variable was crossed orthogonally with the side of response, either left or right finger, making a total of 300 trials (120 left valid, 120 right valid, 30 left invalid, 30 right invalid). The analysis involved evaluating the individual and joint effects of validity and response side on RT. Although accuracy was also measured, the task was simple and the exposure duration of the target unlimited so that very few errors were made. Important to note is that, in this task, there is a horizontal spatial dimension for the side of the response but not for the stimuli and the response hand is centered over the midline of the computer screen.

The trials from the four conditions were randomized within a block of either 50 or 100 trials with each block maintaining the valid:invalid ratio and the equal probability of left or right finger response. With the exception of 2 subjects, all of the normal control subjects completed three blocks of 100 trials each with a break between each block. The remaining 2 subjects completed one block of 100 trials and then four blocks of 50 trials. All the Neglect and Nonneglect subjects, with the exception of one who completed three blocks of 100 trials, completed six blocks of 50 trials.

RESULTS

Two major analyses were undertaken, the first to examine differences in performance between the three groups and the second to examine the individual neglect patient data in more detail. The perils of averaging data in neuropsychology are well known (Caramazza, 1984, 1986) and it is for this reason that we examine the performance of the groups as a whole as well as the performance of the individual subjects.

Group Comparisons

Figure 1 shows the mean of the median RTs and errors (in brackets) of the control group as a function of validity and side. The mean error rate (including anticipatory responses which refer to key presses to the arrow rather than to the target) for the control group constituted fewer than 1% of the total trials, too few for a full analysis.

Figure 2 shows the mean of the median RTs and errors for the Non-neglect group as a function of validity and side. The mean error rate (including anticipatory responses) for the non-neglect group collapsed across all conditions was equal to 2.6% of the total trials. A two-way ANOVA with the error data alone reflects no significant effects of validity or side on subjects' performance, nor an interaction between side and validity [validity ($F(1,14) = .16$, $MSe = .42$, $p > .5$); side ($F(1,14) = .15$, $MSe = .41$, $p > .5$); interaction ($F(1,14) = .22$, $MSe = .22$, $p > .5$)].

Figure 3 shows the mean of the median RTs and error percentage for the Neglect group as a function of validity and side. The error rate (including anticipatory responses) collapsed across all conditions was equal to 3.9% of the total trials. A two-way ANOVA with the neglect subjects' error data reveals no significant

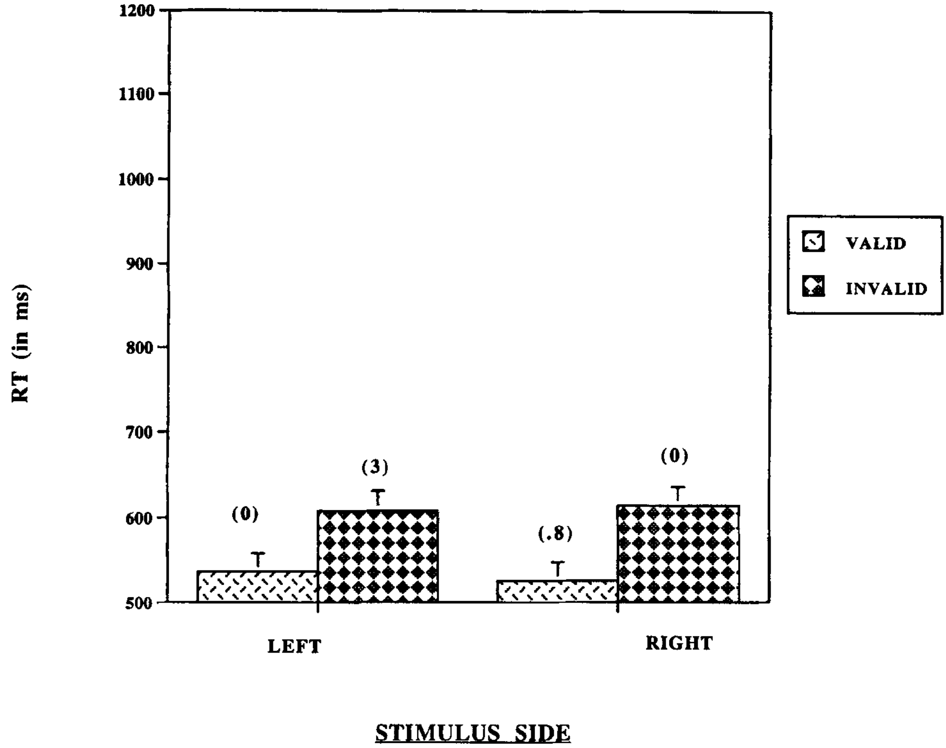

Fig. 1. Mean of the median RT and percentage error (in brackets) for the normal control subjects in the action cuing task as a function of side and validity.

effects of validity or side on subjects' performance, nor an interaction between side and validity [validity ($F(1,17) = 1.1$, $MSe = 1.13$, $p > .1$); side ($F(1,17) = 1.8$, $MSe = 3.1$, $p > .1$); interaction ($F(1,17) = 1.5$, $MSe = 1.2$, $p > .2$)].

A repeated measures ANOVA on the 51 subjects' median RTs was performed with group (neglect, non-neglect, and normal) as a between-subjects factor, and validity (valid, invalid) and response side (contralesional, ipsilesional) as within-subject variables. Post-hoc pairwise comparisons, using a Tukey test for unequal Ns with a cut-off of $p < .05$, were carried out to examine the source of the observed interactions.

The most critical result of the three-way ANOVA is that, as predicted, the three-way interaction with group, validity, and side was significant ($F = (2,48) = 9.5$, $MSe = 8284.8$, $p < .001$). Post hoc analysis of these data show that the major result comes from the relative differences in the way in which the combination of side and validity affected each group's performance. Because the group differences in the three-way interaction are of paramount interest, the results of the post hoc tests and individual analyses performed within each group are reported for each group separately.

Normal subjects

The post hoc tests on the normal subjects showed no significant joint effects of side and validity. These results suggest that, whereas normal subjects are slower in the invalid condition relative to the valid condition by an average of 81 ms, the side of the action or response does not significantly affect the control subjects' RTs nor does it interact with condition of cuing (see Fig. 1). A two-way ANOVA conducted just with the data from the control group

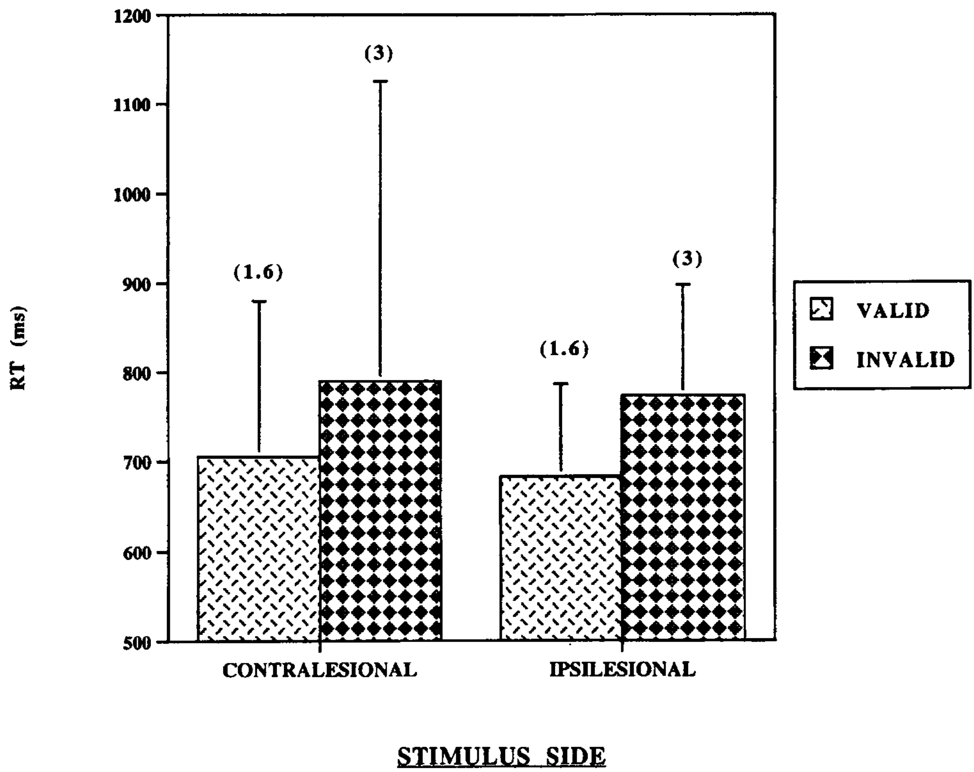

Fig. 2. Mean of the median RT and percentage error (in brackets) for the Non-neglect subjects in the action cuing task as a function of side and validity.

and with validity and side as within-subject variables supports the significant main effect of validity ($F(1,14) = 35.6$, $MSe = 2776.1$, $p < .0001$) and the absence of any other effects [side: ($F(1,14) = .11$, $MSe = 840.7$, $p > .5$); interaction ($F(1,14) = 1.9$, $MSe = 567.5$, $p > .1$)].

Non-neglect group

The post hoc test in the three-way interaction shows that, in the Non-neglect group, the RTs in the ipsilesional valid condition were the fastest relative to all other conditions. On a two-way ANOVA using only the mean of median RTs for the non-neglect group, however, the interaction between side and validity was not significant (see Fig. 2). In fact, the findings were similar to that of the control group with validity significantly affecting RT ($F(1,19) = 20.8$, $MSe = 7379.7$, $p < .001$) and no other significant effects on performance [side: ($F(1,19) = 2.5$, $MSe = 2785.5$, $p > .1$); interaction ($F(1,119) = .06$, $MSe = 2270.8$, $p > .5$)]. The overall cost of the invalid over the valid condition was, on average, 91 ms. These results suggest that the performance of the Non-neglect group was similar to that of the control group in that there was no effect on performance of effector side but only of cuing or validity. The RTs of the Non-neglect group are slowed overall relative to the control group as is usually the case in patients with brain damage.

Neglect group

The post hoc tests on the data from the neglect group shows that the mean RT on the invalid contralesional trials (mean 1166 ms) was significantly different from all the other conditions (invalid ipsilesional, valid contralesional, and valid ipsilesional) while these other conditions

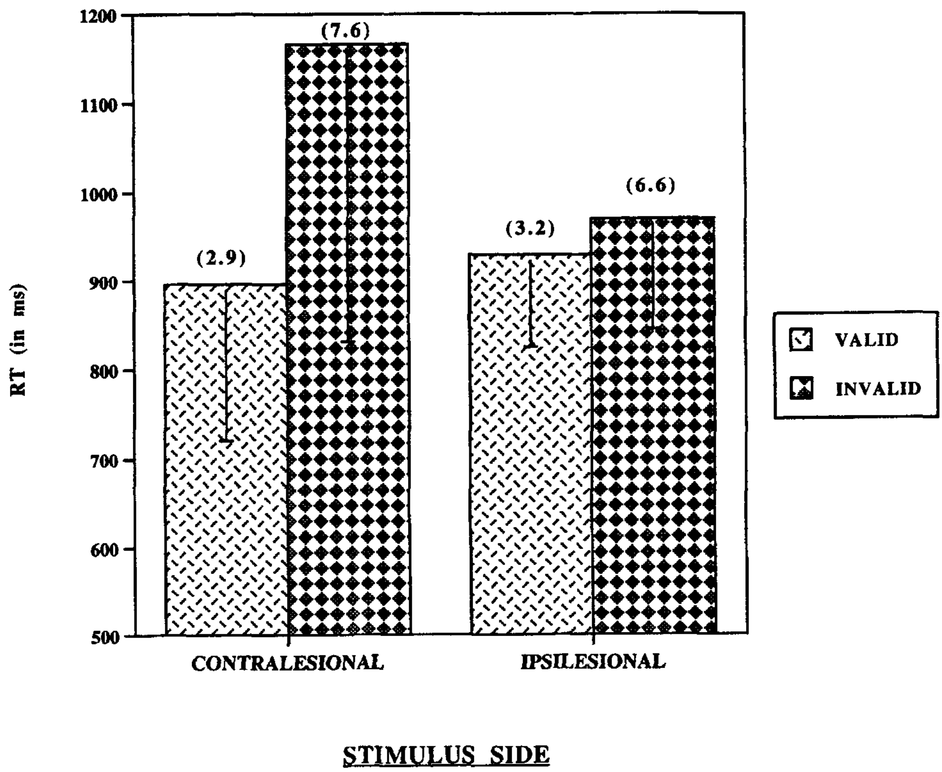

Fig. 3. Mean of the median RT and percentage error (in brackets) for the Neglect subjects in the action cuing task as a function of side and validity.

did not differ from each other (see Fig. 3). Whereas the difference between valid and invalid trials on the ipsilesional side was, on average, 41 ms, the difference between valid and invalid trials on the contralesional effector side was 270 ms. The two-way ANOVA on the mean of median RTs for the neglect group alone showed the interaction between validity and side and revealed the disproportionate slowing of RTs in the contralateral invalid condition ($F(1,15) = 9.04$, $MSe = 23105.4$, $p < .001$). In addition, a main effect of validity was noted with slower invalid than valid RTs ($F(1,15) = 10.8$, $MSe = 35714.4$, $p < .005$). A main effect of side was also observed with slower contralesional than ipsilesional responses ($F(1,15) = 5.5$, $MSe = 19342.6$, $p < .05$).

Individual Subjects Comparisons

Although the three-way between-group interaction is significant and the side of response by validity interaction holds only for the neglect group as predicted, further analysis is necessary to claim that the joint effects of side and validity are not merely an artifact of the group data. One way in which such an artifact may arise is through one half of the group showing one of the effects (e.g., side) and the second half showing the second effect (e.g., validity) rather than each subject being influenced by the joint effects of side and validity. To make the argument more compelling that it is the simultaneous and joint effects of the side and the validity of the trial that influences each subject's performance significantly, it would be important to demonstrate that the expected interaction also holds in the individual subject data. To this end, a two-way ANOVA on the individual data was conducted for each of the 51 subjects using the RTs of a single subject with trial as a random factor and validity and side as the two variables.

Two of the 15 control subjects showed the interaction of side and validity in their individual data although they do so in opposite directions. One subject showed disproportionate slowing in the left invalid condition relative to the other conditions and the other showed disproportionate slowing in the right invalid condition. Four Non-neglect patients (3, 6, 9, and 20, see Table 1) demonstrated the side by validity interaction but not all show it in the manner expected in patients with neglect. In 2 subjects (subjects 3 and 9), the interaction comes from greater cost of the invalid relative to the valid ipsilesional trials rather than contralesional trials, a pattern opposite to that seen in patients with neglect. One subject (subject 6) showed a cross-over interaction with fastest contralesional valid trials and slowest ipsilesional invalid trials. The final Non-neglect subject (subject 20) showed the interaction that reflects the attentional deficit, that is, the valid contralesional condition is slower than the valid ipsilesional condition and the cost on the invalid contralesional side is greater than on the invalid ipsilesional side.

Most importantly, in turning to the individual data in the Neglect group, 3 of the 16 subjects (subjects 6, 13, and 14, see Table 2) showed the predicted side by validity interaction in the direction of interest and 5 more (subjects 1, 9, 12, 15, and 16) showed the interaction but it did not quite reach statistical significance. The finding that the interaction does not quite reach significance is not surprising given that the power in the individual analyses, relative to the group analysis, is markedly reduced and that the variance in the individual data is high (as is well known for patient data). That 8 of the 16 subjects show the interaction in the individual data and none show it in the opposite direction (binomial test p = .004) and that 15 of them have greater cost of invalid over valid trials on the contralesional than on the ipsilesional side attests to the robustness of the result.

DISCUSSION

The findings from the present experiment confirmed the prediction that subjects with an attentional deficit following brain damage reveal a disproportionate increase in RT to invalidly cued trials in which the required response involves the contralesional side of action space. This 'extinction pattern' (Posner et al., 1984) is clearly seen in the group data and, to the extent possible because of high variance in the individual data, a similar pattern in seen in the individual RT analyses. Neither the normal control group nor the non-neglect brain-damaged subjects showed the interaction between side and validity in this direction. Whereas the latter two groups did show a cost associated with the invalid over the valid trials, the cost was equivalent for both response sides. These findings suggest that the critical side by validity interaction, which is now taken as a hallmark feature of visuospatial neglect, is also seen in the analogous response cuing task in which selective attention influences the coding of spatial information for the side of response.

EXPERIMENT 2: VISUOSPATIAL ATTENTION AND NEGLECT FOR THE CONTRALATERAL SIDE OF RESPONSE SPACE

The findings from the previous experiment are relatively straightforward – in a spatial cuing action paradigm, most patients in the neglect group, and no other group, produced slower responses with the invalidly cued contralesional effector relative to all other conditions. One interpretation of the contralateral response neglect is that the deficit arises from an underlying impairment of spatial attention (Cohen et al., 1994; Posner & Petersen, 1990; Posner et al., 1984). Furthermore, because visuospatial processing and action are closely coupled, the underlying attentional impairment which gives rise to response neglect might be the same as that which gives rise to neglect in the visuospatial domain. A stronger test of this hypothesis would be to show that the hallmark side by validity interaction is observed within the same patients on both the action analog task as well as on the visuospatial cuing task. To assess this, 10 of the neglect patients who participated in Experiment 1 also completed the visuospatial cuing task used by Posner and his colleagues (1980, 1988, 1990; Posner et al., 1984). The important difference between the two experiments is that, in the action task in Experiment 1, the stimuli remained in the foveal position and the responses had a relative left and right position whereas in the visuospatial task in Experiment 2, the stimuli have a relative left and right position and the response remains centered in the midline position.

METHOD

Subjects

In order to carry out this within-subject analysis, 10 of the neglect subjects (listed as subjects 7-16 in Table 1) who participated in Experiment 1 also participated in Experiment 2. These subjects were not selected specifically but rather, they were the only subjects to whom we had access for sufficient time to allow for the completion of both tasks.

Procedure

The procedure was similar to that of Experiment 1 and the design was identical. The task adopted here was the visuospatial attentional cuing task used by Posner and his colleagues (Posner, 1980, 1988; Posner et al., 1982, 1984). In response to the appearance of a single target which appeared on either the left or right side of space with equal probability, subjects pressed a single, centrally located key as quickly as possible. The events in a trial followed the same course as in Experiment 1 and were as follows: A central black fixation point appeared in the foveal position on a white computer screen for 1s followed by a 500-ms delay. Thereafter, an arrow replaced the fixation point and appeared centrally for 250 ms. The arrow was immediately replaced by the target, an asterisk, which appeared 4.5° to the right or left of fixation and which remained on the screen until a response was made. This is a simple target detection task with no choice or decision. The intertrial interval (measured from response) was 1 s. Accuracy of key response and reaction time were measured. Responses were made on the keyboard using a single key, either the "," or the '.' key, counter-balanced across subjects. Subjects responded with the index finger of the same hand used in Experiment 1. The key and hand were positioned along the midline of the screen.

Design

There were two conditions in the experiment: (1) *valid* trials, making up 80% of the total, in which the arrow reliably indicated the side of space on which the asterisk would appear and (2) *invalid* trials, making up the remaining 20% in which the opposite held, for example, the arrow cued to the right and the target asterisk appeared on the left. The two conditions were crossed orthogonally with the side of stimulus, either left or right side, making a total of 300 trials (120 left valid, 120 right valid, 30 left invalid, 30 right invalid). As in Experiment 1, the analysis involved evaluating the individual and joint effects of validity and target side on RT. Although accuracy was also measured, the task was simple and the exposure duration unlimited with the result that very few errors were made.

The trials from the four conditions were randomized within a block of either 50 or 100 trials with each block maintaining the valid:invalid ratio and the equal probability of left or right stimulus location. All subjects received 24 practice trials, reflecting the same distribution of conditions as the experiment, prior to the start of the experiment. The same 10 subjects completed both Experiments 1 and 2 (and the order of presentation of the two tasks was counterbalanced as far as possible) and a within-subject comparison of performance on both tasks was carried out. The prediction was that, if the neglect for side of response and neglect for the side of the stimulus were attributable to a common underlying deficit affecting the coding of spatial information, then a comparable pattern of results would be obtained across the two tasks.

RESULTS

The median RTs and percentage error responses for the 10 neglect patients on the visuospatial perceptual task and the response task are shown in Figures 4 and 5, respectively. In the visuospatial task, only 1.3% of the data was excluded, with 1.1% arising from anticipatory responses and .2% from errors. In the response task (calculated from the subset of the data from Experiment 1 for the 10 subjects), 3.3.% of the data were excluded, 1.2% from anticipatory responses and 2.1% from errors.

A repeated measures three-way ANOVA was conducted on the median RTs for the neglect subjects with task (visuospatial, response), side (contralesional, ipsilesional) and validity (valid, invalid) as within-subject variables. The three-

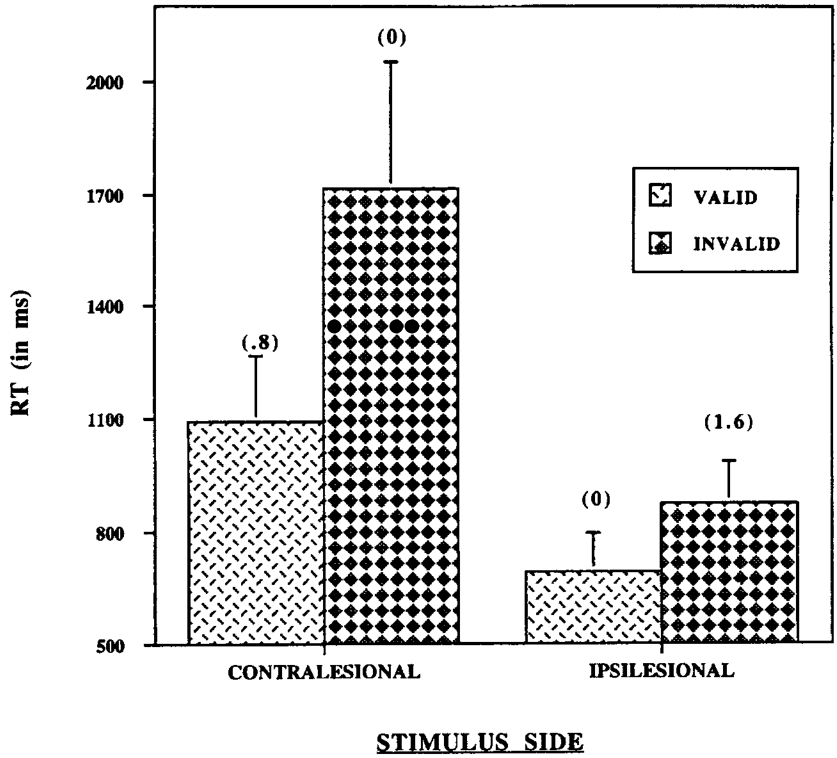

Fig. 4. Mean of the median RT and percentage error (in brackets) for the 10 Neglect subjects in the visuospatial cuing task as a function of side and validity.

way interaction was not significant ($F(1,9) = 2.46$, $MSe = 22925.8$, $p > .1$) showing no differential effects of the side and validity variables across the two tasks. All two-way interactions reached significance. In the interaction with task, a greater overall cost in the invalid over valid trials was seen in the perceptual (366 ms) than in the response task (106 ms) ($F(1,9) = 8.9$, $MSe = 37545.6$, $p < .02$). Similarly, the impairment on the contralesional side relative to the ipsilesional side was also greater in the perceptual task (566 ms) than in the response task (98 ms) ($F(1,9) = 10.2$, $MSe = 107884.6$, $p < .02$). Both these effects are presumably attributable to the exaggerated slowing in the contralateral invalid trials on the perceptual task relative to the response task. Finally, the two-way interaction between validity and side was also significant with greater contralesional (378 ms) than ipsilesional (95 ms) cost for invalid over valid trials. There were significant main effects of validity ($F(1,9) = 13.5$, $MSe = 163378.7$, $p < .01$) and side ($F(1,9) = 13.5$, $MSe = 82925.4$, $p < .01$), manifest as slower responses to invalid (mean 1091 ms) than valid trials (mean 854.3 ms) and slower responses to contralateral (mean 1138 ms) than ipsilateral targets (mean 806.4 ms). In contrast, there was no main effect for task ($F(1, 9) = 2.5$, $MSe = 190597.1$, $p > .1$) confirming the comparable patterns of performance in the visuospatial and response tasks. Although, intuitively, the action task appears to be the more difficult of the two tasks as it has a forced-choice stimulus-response mapping and the visuospatial task is a simple target detection paradigm, this does not seem to be the case, at least as reflected in base RT. In fact, RTs on the ipsilesional side are relatively comparable across tasks and the major difference is restricted to one condition, with considerably slower

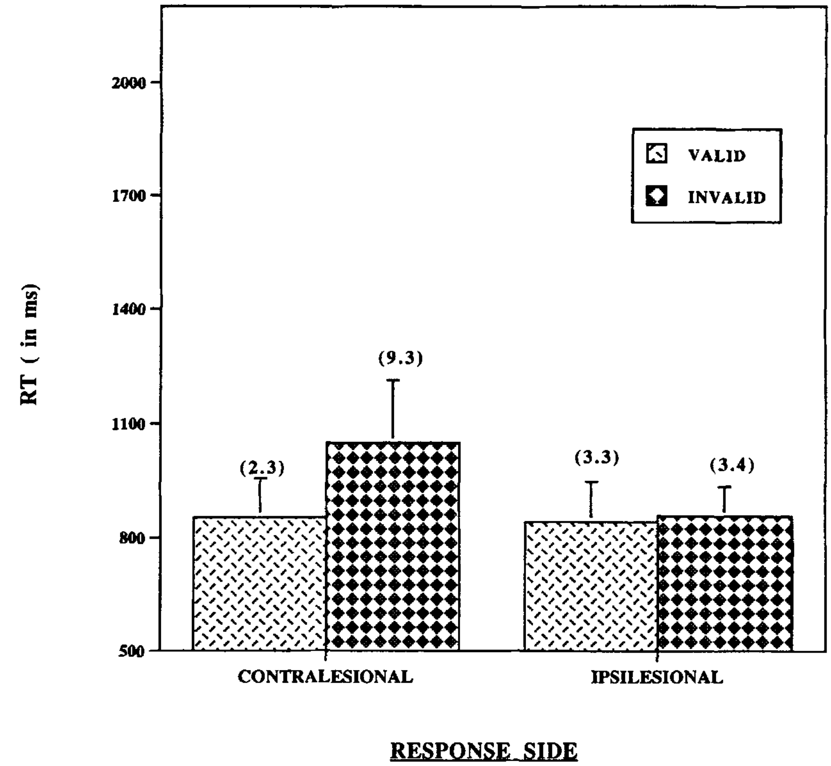

Fig. 5. Mean of the median RT and percentage error for the 10 Neglect subjects in the action cuing task as a function of side and validity.

RTs to the invalid contralateral trials in the visuospatial task. A possible explanation for the difference to the contralesional targets across the two tasks is suggested later.

The critical result from this experiment is that the disproportionate slowing of processing on the contralesional side in the response cuing task is replicated on the visuospatial cuing task in the same patients. To examine the extent to which this pattern is observed in the individual patient data, a two-way ANOVA with side and condition as within-subject factors and subject as the random factor was carried out. Five of the 10 subjects showed a statistically significant interaction in the visuospatial cuing task with all showing it in the same direction, that is, a greater cost of invalid over valid trials on the contralesional than ipsilesional side. The data from the remaining 5 subjects approached significance and the results show trends in the same direction for all of them (binomial test $p =$ .001). These findings replicate the original results of Posner and his colleagues as well as those of subsequent studies (Morrow & Ratcliff, 1988), all of which demonstrate an impairment in deploying attention to the contralesional side when cued to the ipsilesional side. Unlike in the Posner et al. studies (Posner et al., 1984; Posner, 1988; Posner & Petersen, 1990), however, these patients do not have lesions restricted to the parietal lobes, although in almost all the cases in the current study, the parietal lobe is implicated.

The hallmark feature of the visuospatial and the response tasks is an exaggerated difficulty in processing the stimulus or in executing the response on the contralesional side when attention is invalidly cued to the ipsilesional side. As predicted by the common spatial coding view, performance on the two tasks should be correlated if a common mechanism is implicated for both of them. The correlation was calculated by comparing the cost in RT (in ms) for the invalid over valid trials on the contralesional side over and above the ipsilesional side on both tasks for each individual. For the 10 subjects, the Pearson R correlation was 0.504. This correlation is modest (but probably robust given the small sample size) and suggests a substantial relationship between the two domains. The results thus far suggest that the pattern of impairment observed in the action task is also seen in the visuospatial task and that performance on the two tasks is moderately correlated in a small group of subjects.

A further method of examining the relationship or dissociability of performance in the two tasks is to see whether there are subjects who show, the extinction-like effect in only one of the two tasks and if so, whether the direction of the dissociation is consistent across the patients. To examine this, the number of patients who show the side by validity interaction on either or on both the visuospatial and response tasks was counted. Of the 5 neglect subjects who show the significant interaction on the visuospatial task, 3 also show the interaction significantly on the response task. The remaining 2 subjects do not show a significant interaction on the action task although, in one of them the interaction is present but not significant. Of the 5 patients who do show the trend towards the significant interaction on the visuospatial task, none shows the interaction significantly on the response task , 3 show the trend towards significance and one does not show the side by validity interaction on the action task at all. Of major interest is that no subject shows the significant interaction on the response task but not on the perceptual task whereas the converse is true. That the hallmark interaction is more evident in the visuospatial than in the action task and that no subject shows the converse pattern indicates that there may be some task-specific differences that need to be explained.

DISCUSSION

The results from Experiment 2, as in Experiment 1, reflect the critical result of a greater cost of invalid over valid trials on the contralesional side relative to the ipsilesional side. The group data and, in most cases, the individual data replicate those of Posner's original report and confirm that the impairment giving rise to the neglect in these patients is one of attention. Comparing the data of the 10 subjects who completed both the visuospatial cuing and the response task reveals a moderately high correlation between their performance and shows no interaction of these tasks with the other variables of side and validity. That the joint effects of side and validity are similar across the tasks is consistent with the hypothesis that a common set of spatial representations is involved in both domains. In addition to the similarity, there are differences between the two tasks, as reflected in the imperfect correlation and the stronger effects of validity and side in the perceptual than in the action task, possibly suggesting some dominance or salience for the visual task. Consistent with this is a finding of directionality: no patient shows the extinction-like pattern in the response task without also showing it in the visuospatial task whereas the converse does apply.

One interpretation of the difference between the tasks is that a common internal spatial representation is involved in both but that the exaggerated effects on the visuospatial task arise because of a difference in the demands of the two tasks. On the visuospatial task, the asterisk which was left-right lateralized appeared at a 4.5° visual angle from fixation on either side. The left-right disparity is greater here than in the response task in which the fingers were positioned on adjacent keys on the keyboard and the distance between the fingers was approximately one inch. An increase in the severity of neglect as a function of the left-right position of the stimulus has been documented (Behrmann, Moscovitch, Black, & Mozer, 1990). The further to the right the stimulus appears, the better is performance and conversely, the farther over to the left the stimulus appears, the poorer is performance. That the contralesional impairment is greater in the visuospatial than in the action task may be explained by this difference in horizontal distance. An obvious test of this explanation would be to keep constant the spatial distance between the left-right stimuli and the left-right responses. If the difference between the tasks is simply an artifact of the spatial distance, performance should be strongly correlated across the two tasks when distance is equated.

GENERAL DISCUSSION

Many human activities require the coordination of perception and action for integrated and organized behavior. Selectively attending to the location of an object and then executing an action to that location are both inherently spatial operations. The purpose of this paper is to examine to what extent these two activities, visuospatial processing and goal-directed spatial action, share a common set of internal representations. The answer to this question may shed light on the debate of whether spatial attention is a module (Moscovitch & Umiltà, 1990) operating over a restricted domain or a more general-purpose central processor (Fodor, 1983, 1985). A better understanding of this issue may provide important constraints on the status of attention in the mental architecture.

In order to address this issue, we studied the performance of a group of patients with hemispatial neglect, a disorder attributed to an impairment in spatial attention (Marshall et al., 1993; Posner, 1988; Posner et al., 1982, 1984) on two experimental tasks both of which involved cuing of spatial attention. On these tasks, a centralized arrow indicated, with high probability, the side of space on which the stimulus would appear (visuospatial task) or the side on which the response key (response or action task) was to be pressed. On a subset of the trials, making up 20% of the total, the cue did not reliably predict the side and the stimulus or response fell on the uncued side. In the action or response version of the task, the visual stimuli appeared foveally and the response component was lateralized with two fingers of a single hand positioned each in relative right and left space. The converse was true for the visuospatial task in which the stimuli were lateralized in space and the response component (a single key) remained constant in the midline position. In addition to the neglect group, two other groups participated: patients with brain damage without neglect and normal elderly control subjects. The first prediction was that if an attentional mechanism is involved in coding information in the response task, then neglect for the contralateral response, especially in the invalidly cued condition, would be seen in the neglect group but not in the other groups. Second, if the same spatial attentional mechanism subserves both the visuospatial and the action domain, then performance on the two tasks would be associated and comparable deficits would be seen in the neglect patients across both tasks.

The results of the action task in the neglect patients revealed the predicted impairment on the contralateral side of the response space. When the central arrow cued attention ipsi-lesionally and the response on the contralesional side was required, performance was slowed disproportionately relative to all other conditions. This significant interaction of side by validity on RTs or 'extinction-like' pattern (Posner et al., 1984) held across the group which contained both right- and left-lesion subjects and, to the extent possible, was confirmed in the individual data. Although this pattern did not reach significance in every subject, most showed a trend in the correct direction and all but 1 of the 16 patients had the longest RTs in the invalid contralateral condition. The specificity of the 'extinction-like' pattern in patients with an attentional disorder is confirmed by the data from the control groups: the side by validity interaction was not seen in the group nor in the individual data of either the non-neglect or normal elderly control group (with one exception out of 35 subjects). These findings are consistent with the view that neglect for the left of action or response space does exist and that it is specific to patients with an attentional deficit, acquired following brain damage.

Ten of the patients who completed the action cuing task also participated in the visuospatial cuing task, thereby allowing a within-subject comparison across the two tasks. The results of the visuospatial task also revealed a significant side by validity interaction for the group, suggesting a deficit comparable to that revealed on the action cuing task. A closer examination of the data across the two tasks showed a moderate correlation between performance in the two domains although the main effects of validity and of side were more exaggerated in the visuospatial than in the response task. The exaggerated effect in the former task may be attributed to the fact that the distance between the left and right visual stimuli exceeded the distance between the left and right effectors. This explanation is consistent with views of an attentional gradient underlying neglect with maximal distribution to the right and incrementally less attention leftwards across space (Behrmann et al., 1990; Kinsbourne, 1987; Làdavas, 1993). On this account, the severity of neglect is increased as stimuli appear further over to the left side of space.

Although we have argued that the findings from these experiments favor a view of a common underlying representation, the results, based on the findings of associated and correlated performance, may also favor other possible interpretations. For example, one view consistent with these data is that there may indeed be a common spatial code underlying the visuospatial and action tasks but that it is not the shared representation itself that is affected following brain damage. Rather, the impairments observed on the two tasks might arise from independent damage to two routes, one for responding and one for perception, through which this shared information is accessed ('access' disorders, Shallice, 1987). While theoretically possible, this task- or modality-specific access account is unlikely; because performance is reasonably well correlated across the tasks, this account must assume that the access routes for visuospatial and for response processing are damaged to an equivalent degree and this is not particularly parsimonious. Another view which is consistent with the data but which goes even further and challenges the existence of a shared representation itself is one which asserts that the correlation between performance on the action and visuospatial tasks does not come from damage to a shared mechanism at all. Rather, the claim is that the co-occurrence of the deficit arises because two independent areas, each subserving a separate representation, are both impaired following an extensive brain lesion. The lesions of the neglect subjects in this study are all fairly large, consistent with this view. Again, however, the view would have to argue that the lesions affect the two separate mechanisms to a comparable degree such that performance on the two tasks is moderately correlated. While some of these alternative views, such as that suggesting a deficit in independent access routes or of independent areas with separate representations, may provide an explanation for the data, the most parsimonious interpretation of these findings is still that a common set of spatial representations is utilized in both tasks.

Throughout this paper the claim is made that the underlying deficit in neglect is one of attention and that this attentional deficit gives rise to an impairment in an underlying representation. One of the recurring issues of debate in the neglect literature is whether the deficit is one of attention or whether it is an impairment in the underlying mental representation. Attentional explanations, for example, argue that attention operates as a spotlight illuminating various sectors of a representational display (Eriksen & St. James, 1986; Posner, 1980), as a competition between equal areas (Cohen et al., 1994) or possibly as a gradient across the entire field (Downing & Pinker, 1985; Kinsbourne, 1987). In all cases, following brain damage, the distribution of attentional resources is unbalanced, giving rise to neglect. Representational explanations, on the other hand, assume that it is the internal, mental representation itself that is neglected. The classic example of this is the reporting of the Piazza del Duomo scene in which patients with neglect omit details from the left of their internal, imagined representations (Bisiach & Luzzatti, 1978). Although the attentional-representational dichotomy has generated considerable debate and empirical pursuit, the distinction between the opposing schools is becoming blurred. For example, Bisiach (1993) has suggested that the attentional and representational explanations are logically indistinguishable from one another and has proposed instead that neglect should be considered a deficit in spatially structured representational activity. The hybrid view of attention and representation, such as that proposed here, assumes that the attentional process, through which contralesional spatial information is coded, is affected in patients with neglect, and that this impoverished or damaged representation serves as the basis of subsequent behavior.

Common Code for Visuospatial and Action Tasks

Based on the findings from this study, we have argued for the view that a common internal spatial representation subserves both perception and action. A further source of support for the derivation of a common code for action and perception comes from research with normal subjects in various stimulus-response compatibility studies. Using stimuli and effectors which have some horizontal extent, that is, appear on the left or right of space and responses are made with left or right hand, many of these studies show that when the codes for action are congruent with the visual stimulus (left stimulus – left hand response), performance is facilitated relative to when they are incongruent (left stimulus – right hand response) (Nicoletti, Umiltà, & Làdavas, 1984; for examples of recent papers, see O'Leary & Barber, 1993 and Proctor, Van Zandt, Lu, & Weeks, 1993). An important finding of these studies that is particularly relevant to the current work is that, in executing a response, subjects code the relative spatial position of the effectors (Nicoletti et al., 1984) even when the hands remain fixed in one spatial position (i.e., have no directional movement) as in the present task. Furthermore, these spatial effector codes may be formed through attentional processes which allow the differentiation between left and right coding (Umiltà & Liotti, 1987; Umiltà & Nicoletti, 1990). That the spatial location of the effectors is coded and that this code is then used in carrying out the task provides converging evidence for the view that a spatial representation underlies response execution and that when this representation is disrupted, response neglect occurs.

While the spatial compatibility studies are informative as far as delineating the type of codes derived for task execution, the role of attentional selection in accessing the codes for action is often not considered in detail. An exception to this is the recent study by Tipper, Lortie, and Baylis (1993) who examined attentional selection for action directly in a reaching paradigm in a group of college students. In this paradigm, the subject is required to reach and press a target key identified by a red LED from among nine possible keys which are displayed in a 3x3 matrix. On some trials, along with the illuminated red LED, a yellow LED, associated with one of the other keys (above, below, left, or right of the target), is concurrently activated and the effect of this distractor on RT to press the target key is measured. The two major findings of this study are that visual distractors inhibit responses relative to the no-distractor condition and that the spatial location of the distractor determines the extent of the inhibition. Distractors in the path of the response trajectory cause more interference than those outside the path, and distractors ipsilateral to the responding hand produce more inhibition than those contralateral to it. The conclusion from these findings is that when more than one response is simultaneously activated, attentional selection must take place because action is sequential and only one response can be produced. That the spatial location of the alternatives influences the speed of the action suggests that attentional selection for action operates on a spatial representation.

To demonstrate further that spatial attentional selection is critical, using this same action-attention paradigm, Megan, Behrmann, and Tipper (in preparation) have shown that patients with left neglect are significantly impaired on this task relative to normal control subjects but only under certain conditions. Two measures of performance were taken in this study: initiation time, measured as the time to release the starter button following the onset of the target light, and transport time, measured as the time to press the target key from release of the starter button. Whereas there is no difference between the patients and age-matched controls on execution time, there is a significant difference in initiation time as a function of the location of the target and the simultaneously activated distractor. When the target appears contralaterally, the presence of an ipsilesionally positioned distractor slows performance significantly for the patients relative to controls whereas the same is not true for ipsilesional targets and contralesional distractors. These results, in which left response neglect is exacerbated by the presence of a right-sided visual stimulus, further confirm the close coupling between spatial attention and action. What remains unanswered from this study is with respect to what coordinates the left and right are coded in this task and whether these coordinates are shared for perception and action as might be expected from the common mechanism view. A number of recent findings have demonstrated that the coordinates for vision and motor behavior are closely integrated. For example, in the oculomotor domain Goldberg and his colleagues propose that visual input is directly remapped into motor coordinates. This dynamic remapping is achieved through activity in posterior parietal cortex which represents the vector shift in spatial attention necessary for transforming the retinal input (Goldberg & Colby, 1989; Goldberg, Colby, & Duhamel, 1990; Goldberg & Segraves, 1987). Similarly, the view that spatial attention is critically related to motor preparation is the essence of the 'premotor theory' in which, according to Rizzolatti and his colleagues (Rizzolatti & Camarda, 1987; Rizzolatti, Riggio, & Sheliga, 1994; see also Chieffi, Gentilucci, Allport, Sasso, & Rizzolatti, 1993), the system and the coordinates that control motor plans are the same as those that control attention.

Spatial Attention: Neither Simply Modular nor Simply Central Processor

The results of this study, together with converging findings from cognitive psychology and neurophysiology, favor the view that there is a common, spatially structured representation mediating visuospatial and spatial action performance. A straightforward interpretation of this result is that the mechanism responsible for deriving such a spatial representation functions as a central processor rather than as a more circumscribed module in the mental architecture. In a coupled domain, such as visuospatial processing and spatial action, then, a common general-purpose representation serves as the link for sensorimotor interactions. These findings are more consistent with Fodor's view of attention as a central processor than with Moscovitch and Umiltà's view of spatial attention as a circumscribed, domain-specific module.

This interpretation, however, is not fully consistent with all of Fodor's criteria of a central processor. Whereas Fodor argued that central processors have no fixed neuroarchitecture, this study shows that a defined cortical lesion can give rise to a cross-domain attentional deficit. Furthermore, although the results of this study support the view of a general-purpose processor, the literature is replete with data showing dissociations between various modalities, tasks, and domains in patients with neglect (Bisiach et al., 1990; Costello & Warrington, 1987; Halligan & Marshall, 1993; Riddoch, 1990; Young, de Haan, Newcombe, & Hay, 1990). That such fractionation is possible suggests that spatial attention may not be unitary in all aspects. The co-occurrence of strong patterns of association as well as of dissociations favors neither the view of attention functioning solely as a domain-specific module (Moscovitch & Umiltà, 1991; Umiltà, this volume) nor the view of attention functioning solely as a central processor as defined by Fodor's criteria. Instead, spatial attention may operate as a module under some conditions but, in domains in which sensorimotor integration is necessary, a common internal representation is implicated.

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