

Neglect in vision and visual imagery: a double dissociation

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Summary

We report two patients with right hemisphere lesions who demonstrate a double dissociation on visual imagery and visual perceptual tasks. One (M.N.) performed normally on a variety of standard tests for neglect as well as on measures of visual attention known to be sensitive to the presence of neglect, yet failed to report items from the left side of an imagined scene. In contrast, the other (C.I.) performed

normally on tests of visual imagery but demonstrated substantial neglect on visual perceptual and visual attentional tasks. These data are not readily accommodated by accounts which attribute neglect to a single processing deficit, but suggest that the disorder is a heterogeneous syndrome attributable to disruptions of different aspects of spatial cognition.

Keywords: neglect; visual imagery; visual perception

Abbreviations: ANOVA = analysis of variance; ISI = inter-stimulus interval; RT = reaction time

Introduction

Bisiach and Luzzatti (1978) reported two patients who neglected not only the left side of their environment but also failed to report the left side of mental images. When asked to describe a familiar scene, the Piazza del Duomo in Milan, these patients reported a greater number of landmarks from the right side of the imagined square; critically, the tendency to report more landmarks from the right side was apparent both when the patients imagined themselves standing with their backs to the cathedral and when facing the cathedral from the opposite end of the square.

Bisiach and colleagues (Bisiach and Luzzatti, 1978; Bisiach *et al.*, 1979) attributed this pattern of performance to a failure to generate or maintain an adequate representation of the left side of the image. They accounted for the correspondence between performance on perceptual and mental imagery tasks in terms of a common cognitive capacity, i.e. the ability to construct and maintain a representation of the external environment, that was critical to visual perception as well as visual imagery.

An alternative account of these and similar data was proposed by Meador *et al.* (1987). These investigators reported a patient with neglect on perceptual tasks who also failed to report information from the left side of imagined

scenes. The patient's performance, however, was influenced by head position; when asked to turn his head toward the neglected side, the patient reported significantly more items from the left side of the imagined scene than when instructed to turn his head to the right. These investigators suggested that the neglect of the left side of the image was attributable, at least in part, to an impairment in the ability to direct attention to this portion of the imagined scene.

More recently, dissociations in performance on tasks assessing neglect in imagery and visual perception or exploratory behaviour have been noted. For example, Guariglia *et al.* (1993) reported a patient who neglected the left side of mental images but exhibited no clear neglect on perceptual tasks (see also Brain, 1941). Additionally, Bartolomeo *et al.* (1994) tested 30 patients with right and 30 with left hemisphere lesions on a battery of tests assessing visuospatial function as well as the ability to generate mental images. They identified one patient who initially demonstrated neglect on both visuospatial and imagery tasks, but 8 months later exhibited neglect only on imagery tasks. Twelve patients manifested neglect on visuospatial tasks but not imagery tasks (see also Anderson, 1993).

We report two patients with right hemisphere lesions to

whom sensitive measures of visual attention and visual imagery were administered. A clear double dissociation was noted such that one patient, C.I., exhibited profound neglect on visual perceptual and attentional tasks but performed normally on a visual imagery task; the second patient, M.N., performed normally on tasks assessing visual attention, but failed to report items from the left side of imagined arrays. This double dissociation cannot be readily accommodated by either of the accounts described above; these data are most consistent with the hypothesis that 'neglect' is a heterogeneous syndrome attributable to disruptions of different visuo-spatial representations or systems mediating intention to act in the neglected domain.

Subjects

Subject M.N.

M.N. is a 30-year-old right-handed woman with a high-school education who suffered an extensive right fronto-parietal ischaemic infarct at the age of 28 years, probably due to an embolus from an intra-cardiac tumour. Initially, she exhibited a left hemiplegia and hemisensory deficit as well as very mild and transient left-sided neglect. At the time of the testing reported here (2 years after the infarct), M.N. was living independently but unemployed. Neurological examination revealed a moderately severe left hemiparesis and mild left hemisensory impairment. Visual fields were full and ocular movements, including smooth pursuit, saccades and anti-saccades, were normal. There was no extinction of visual, auditory or tactile stimuli. CAT scan demonstrated an extensive right fronto-parietal infarction. As demonstrated in Figs 1 and 2 the right superior parietal lobule was infarcted, whereas the inferior portions of the angular and supramarginal gyri appeared to be at least largely preserved.

Neuropsychological examination revealed no evidence of neglect on a line-bisection task in which lines ranged in length from 4 to 32 cm; she performed equally well bisecting lines in the right and left hemispheres. Similarly, she performed normally on letter- and line-cancellation tasks presented at the midline and to the right and left of the midline.

On neuropsychological examination, M.N. performed normally on Teuber's visual search test (Teuber *et al.*, 1951) and scored in the 30th percentile on Raven's Standard Progressive Matrices (score of 35). She performed perfectly on a series of tests requiring that she made judgments about the physical attributes of named objects or line drawings; thus, for example, she reported that a ladder was larger than a shovel and that a lime was green.

M.N. was impaired on a number of visuo-spatial tasks. For example, she obtained a score of 11 out of 16 on the Benton Visual Form Discrimination task and 19 out of 30 on the Judgement of Line Orientation. Although drawings were poorly executed, there was no evidence of neglect of the left side on these tasks.

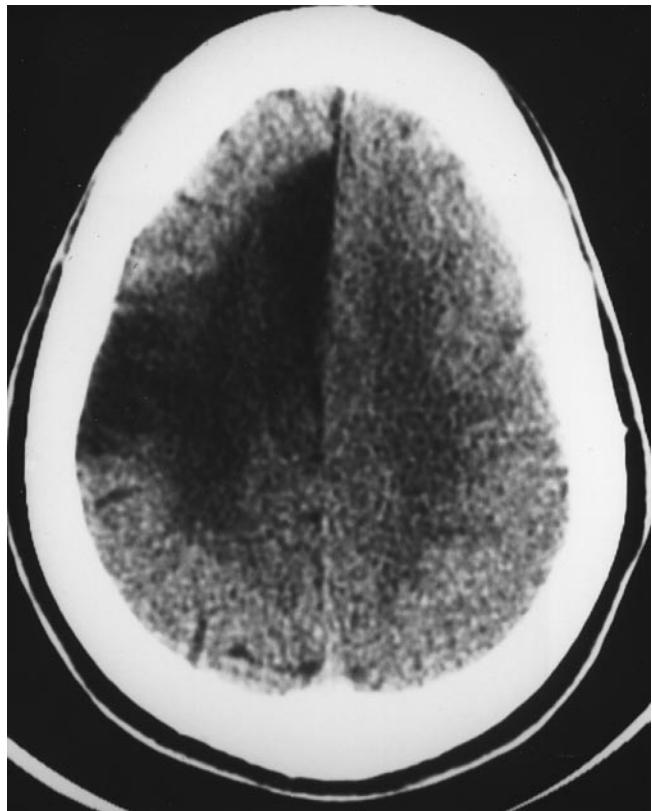


Fig. 1 A supra-ventricular CT scan image (M.N.) demonstrating infarction of the right mesial frontal lobe as well as portions of the post-central gyrus and, perhaps, the supramarginal gyrus on the right.

Subject C.I.

C.I. was a 70-year-old right-handed retired labourer, with a history of focal motor seizures involving the right arm, who had noted the sudden onset of left-sided weakness and sensory loss 2 years prior to the investigations reported here. He initially exhibited profound left-sided neglect but only mild left-sided weakness.

At the time of the investigations reported here (18 months after the right hemisphere infarct), C.I. exhibited mild bilateral pyramidal clumsiness and spasticity which was more prominent on the left. A left hemisensory deficit was also noted. Visual fields were full and ocular movements were normal except for hypometric saccades, noted both when following an object moving to the left and when deviating his eyes to the left to verbal command.

C.I. exhibited evidence of neglect on a variety of standard clinical measures. He erred to the right a mean of 18 mm when bisecting 32 lines varying in length from 4 to 32 cm. Similarly, he cancelled only the rightmost eight of a total of 40 'P's randomly arrayed on a 20.3×35.6 cm² sheet of paper. He omitted the left sides of drawings.

CAT scan revealed an extensive right hemisphere infarction involving the temporal, lateral frontal and inferior parietal lobes as well as small infarcts involving the lateral frontal lobe and superior occipital lobe on the left (see Fig. 3).

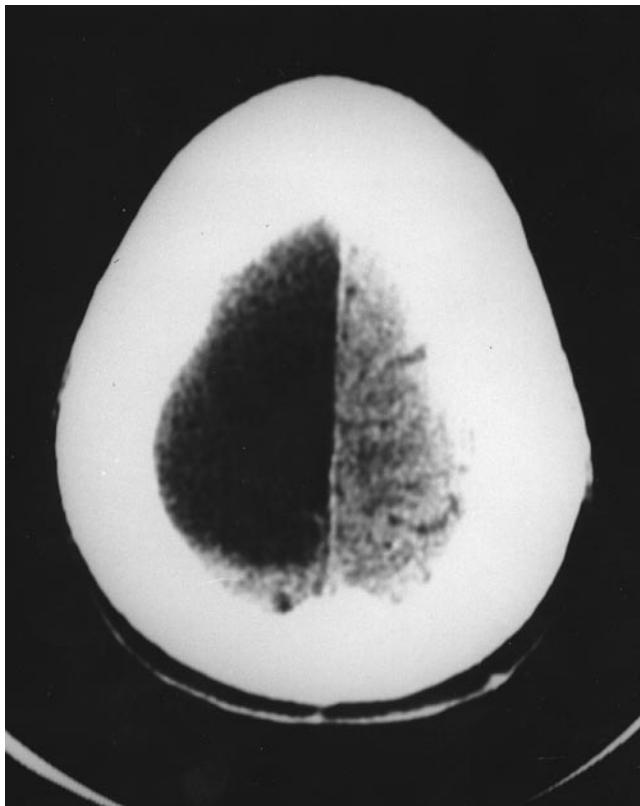


Fig. 2 A section CT scan image of M.N., higher than that in Fig. 1, demonstrating infarction of the superior frontal lobe, superior portions of the post-central gyrus, the superior parietal lobule and precuneus on the right.

C.I. was tested on the paradigm employed by Coslett *et al.* (1990) in an attempt to distinguish between directional hypokinesia and hemispatial inattention. In this task, subjects are asked to bisect a series of lines situated in either the right or left (body and head) hemispheres. Subjects are not permitted to gaze directly at the line to be bisected but receive visual input to guide their performance from a video monitor; as the monitor and lines to be bisected may be placed in different hemispheres, the effects of directional hypokinesia and directional hypokinesia may be dissociated. Consistent with the hemispatial inattention account, C.I.'s performance was not significantly influenced by the hemisphere in which he bisected the lines; his performance was significantly influenced, however, by the location from which he received visual information.

The testing reported here was approved by the Temple University Institutional Review Board. Both subjects and controls gave written, informed consent.

Experimental investigations

The data presented thus far indicate that C.I., but not M.N., exhibited substantial neglect on standard visual perceptual tasks. The following two experiments assessing visual attention were administered for two reasons. First, experience in our laboratory has demonstrated that line bisection,

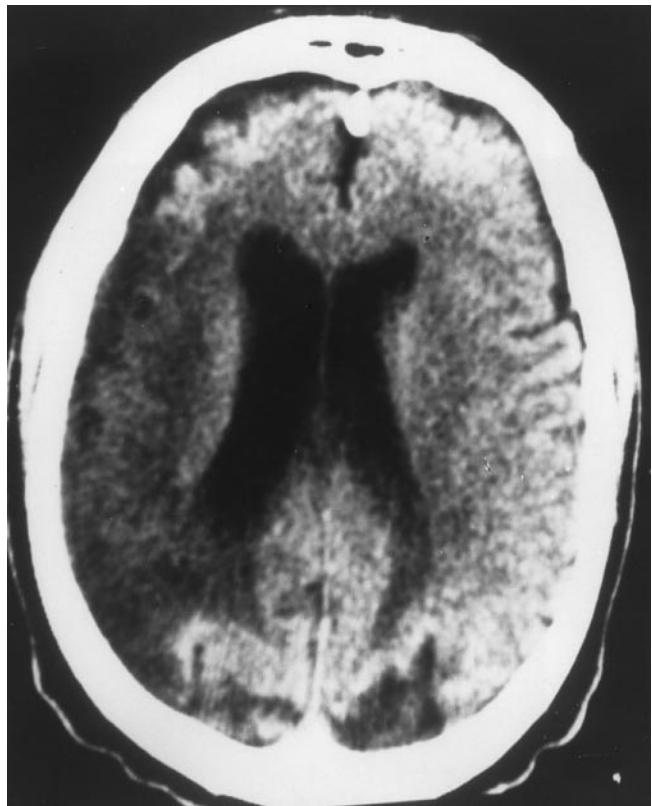


Fig. 3 A CT scan image (C.I.) demonstrating infarction of the right inferior frontal gyrus, lateral portions of the pre- and postcentral gyri and portions of the supramarginal, superior and middle temporal gyri on the right. A small left occipital lobe infarct is also noted.

cancellation and a number of other clinical measures of neglect may be insensitive to subtle deficits; i.e. we have encountered patients who do not exhibit a deficit on line-bisection and cancellation tasks yet exhibit a clear and substantial lateralized impairment on the more demanding tasks described below (see also Posner *et al.*, 1984). Secondly, the tasks were included to provide more direct measures of the integrity of visual attention.

Experiment 1: attentive and pre-attentive processes in vision

An experiment similar to that described by Treisman and Souther (1985) assessing 'pre-attentive' and 'attention-requiring' visual processes was performed. The experimental paradigm requires that subjects discriminate between circles (or 'O's) and circles of the same size with an intersecting vertical line at the 'six o'clock' position ('Q's). In the pre-attentive condition the task is to detect a 'Q' in an array of 'O's; in this task, detection of a 'Q' is normally rapid, effortless and independent of the size of the array. In the attentive condition, the task is to detect an 'O' in an array of 'Q's; normal subjects show an effect of array size in this condition, presumably reflecting the need to carry out a serial

Table 1 Pre-attentive and attentive processes in vision

	M.N.		C.I.	
	Left	Right	Left	Right
Simple RT	522 ± 93 (0)	549 ± 149 (0)	948 ± 290 (0)	786 ± 137 (0)
Pre-attentive (six items)	647 ± 127 (0)	624 ± 106 (0)	2114 ± 678 (25)	1425 ± 530 (0)
Pre-attentive (12 items)	582 ± 74 (0)	572 ± 48 (0)	2702 ± 821 (50)	1718 ± 652 (0)
Attentive (six items)	750 ± 120 (0)	776 ± 146 (0)	NR (100)	2262 ± 145 (90)
Attentive (12 items)	1124 ± 291 (0)	1017 ± 256 (0)	NR (100)	3989 (95)

The values given are mean RTs in milliseconds ± SD (and % misses). NR = not recorded.

search of the array. Extensive experience with this task with both normal (Fitzpatrick-DeSalme *et al.*, 1988) and brain-damaged subjects (e.g. Stark *et al.*, 1996; Coslett *et al.*, 1995) has demonstrated it to be a sensitive test of attention-requiring mechanisms in visual perception.

The experiment was performed in two sessions; there was a total of five conditions. In both the pre-attentive and attentive conditions, two set sizes of six and 12 items (Os or Qs) were used. In addition, a simple reaction-time task was included as a baseline measure. This task required detection of a single 'O' on an otherwise blank field. For all five conditions, the target appeared with equal frequency in each quadrant of the display. Stimuli were presented with a Gerbrands four-field tachistoscope.

There were 80 trials in the simple reaction time (RT), pre-attentive (six item), pre-attentive (12 item), attentive (six item) and attentive (12 item) conditions. The target was present on half of the trials in each condition. Exposure duration of the stimuli was controlled by a microcomputer which provided millisecond accuracy. Trials were initiated by the experimenter. Each trial consisted of a 1000-ms fixation point, followed by a stimulus card which was presented until the subject responded or for a maximum of 4 s. The subject's task was to depress the telegraph key if the target item (O or Q) was present and to refrain from responding if the target was absent. Feedback was provided only on practice trials. Note that as subjects were to respond only to the presence of the target, the numbers in parentheses in Table 1 indicate the percentage of trials on which subjects failed to detect the target rather than the overall error rate.

Results

As indicated in Table 1, M.N. performed normally on this task. Like controls, she exhibited a significant effect of array size on the attentive task for both the left ($t = 5.32$, $P < 0.05$) and right ($t = 3.66$, $P < 0.05$) hemispheres; no effect of array size was noted on the pre-attentive task (left: $t = 1.67$; right: $t = 1.03$). Additionally, there were no

differences in accuracy for stimuli presented on the left compared with the right.

C.I., in contrast, demonstrated a profound impairment on this task. RTs were significantly longer on the left compared with the right, on the simple RT and both pre-attentive tasks (all $P < 0.05$). He was slower to respond on the pre-attentive (12 item) compared with the pre-attentive (six item) condition but this difference was not significant for either the right or left. Additionally, he made significantly more errors on left-compared with right-sided stimuli on both the pre-attentive (six item) (Fisher's exact probability = 0.024) and pre-attentive (12 item) (Fisher's exact probability = 0.0002) tasks. Age-matched controls miss an average of 2% of stimuli. C.I. performed quite poorly on the attentive tasks, detecting only three of 40 targets during the 4 s display on the attentive (six item and 12 item) conditions combined; all of the detected targets were situated on the far right of the display. Controls make fewer than 5% errors on both attentive tasks.

In summary, M.N. performed as well as age-matched controls on this demanding test of visual search whereas C.I. exhibited a pattern of performance similar to that demonstrated by other patients with neglect in our laboratory (see also Eglin *et al.*, 1989).

Experiment 2: shift of attention

Posner *et al.* (1984) reported that patients with parietal lobe lesions are impaired in shifting attention into the contralesional hemisphere when anticipating a target in the ipsilesional hemisphere; this deficit was attributed to an impairment in disengaging attention from the cued location. As this 'disengage deficit' has been regarded by some to be a fundamental component of the neglect syndrome, an experiment similar to that described by Posner *et al.* (1984) was performed to assess the mechanisms controlling the shift of attention. In this experiment, the patient was asked to respond as quickly as possible to a stimulus presented laterally in either the right or left visual field. A cue was presented

Table 2 Shift of attention

	M.N.		C.I.	
	Left	Right	Left	Right
Interstimulus interval = 50 ms				
Valid	487 ± 89	460 ± 121	840 ± 203	754 ± 291
Invalid	613 ± 183	534 ± 121	1402 ± 456	694 ± 247
Validity effect	126	74	562	-60
Interstimulus interval = 150 ms				
Valid	444 ± 92	461 ± 86	682 ± 177	713 ± 180
Invalid	472 ± 117	527 ± 75	1299 ± 393	684 ± 163
Validity effect	28	66	617	-29
Interstimulus interval = 500 ms				
Valid	392 ± 86	361 ± 74	566 ± 126	570 ± 148
Invalid	365 ± 53	349 ± 103	870 ± 419	567 ± 192
Validity effect	-27	-12	304	-3
Interstimulus interval = 1000 ms				
Valid	400 ± 81	331 ± 64	445 ± 76	430 ± 124
Invalid	301 ± 36	310 ± 95	704 ± 234	518 ± 137
Validity effect	-99	-21	259	88

Shift of attention is given in milliseconds (±SD).

Table 3 Report of visual images (number of items reported)

	M.N.		C.I.	
	Left	Right	Left	Right
Living room	3	14	9	8
Dinging room	4	10	6	8
Kitchen	2	7	6	5
Route description	3	15	-	-

at a varying inter-stimulus interval (ISI) prior to the stimulus. On most trials, the cue was presented at the same site at which the stimulus subsequently appeared ('valid' trials); on some trials, however, the cue appeared at one position but the stimulus subsequently appeared in the opposite visual field ('invalid' trials). Normal subjects typically respond more rapidly on valid compared with invalid trials, presumably because the cue permits them to shift attention to the probable location of the target; as demonstrated by Posner *et al.* (1984), subjects with left-sided neglect typically exhibit greatly prolonged RTs on invalid trials in which the cue appears in the right visual field and the stimulus appears in the left or neglected visual field.

On each trial, three outline boxes were presented, one box was at the midline and the others were centred 5° to the right and left of the midline. On valid trials, the box within which the target subsequently appeared brightened for a period of 300 ms. On invalid trials, the box on the opposite side brightened for the same length of time. On neutral trials, the central box brightened. The target was a filled diamond which appeared within one of the laterally placed boxes. There were an equal number of trials on which the ISI were 50, 150, 500 and 1000 ms.

Two-hundred trials were performed in each of two sessions. Seventy-two percent of the trials were valid, 20% were invalid and 8% were neutral. There were equal numbers of valid, invalid and neutral trials for each ISI. Trials were presented in a random sequence. Subjects were instructed to maintain fixation on the middle box. The subject's eye position was monitored by the investigator; those trials on which subjects shifted their gaze were repeated at the end of the session.

Results

M.N. performed normally on this task. She exhibited validity effects (i.e. RT on invalid trials minus RT on valid trials) that are well within the range of normal in our laboratory; more importantly, the validity effects were comparable in the right and left hemispheres.

The RT data (excluding the neutral trials which were judged to be too few to analyse) were analysed with an analysis of variance (ANOVA) in which factors included target side (right, left), validity (valid, invalid) and ISI (50, 150, 500 and 1000 ms). M.N. exhibited main effects of validity ($F = 7.393, P = 0.007$) and ISI ($F = 59.707, P = 0.001$); she responded significantly faster to valid (407 ± 112 ms) compared with invalid (434 ± 151 ms) trials. Tukey's test ($P < 0.05$) demonstrated that M.N. was significantly slower with ISIs of 50 ms (495 ± 122 ms) and 150 ms (463 ± 93 ms) compared with ISIs of 500 (372 ± 80 ms) or 1000 ms (353 ± 82 ms). Finally, there was a validity-ISI interaction ($F = 9.455, P = 0.001$) reflecting the fact that validity effects diminished with longer ISIs. We note in this context that M.N. was faster (but not significantly) on invalid trials with long ISIs. Although we have encountered

this pattern of performance in control subjects in our laboratory, we can offer no clear explanation; one possible account is that on trials with long ISIs subjects assume that the target will not appear at the cued location and therefore shift their attention to the uncued location prior to target presentation.

C.I., in contrast, performed abnormally, exhibiting strikingly asymmetric validity effects. ANOVA revealed main effects of target ($F = 71.677, P = 0.0001$), validity ($F = 61.477, P = 0.0001$) and ISI ($F = 43.539, P = 0.0001$) as well as significant target–validity ($F = 62.178, P = 0.0001$), target–ISI ($F = 5.946, P = 0.0006$) and target–validity–ISI ($F = 4.508, P = 0.0041$) interactions. From the perspective of the present investigation, the most relevant finding is the target–validity interaction; *post hoc* analysis with Tukey's test demonstrated that RTs to left invalid trials (1069 ± 529 ms) were significantly slower than RTs for right invalid (616 ± 151 ms) and left (633 ± 231 ms) and right (616 ± 214 ms) valid trials ($P < 0.05$); the latter three conditions did not differ from each other. These findings are consistent with those reported in other patients with neglect (Posner *et al.*, 1984; Coslett *et al.*, 1988).

Thus, M.N., who demonstrated no evidence of neglect on routine clinical tasks, also performed normally on two sensitive tests of attention-requiring visual processing. On the basis of these data, we conclude that the patient did not exhibit an impairment in attentional processes involved in visual perception. C.I., like other patients with neglect tested in our laboratory, exhibited substantial deficits on both tasks assessing visual attention.

Experiment 3: report of visual images

Methods

In order to assess the patients' ability to generate and analyse visual images of arrays, M.N. and C.I. were asked to report the contents of rooms in their homes as viewed from different imagined perspectives. While sitting in our laboratory, M.N. and C.I. were asked to imagine and list the contents and features of their living rooms as viewed from the main entrance to the room; on different occasions, they were asked to report what they would see in the living room when gazing into the room from the door at the opposite end of the room. Additionally, the patients were asked to describe the contents and layout of their kitchens and dining rooms in a similar fashion. The patients were encouraged to 'look around' and were given unlimited time to respond. They were free to move their head and eyes. The patient's responses were recorded and subsequently compared with a detailed floor plan of the house derived from photographs taken by the investigator on visits to the patients' homes.

Results

M.N. consistently reported more objects (e.g. potted plant) and architectural features (e.g. door to the cellar) on the

right compared with the left, for all of the imagined rooms. Summing across both of the imagined viewpoints for the living room (i.e. from the main entrance and from the dining room door), she reported 14 attributes from the right side of her image but only three from the left side. Similarly, she reported 10 attributes from the right side of the dining room and four from the left and for the kitchen, she named seven from the right and two from the left. In all instances, all items reported from the imagined left side of the room were also reported when they were on the imagined right side of the room from a different viewpoint; thus, the total number of items reported for the living room, dining room and kitchen were 14, 10 and seven. M.N. reported items from the right side of the imagined array more reliably for the living room (Fisher's exact probability = 0.004), dining room (Fisher's exact probability = 0.01) and kitchen (Fisher's exact probability = 0.03).

Data from C.I. were scored in a similar fashion. Summing across both imagined perspectives, C.I. reported eight attributes from the right side and nine attributes from the left for the living room. Similarly, he reported eight from the right and six from the left side for the dining room and five from the right compared with six from the left for the kitchen. The total number of different items reported for the living room, dining room and kitchen were 10, eight and six. The difference in report from the right compared with the left did not approach significance for any of the rooms (all Fisher's exact probabilities >2).

M.N. was also asked to describe what she would encounter in an approximately 15 block walk from her former home to the home of a close friend; on a separate occasion she was given the same instructions but asked to imagine that she was walking from her friend's house to her home. As confirmed by the investigator after he retraced her route, she reported nine landmarks from the right side of her route compared with only two from the left side when walking to her friend's home; she reported six from the right but only one from the left when describing her return walk. This pattern of performance, which has been described by other investigators in patients with overt neglect (Brain, 1941; *see also* Bisiach *et al.*, 1993), was also observed when asked to report the landmarks on her block from different imagined perspectives.

Discussion

We report data from two patients demonstrating a double dissociation between neglect on visual imagery and visual perception tasks. These data are relevant to a number of competing accounts of neglect and visual imagery more generally.

Before considering potential explanations for these data, it may be useful to consider briefly the (relatively uninteresting) account which concerns differences in difficulty between the

visual imagery and visual perception. One might suggest that visual imagery simply requires more processing resources than visual perception (see Ogden, 1985). On this account, the neglect of the left side of imagined arrays as exhibited by M.N. and other patients (Anderson *et al.*, 1993; Guariglia, 1993) might plausibly be attributed to the increased task demands associated with visual imagery. This hypothesis does not, however, provide an adequate explanation for the double dissociation reported here. If deficits on imagery tasks reflect the fact that imagery requires greater processing resources than visual perception, C.I., who exhibits prominent perceptual deficits, would be expected to perform quite poorly indeed on the imagery tasks. Thus, the normal performance on imagery tasks exhibited by C.I. strongly suggests that differences in task difficulty alone do not account for the dissociations reported here (see also Bartolomeo, 1994).

How, then, are these data to be explained? These data are inconsistent with the hypothesis, initially advanced by Bisiach *et al.* (1978, 1979), that neglect is attributable to a defect in an analogue spatial representation system common to both visual perception and imagery. This account may explain the performance of patients exhibiting a concordance between neglect in imagery and perceptual tasks but does not readily accommodate the dissociation reported here.

Similarly, the hypothesis of Meador *et al.* (1987), according to which the deficit in imagery tasks is attributable, at least in part, to a failure to direct attention to the left side of the spatial representation, does not predict the dissociation reported here. If the same intentional systems serve to control visual attention and motor systems, as implied by Meador *et al.* (1987), and M.N. is impaired in directing her attention to the left side of imagined arrays, how is she able to perform well on standard tests of visual processing as well as the demanding tests of visual attention described above which are assumed to depend critically on the ability to direct attention to the left?

To explain the double dissociation in performance exhibited by M.N. and C.I. one must postulate that their deficits arise from different processing impairments. In addition, assumptions regarding the cognitive architecture of the visual and motor systems must be elaborated.

One possible account of M.N.'s performance is that at least two related but isolatable visuo-spatial representations are computed from visual input (Milner *et al.*, 1991; Goodale *et al.*, 1986). The first may be an on-line, real time spatial representation in which retinotopic information, integrated with data about head and eye position, is transcoded into a coordinate system capable of directly accessing motor systems controlling the hand (Bridgeman, 1991) and eyes (Wong and Mack, 1981). As proposed by other investigators, this system may correspond at least in part to 'motor' (Brigdeman, 1991) or 'sensorimotor' (Paillard, 1987) procedures for reaching.

A second visuo-spatial representation may also be computed in which retinotopic information, integrated with data about head and eye position, is represented in an egocentric coordinate system and maintained across saccades,

perhaps for intervals of a few seconds. We have previously suggested that a representation of this type may support judgements about the relative position and size of objects in the environment as well as providing, at least under certain circumstances, access to motor systems (Stark *et al.*, 1996; see also Paillard, 1987; Bridgeman, 1991). This representation may correspond, at least in part, to the 'cognitive' stream postulated by Bridgeman (1991) and Paillard (1987).

Support for these different levels of representation comes from several sources (see also Goodale *et al.*, 1986). Milner *et al.* (1991), for example, reported a patient who exhibited a striking discrepancy between her good performance in on-line reaching tasks and her poor performance on tasks requiring judgments about the size, shape and position of visual stimuli. For example, although this patient was unable to match objects reliably on the basis of shape and size, when reaching to pick up these same objects her hand assumed a posture appropriate to the object in question (Goodale *et al.*, 1991).

We (Stark *et al.*, 1996) recently reported a patient, G.W., whose performance is also relevant in this context. G.W. exhibited dramatic differences in her performance on tasks requiring that she respond to visualized targets compared with those when she was asked to point to, or make judgements about, information not currently in view. For example, G.W. performed well (although not perfectly) when asked to touch a (currently) visualized target; however, when asked to touch the same target after closing her eyes, she groped blindly, often insisting that the target had 'gone'. G.W. also performed poorly on a variety of tasks requiring that she register and maintain spatial information in a format which supported judgments about the location (but not identity) of the stimulus. Additionally, G.W. accurately reported the contents of a room in which she was sitting with her eyes open, but with her eyes closed she was unable to describe the layout or contents of the same room or, indeed, the home in which she had lived for 20 years. G.W., who suffered from a gradually progressive disorder, exhibited focal atrophy in Brodmann's area 7 bilaterally on MRI scan.

We suggest that M.N.'s performance can be accommodated on the hypothesis outlined above according to which at least two visuo-spatial representations are computed. On this hypothesis, M.N.'s good performance on visual perceptual and attentional tasks reflects the integrity of the 'direct' procedure for accessing output systems. Her impaired performance on the imagery tasks, in contrast, is attributable to an impairment of the relatively long-lasting egocentric visuo-spatial representation which we have termed the 'master map of space' (Stark *et al.*, 1996). Unfortunately, we are unable to specify the nature of this deficit.

On the account briefly outlined above there are several possible explanations for the pattern of behaviour demonstrated by C.I.. One possible account is that he suffers from an impairment in the 'direct', on-line system mediating motor interactions with visualized stimuli, whereas the master map of space, which we have suggested is critical for visual

imagery (Stark *et al.*, 1996), is preserved. Furthermore, in light of his poor performance on Experiments 1 and 2, one might speculate that C.I.'s deficit is attentional in nature.

A second possible explanation is that C.I. accurately computes both visuo-spatial representations as described above but that his impaired performance is attributable to a 'directional hypokinesia' (Heilman *et al.*, 1985; Coslett *et al.*, 1990) or premotor deficit characterized by an impairment in the control of movement into or towards the neglected hemisphere. As previously noted, Meador *et al.* (1987) proposed such an account for their patient who exhibited neglect of the left in both perceptual and imagery tasks. Note also that this account requires an additional assumption to explain the dissociation in performance exhibited by C.I. on perceptual and imagery tasks. More specifically, one must assume that the intentional mechanism mediating the movement of the extremities and, perhaps, eyes into or toward the neglected hemisphere is distinct from the mechanism controlling the scanning or search of mental images (cf. Kosslyn, 1994). C.I.'s deficit, on this assumption, would be attributed to a directional hypokinesia involving the former but not the latter mechanism. This hypothesis is weakened by the fact that, as previously noted, C.I. exhibited evidence of hemispatial inattention but not directional hypokinesia when tested with the paradigm reported by Coslett *et al.* (1990).

A third possibility is that C.I. does indeed suffer from an impairment in the exploration or representation of stored images, but that he compensates for this limitation by dividing the task into multiple, sequential operations. For example, from this hypothesis one might suggest that when asked to report the contents of a room, a subject with neglect might report items from the right side of the array only; if aware of the deficit, however, the subject might assume a different imagined perspective from which the originally omitted objects were on the right side of the image. Thus, by shifting the imagined perspective, a neglect of the left side of an image could be masked (see also Bartolomeo *et al.*, 1994). Although this hypothesis cannot be refuted definitively, we believe it to be an unlikely explanation for C.I.'s performance for two reasons. First, the hypothesis assumes that C.I. was either explicitly or implicitly aware of his deficit and acted to minimize its consequences. There was no evidence from perceptual tasks that C.I. was aware of his deficits; indeed, on many occasions a striking discrepancy was noted between his profound neglect and his confident assertion that he had performed well. Secondly, a reliance on a strategy of switching imagined perspectives would be expected to be associated with a predictable pattern of report of items; for example, one would expect items from the same side of an array to be clustered in the report sequence just as they are in the array. Examination of the serial order of reported items demonstrated no consistent clustering of items as a function of the side of the imagined array on which they were located; interestingly, informal inspection of the sequence of items reported suggested that the report sequence was influenced

to a greater degree by semantic category (e.g. type of furniture) than by location.

Although controversy persists, a number of investigators have suggested that visual imagery is supported by at least some of the same neural structures which mediate vision (see Farah *et al.*, 1992; Roland and Gulyas, 1994; and following commentaries: Kosslyn, 1994; Behrmann *et al.*, 1995). It should be noted in this context that the account of the data from M.N. and C.I. offered here does not contradict this claim. We have suggested that the impairment in visual imagery in association with preserved visual perception exhibited by M.N. is attributable to a disruption of an egocentric spatial representation which we have previously suggested provides, at least in part, for the maintenance of visual information across saccades and time, and which articulates with cognitive systems. This putative spatial representation, 'the master map of space', is an integral part of the normal visual system. Thus, the dissociation exhibited by M.N. and, perhaps, C.I. may be attributed to a disruption of a subset of the neural structures and corresponding representations which subserve normal vision.

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