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Dissociating mental transformations and visuo-spatial storage in working memory: Evidence from representational neglect

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A study is reported of visuo-spatial working memory in two individuals suffering from a cognitive deficit known as unilateral spatial neglect, and seven healthy control participants. Both patients have difficulties reporting details on the left side of imaged representations, and one has an additional difficulty with perceptual input to the left of his body midline. All participants were asked to report the location and identity of objects presented in novel 2 × 2 arrays that were either present throughout or were described orally by the experimenter, with no visual input. On half of the trials, the report was to be made from the opposite perspective, requiring 180 degree mental rotation of the mentally represented array. The patients show an impaired ability to report details from the presented or the imagined left, but had no difficulty with mental rotation. Results point to a clear separation between the processes of perception and those of visuo-spatial working memory. Results also suggest that the patients might be suffering from damage to the system used for holding visuo-spatial representations rather than a difficulty with attending to elements of that representation.

There is now a substantial body of evidence to suggest that the cognitive functions for immediate memory and on-line manipulation of visual and spatial material might comprise a distinct cognitive system within working memory that is independent of the system responsible for immediate verbal memory (e.g., for reviews see Logie, 2003; Logie & Della Sala, in press). There also is growing evidence to suggest that visuo-spatial working memory might be quite distinct from, and be accessed only indirectly by, visual perception (e.g., Denis, Beschin, Logie & Della Sala, 2002). This argument maintains that visuo-spatial working memory holds the products of the activation of information stored in our knowledge base, and activation of that stored knowledge might arise from stimulus input and perceptual processes, or it might arise from manipulations within working memory that generate a process of retrieval. In this sense, working memory is not a transit area between sensory input and long-term memory. This latter view remains a topic of debate, given widely held assumptions that perception feeds directly into visual imagery (for reviews and detailed discussion see Logie, 2003; Denis & Kosslyn, 1999), and we address this topic by

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drawing on evidence from individuals who suffer from selective deficits of perception and of visuospatial working memory.

The particular neuropsychological impairments of interest here are those referred to collectively as unilateral spatial neglect. This involves unilateral impairment of perception or of the mental representation of space following brain damage. The damage is most commonly in the right hemisphere with the impairment affecting the left side of perceived or represented space. Patients with the perceptual form of neglect are unable to report details of the visual scene on their neglected side, and this difficulty cannot be attributed to impairments of their primary visual system. Other patients have representational neglect in which they are unable to report from memory details on the left of an imagined, familiar scene such as the main square of their home town (e.g., Bisiach & Luzzatti, 1978). The two forms of the deficit may both occur in the same patient, or may occur in isolation (e.g., Beschin, Cocchini, Della Sala & Logie, 1997; Coslett, 1997).

These dissociations support the suggestion of a more tenuous link between perception and visuospatial working memory, but there remain questions as to precisely what might be impaired in patients with representational neglect. Both Baddeley and Lieberman (1980) and Bisiach (1993) suggested that the problem could either be an inability to attend to details on the left of an otherwise intact mental representation, or that the mental representation system itself is damaged, as if the left side of the ''mental screen'' is torn. One way to gain additional insight into this issue is to examine whether individuals with representational neglect are capable of manipulating the information on the neglected side of their representation, for example mentally rotating their image of a scene and reporting what it would look like from the opposite perspective. It seems reasonable to assume that a problem in directing attention to material on the neglected side of the mental representation would make mental transformation of that material extremely difficult. Evidence that individuals with representational neglect can form representations of a familiar town square from opposite ends (Bisiach & Luzzatti, 1978; Beschin et al., 1997) does not indicate the use of mental transformation, because images of the alternative views could be accomplished by regenerating each perspective from long-term memory rather than mentally rotating the current image.

A more convincing test might be to use novel visual arrays of objects, and ask the patients to describe the array from the opposite viewpoint. This would be impossible to accomplish by drawing on spatial information in long-term memory, and would yield insight into whether mental transformation of the original image is possible. Should the patients succeed, then it would point to the ''torn screen'' metaphor. It would also point to the suggestion that the storage of information may be handled by a different part of the cognitive system from the resources that support processing and manipulating the contents of what is stored. However, if the difficulty faced by the patients arises primarily from an attentional problem, then we might expect that they would have great difficulty manipulating or transforming what residual information is available from the neglected side of the mental representation.

METHOD

Participants

We report two single cases of individuals (PT and BG) who had suffered a stroke affecting both the right parietal and right temporal lobes of the brain. Both patients were assessed using the test battery for the diagnosis of neglect reported by Denis et al. (2002). PT (female, 70 years old, 13 years of education) showed symptoms of pure representational neglect in three out of four of the relevant tasks, but was flawless in the four tests for perceptual neglect. BG (male, 55 years, 5 years of education) showed representational neglect on three out of four of the relevant tasks but also showed perceptual neglect on all four of the tasks testing for this aspect of the disorder. Both patients performed within the normal range on measures of verbal intelligence (Spinnler & Tognoni, 1987), and neither showed any signs of global mental deterioration.

Seven healthy participants were recruited as controls (three male, four female) covering the range of age and educational level for the two patients, mean age was 61.9 years, range 54–70, mean education was 7.9 years, range 5–13.

Experimental materials

Ten groups of four objects were prepared, and all the objects within any one group were drawn from the same category, for example household objects

(vase, coffee pot, ashtray, bottle). No object was repeated across groups. A 15 × 10 cm colour photograph of each object was prepared. A further nine groups of four object names were selected and arranged in short sentences (as described below).

Procedure

The experimental procedure comprised three conditions. In the first condition (Verbal Memory Only), each of four trials consisted of a series of four sentences stating arbitrary non-spatial properties of objects, and each series was drawn at random from the total set of nine groups of sentences that had been prepared. For example, "The pencil is expensive. The penknife is large. The scissors are long. The eraser is nice." Participants were to recall the objects and their properties. This condition served as an assessment of general verbal memory ability.

In the second condition (Visual Perception), each of five trials consisted of one group of four photographs of objects displayed at the extreme corners of a 58 × 41.5 cm area, and each group of four was selected at random from the total set of ten object groups. The array was displayed on the table in front of the participants. The objects remained in view for 90 s, during which time the participants reported the name and location of the objects.

In the third condition (Memory Following Description), there were two sets of five trials, with each trial involving different sets of four objects. However, there were no object arrays in view. Instead, for each trial, the experimenter spoke aloud the names of four objects and their locations. For example, "The cake is in front of the biscuit. The biscuit is on the left of the ice cream. The ice cream is behind the chocolate. The chocolate is on the right of the cake." This procedure was followed to avoid any possible effect of impairments of the visual perceptual system in the construction of the mental representation. It took about 90 s for the experimenter to read aloud the four sentences. The participants were instructed to build a visual image of the scene as it was being described. For each trial, the position of the first named object was indicated by the experimenter on the table (e.g., to the right and closest to the participant). To control for possible recency effects in recall being confounded with object location, and to avoid the problem of response bias, the position of the first named object was counterbalanced across trials. Immediately after the final sentence of each description, the participant was asked to recall the objects and their locations. There was no time limit for recall. Participants were tested on two

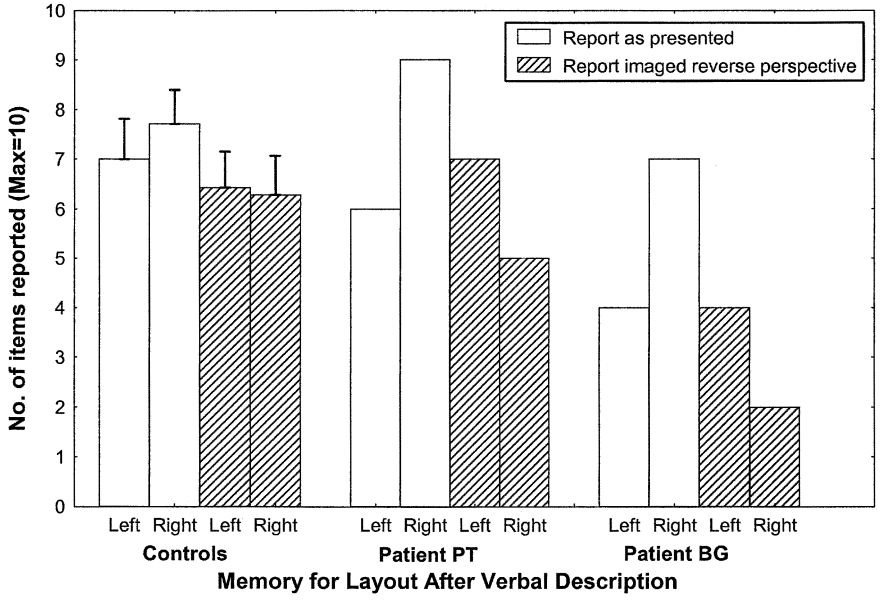

Figure 1. Number of items correctly reported from the left and right side of orally described (not viewed) object arrays from the described perspective and from the imagined opposite perspective by healthy adult controls and by two individuals suffering from unilateral spatial representational neglect.

occasions, separated by an interval of 2–3 months. On one occasion, five trials were presented and participants were asked to recall the objects and their locations from the originally presented perspective (standard condition, Denis et al., 2002). On the other occasion, participants were presented with another set of five trials and were asked to recall items as if they were from the opposite perspective to that recently presented (reversed condition). Patient BG and five of the controls performed the standard condition first, while patient PT and two of the controls performed the reversed condition first.

RESULTS

Mean recall of items in the verbal condition (max = 16) was 12.6 (range 8–16) for the controls, 16 for PT, and 11 for BG. The verbal memory scores for the patients were well within the range for the controls.

In the perception condition controls performed at ceiling with a maximum score of 10 for items on both sides. Patient PT was also at ceiling on this condition, reporting all 10 items on both sides. Patient BG reported none of the items depicted on the left, but reported all 10 items from the right, demonstrating his clear perceptual neglect.

Mean recall performance for the memory following description condition is shown in Figure 1 for both the standard report and the report from the imagined opposite perspective. Control participants showed evidence of some forgetting overall, and lower performance in the reverse than in the standard recall, $F(1, 6) = 7.64$; $p < .05$, but there was no evidence of any lateralised bias in their results in either form of recall. Both patients achieved the same level of performance as the controls for items in the standard recall that were presented on the right and reported from the right. However both patients were poorer than the controls in standard recall for items that were presented on the left and were reported from the left.

From the reverse perspective, the data pattern also reverses. Both patients showed poorer performance for items that were imagined on the left, even although the items were presented on the right, non-neglect side. Moreover, items that were presented on the left showed no loss when they were reported from the imagined right—performance is the same or better for items that were presented on the left and reported on the left. In other words, the patients appeared to be able to undertake the mental transformation successfully, and the mental transformation resulted in no loss of material. More important was the side of the representation on which they based their recall.

DISCUSSION

Results confirmed the clear dissociation found in previous studies (e.g., Beschin et al., 1997; Denis et al., 2002) between different types of neglect patients in their ability to report details of material that is in view, and to report details of material that is held in a temporary visuo-spatial representation in working memory. When the objects for report from a novel visual array were in view, PT showed no perceptual difficulties, while BG failed to report any of the items presented on the left of the array, coupled with reporting all of the items depicted on the right.

In contrast, when there was no visual array present, and participants relied on their memory for a verbally described novel layout, both patients showed neglect for items on the left of their representation. This confirms our previous finding (Denis et al., 2002) that their representational problem does not arise from difficulties with visual perception. The results are consistent with the view that visuo-spatial working memory and visual perception are less closely linked than is sometimes widely assumed, in line with the view of working memory (Della Sala & Logie, 2002; Logie, 1995, 2003) as dealing with the products of activation from stored knowledge rather than being driven directly by perception.

When the patients were asked to imagine the layout from the opposite perspective, it was clear that they could do so successfully, despite their representational difficulties. From Figure 1, it appears that the patients could mentally rotate their representation of the picture array, and whatever information was available to them from the impoverished left of the representation was still available when it was imagined on the right. Although their mental representation system is impaired, the process of manipulating information results in no loss of information.

In contrast, several items that were presented on the right are lost when they are subsequently imagined on the left. That is, the ability to transform images seems unimpaired, but whatever information is reported from the neglected side of

the representation is degraded. These results point to the suggestion that at least some of the processes that can operate on images (i.e., mental rotation) appear to be intact, but the part of the system responsible for holding the material is damaged. If the representational difficulties arose from some difficulty with controlling attention, or directing attention to material held on the neglected side of the mental representation, then we might expect some difficulty with mental rotation of that material. Therefore, in terms of the Baddeley and Lieberman (1980; Bisiach, 1993) metaphor, the evidence points to a torn mental screen rather than a problem of attentional control. Moreover, data from these patients add greater weight to the argument that manipulation of material within visuo-spatial working memory is not reliant on the intact functioning of visual perception.

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