ELSEVIER

Neuropsychologia 42 (2004) 1358–1364

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Preserved visuo-spatial transformations in representational neglect

Sergio Della Sala [a,*], Robert H. Logie [a], Nicoletta Beschin [a,b], Michel Denis [c]

[a] *Human Cognitive Neuroscience, PPLS, University of Edinburgh, 7 George Square, Edinburgh, UK*
[b] *Unit of Rehabilitation, Somma Lombardo, Gallarate Hospital, Varese, Italy*
[c] *Groupe Cognition Humaine, LIMSI-CNRS, Orsay, France*

Received 1 September 2003; accepted 10 February 2004

Abstract

Patients with representational unilateral neglect were impaired in immediate recall of novel material on the neglected side as presented (viewed and removed or verbally described) or following mental rotation. Transforming material from the neglected (left) side to the non-neglected (right) side resulted in no additional loss; patients were unimpaired in directing attention to the neglected side of their representation in order to perform the mental rotation. These findings cannot be explained by the widely adopted attention deficit hypothesis for representational neglect. It is suggested that the disorder arises from damage to temporary storage functions of visuo-spatial working memory.

Keywords: Mental rotation; Brain damage; Temporary visuo-spatial storage; Short-term visual memory

1. Introduction

Theoretical accounts of representational neglect are rare (see e.g. Berti, 2004; Rode, Rossetti, Perenin & Boisson, 2004), and following the most widely accepted theories of perceptual neglect (Heilman, Bowers, Valenstein, & Watson, 1987; Kinsbourne, 1987), are focused on the suggestion that there is some form of inability to direct attention to areas of imagined space (Bisiach, 1999; Meador, Loring, Bowers & Heilman, 1987). However, it is clear that perceptual and representational forms of neglect can appear independently (Bartolomeo, 2002; Beschin, Basso & Della Sala, 2000; Beschin, Cocchini, Della Sala & Logie, 1997; Coslett, 1997; Guariglia, Padovani, Pantano & Pizzamiglio, 1993). Therefore, the interpretation of perceptual neglect is not necessarily adequate as a basis for an explanation of representational neglect. That is, an impairment in directing covert attention within a mental representation might not offer the most convincing account of the representational deficit. Previously, we presented an alternative account of representational neglect set within the context of visuo-spatial working memory (Beschin et al., 1997; Denis, Beschin, Logie & Della Sala, 2002; Ellis, Della Sala & Logie, 1996). In this account the impairment arises from lateralized damaged to the representational medium in the form of a temporary visuo-spatial memory system (e.g. Baddeley & Lieberman, 1980; Bisiach, 1993). However, the evidence offered in our previous work (Beschin et al., 1997; Denis et al., 2002) did not rule out a key role for a deficit in directing attention to the imagined left hemispace.

One way to gain significant 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. Mental rotation necessarily requires the direction of attention to the contents of the mental representation that are to be transformed. Therefore, an impairment in directing attention would result in an inability to select and manipulate material on the neglected side of the representation, precluding performance of mental rotation.

At first blush, there appears to be evidence that patients can transform representations of familiar scenes; they can imagine the square in their home town from the opposite end of the square to that used for their previous report, and can report details, now on their imagined right, that were previously omitted from their imagined left (Bisiach & Luzzatti, 1978; Meador et al., 1987). However, this could be accomplished by regenerating from long-term memory (or from a deep representation as referred to by Meador et al., 1987) an image of the square in the new perspective view. That is, generating an image from the opposite perspective

* Corresponding author. Fax: +44-131-6503461.
E-mail address: sergio@ed.ac.uk (S. Della Sala).

0028-3932/$ – see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2004.02.011

would not necessarily require any kind of mental rotation or transformation of the image from the original perspective in any kind of spatial co-ordinate mental representation (for a discussion see Behrmann & Tipper, 1999).

A more convincing test would be to use novel visual arrays of objects that have been removed from view just prior to the process of mental rotation. The required mental transformations would be impossible to accomplish by drawing on spatial information in long-term memory. A deficit in directing attention to the left side should make it extremely difficult to employ the attentional resources required to attend to whatever material is held on the impaired left side of the representation and then mentally to transform it to the right. An account of representational neglect in terms of an attentional deficit would predict that mentally rotating material from the left to the right would show substantial loss of information relative to standard report of the material as presented.

On the other hand, an account of representational neglect based on a lateralized deficit of visuo-spatial working memory, would predict that the attentional resources required for mental rotation might be intact, and whatever limited information is held in the impaired left side of the representation will successfully be rotated to the intact right, with performance dropping to the level found for material actually presented on the left. This result also would 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.

2. Methods

2.1. Participants

Patients for the study were selected from among a group of 15 individuals who had suffered damaged to the right hemisphere of the brain, and who showed symptoms of perceptual or representational neglect in initial clinical testing.

The patients were tested further with a battery of neuropsychological tests drawn from previous literature and designed to detect the presence of perceptual or representational neglect (see further). In all cases, the diagnosis of neglect was based on the difference in performance between the left and the right hemispace on more than one task.

2.2. Tests for neglect

2.2.1. Perceptual tests requiring motor response

2.2.1.1. Line cancellation (Albert, 1973). This test requires the participants to cross out short lines arranged randomly on a sheet. There are no distractors. The test shows neglect when participants omit at least one stimulus on the left, but none on the right (Albert, 1973). If omissions are present on the right as well, then neglect would be diagnosed if omissions on the left are at least three times those on the right (Nichelli, Rinaldi, & Cubelli, 1989).

2.2.1.2. Star cancellation (Wilson, Cockburn, & Halligan, 1987). This test requires the participants to cross out small stars among distractors. It shows neglect when participants omit at least one stimulus on the left, but none on the right (Wilson et al., 1987). If omissions are present on the right side as well, neglect is diagnosed if omissions on the left are at least three times those on the right (Beschin et al., 1997).

2.2.2. Perceptual tests not requiring motor response

2.2.2.1. Reading of single words. This test consists of reading 48 single words, short (four letters) and long (up to 12 letters). Neglect is diagnosed if leftward errors (omissions or substitutions) are more than three times as frequent as the rightward errors (Beschin et al., 2000).

2.2.2.2. Description of a scene. The patients were asked to report objects and characters shown in a complex picture that remains in view throughout the test. The score ranges were 0–22 and 0–18 for the left and right side, respectively. Neglect was diagnosed if participants scored two standard deviations below the mean of controls (left, mean = 9.4, S.D. = 2.42; right, mean = 12.4, S.D. = 1.85; Cocchini, Cubelli, Della Sala, & Beschin, 1999). There were no time limits in this test.

2.2.3. Representational tests requiring motor response

2.2.3.1. Fluff test with eyes closed. The participants blindfolded were asked to remove targets attached to the front of their clothes both on their right and left side. Left sided neglect was considered present when participants performed below the cut-off score (13 out of 15 targets removed from the left side; Cocchini, Beschin & Jehkonen, 2001).

2.2.3.2. Drawing a clock from memory. The participants were provided with the outline of a clockface and were asked to insert the numbers for the hours. Neglect was considered present when left-side numbers were omitted or drawn on the right (Anderson, 1993).

2.2.4. Representational tests not requiring motor response

2.2.4.1. Description of a square from memory. The participants were asked to describe a familiar city square first from a given perspective, and then, 1 week later, from the opposite perspective. Absolute scores were different because participants were assessed with different town squares (the central square of their home town). Neglect was diagnosed when the overall number of elements (sum of both viewpoints) reported on the left were half (or less) those reported on the right (Bisiach & Luzzatti, 1978).

2.2.4.2. Description of a novel scene from memory. The patients inspected a picture (with 22 items on the left and 18 on the right) silently for 2 min while invited to trace the whole scene with their finger. After this, the picture was removed and they were asked verbally to recall the items in the picture. Neglect was diagnosed if participants scored below the cut-off based on the performance of a control group (Beschin et al., 1997). Cut-off scores were 5.0 for the left side and 3.2 for the right side.

Patients were diagnosed as being affected by perceptual neglect if they performed poorly on at least two of the four perceptual tests, and diagnosed as showing representational neglect if they performed poorly on at least two of the four representational tests.

Of the 15 patients, four showed no evidence of representational neglect and one showed a very severe perceptual neglect that made it very difficult for him to perform the experimental tasks. Therefore, 10 patients entered the study. Their mean age was 56.0 and their mean education level was 9.6 years. All patients were tested for verbal intelligence using the verbal judgement test (Spinnler & Tognoni, 1987). None of the patients included in the study showed any signs of global mental deterioration. All patients underwent a standard neurological examination which encompassed the detection of paresis, visual field defects, and extinction (Bisiach, Perani, Vallar & Berti, 1986). Extinction was tested in all modalities whenever possible. Demographic and clinical details of the participating patients are shown in Table 1.

Details of the performance of each patient on each test assessing neglect are shown in Table 2.

The 10 control participants (4 male, 6 female) were matched with the patients on age and educational level. Mean age was 53.0, range 27–70, mean education was 10.2 years, range 5–17.

2.3. Experimental materials and procedure

Ten groups of four objects were prepared, and all the objects within any one group were drawn from the same category. For example, one group included four household objects (vase, coffee pot, ashtray, bottle), another one included four types of food (egg, cheese, pasta, salad), and so on. No object was repeated across groups. A 15 cm × 10 cm colour photograph of each object was prepared. All participants were shown sets of four photographs in a two by two array, with each photograph displayed at the extreme corners of two A3 sheets joined together to form a 58 cm × 41.5 cm area. They were asked to specify aloud the name of each object and its location, and they were scored as correct only if objects were recalled in the correct location. In order to be included, each patient was required to achieve a minimum score of 8 out of 10 items on each side. The mean score of patients included was 9.2 items from the left and 10 items from the right. The difference between right and left was significant ($t(9) = 2.75$, $P < 0.025$), indicating mild perceptual neglect for the experimental material. The control participants scored a maximum 10 out of 10 for the left and right of the array.

Table 2
Tests in which the 10 patients entering the study show evidence of representational or perceptual neglect

Patient	Representional neglect	Perceptual neglect
1	b, c	e, f, h
2	b, c	e, f
3	a–d	e–h
4	a, d	e, f
5	a–d	–
6	a–d	e–h
7	a–d	e–h
8	a, b, d	–
9	a–d	e–h
10	a–d	e–h

Tests for representational neglect: a, drawing a clock from memory; b, description of a familiar town square from memory; c, fluff test with eyes closed (reach for markers on body); d, description from memory of a recently perceived, novel complex picture; tests for perceptual neglect; e, star cancellation; f, line cancellation; g, description of a novel complex picture while in view; h, reading 30 words, details and scoring procedures for all tests and relevant original references are reported elsewhere (Denis et al., 2002).

Table 1
Demographic and clinical features of the patients included

Patients	Age	Sex	Years of education	Type of lesion	Site of lesion	Interval from onset (days)	VFD	Extinction	Left paresis	VJ
1	34	Male	11	I	bg	90	−	+	+	56
2	63	Male	8	I	F-T-P	200	−	+	+	42
3	27	Male	16	CHI	F-P-ic-TL	150	−	+	+	40
4	41	Female	13	H	F	80	−	−	−	58
5	70	Male	5	I	P	180	+	+	+	52
6	72	Male	5	I	P-O	30	+	+	+	42
7	70	Female	3	I	P-O	30	+	+	+	46
8	70	Female	13	H	P-T-O	200	−	+	−	58
9	40	Male	17	I	F-P	360	+	+	+	50
10	73	Female	5	I	bg	15	−	+	−	42

+, Present; −, absent; H, haemorrhagic stroke; −, absent; I, ischaemic stroke; CHI, closed head injury; bg, basal ganglia; F, frontal; ic, internal capsule; O, occipital; P, parietal; T, temporal; TL, T left; VFD, visual field defect; VJ, verbal judgement test, range 0–60, cut-off score: 32 (Spinnler & Tognoni, 1987).

Following Denis et al. (2002), the experimental procedure comprised two conditions. In the first condition (memory following visual perception), two sets of five trials, each involving four different objects, were presented visually following the basic procedure described above, except that the array was removed after 90 s and the participants were to report the objects and their position from memory. It was suggested to participants that they try to build a visual image of each scene. Recall was required from two different perspectives. One set of five trials involved the standard perspective in which the participants were to recall the objects and the locations in which they were viewed. In the reverse perspective, participants performed another set of five trials in which they had to imagine the layout of the recently presented objects as if they were sitting on the other side of the table and to report the objects and their locations from that opposite perspective.

In the second condition (memory following description), again there were two sets of five trials, with each trial involving different sets of four objects. However, there was no object array 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." 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" (Bisiach, Ricci, Lualdi, & Colombo, 1998), 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. As in the memory following perception condition, for one set of five trials participants were asked to recall the objects and their locations both from the originally viewed perspective, and for another set of five trials were asked to recall items as if they were from the opposite perspective to that recently presented. This verbal description procedure removed any possible impact of perceptual neglect on encoding and on the construction of the mental representation of the array. Also it offers a means to assess whether representational neglect patients are capable of constructing and mentally transforming such representations derived from verbal descriptions, and serves to demonstrate the generality and replicability of the results from the first experimental procedure.

Within each condition, the order of presentation of the groups of objects was fixed. Each participant was assigned to one of four different orders of presentation of the four conditions. For the memory following perception and memory following description conditions, half of the patients and controls performed the standard condition first, and half performed the reverse condition first. There was a 2–3 month gap between the testing occasions for the standard and reverse conditions.

Finally we tested the general verbal memory ability of all participants using the names of the objects that were employed in the main experimental conditions. 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.

3. Results

Mean recall of items in the general verbal memory condition (max = 16) was 13.6 for the controls and 11.1 for the patients. These means were not significantly different: $t(18) = 1.78$, ns.

Fig. 1 shows the mean scores for the memory following visual perception condition. In both the standard and the reversed report, control participants perform just below ceiling. A two (left/right) by two (standard/reversed) analysis of variance (ANOVA) on these data showed no effect of standard/reversed mode of report ($F < 1$) or side of presentation ($F(1, 9) = 2.6$, ns) on performance. The same figure shows the mean scores from this condition for individuals with representational neglect, and the ANOVA indicated a significant effect of standard/reversed mode of report ($F(1, 9) = 6.4$; $P < 0.05$), a significant effect of side of presentation ($F(1, 9) = 9.99$; $P < 0.025$), and a significant interaction ($F(1, 9) = 28.58$; $P < 0.001$). The interaction indicated that there was a clear difference in performance between standard and reversed report for items presented on the right (two bars on extreme right of Fig. 1); there was better performance for items presented on the right and recalled from the right (standard mode) than for items presented on the right but imagined and recalled as if on the left (reversed mode). A Newman–Keuls post hoc test showed this contrast to be significant ($P < 0.001$). In other words, the patients show a difficulty in reporting recently presented items from novel arrays that they have transformed from the non-neglected (right) side to the neglected (left) side of their representation. The other half of the interaction (first two bars for patients in Fig. 1) shows a striking contrast in that there is no difference between the standard and reversed conditions (Newman–Keuls, ns); when the patients are asked to transform items that are presented on the neglected (left) side and to imagine them on the non-neglected (right) side of their representation, they show no loss of information. In other words they can direct their attention to the neglected (left) side, extract whatever information is available, and successfully mentally rotate that information so that it can be recalled intact from the non-neglected (right) side of the rep-

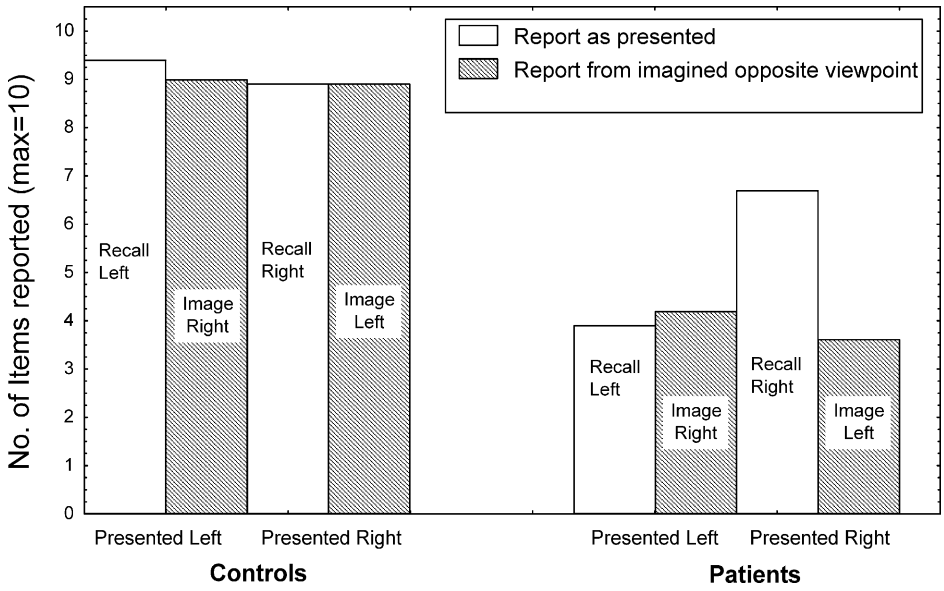

Fig. 1. Number of items correctly recalled from the left and right side of object arrays from the recently viewed perspective and from the imagined opposite perspective by healthy adult controls and by individuals suffering from unilateral spatial representational neglect.

resentation. Moreover, performance for items presented on the right and imagined as if on the left (bar 4 for patients in Fig. 1) was not significantly different (Newman–Keuls, ns) from performance for items actually presented on the left and recalled from the left (bar 1 for patients in Fig. 1).

Fig. 2 shows the mean scores for the memory following description condition. The control participants again performed below ceiling, and the ANOVA showed that there was no evidence of any lateralized bias in their results ($F(1, 9) = 1.8$; ns). There was a suggestion that control participants reported fewer items in the reversed mode than in the standard mode ($F(1, 9) = 7.11$; $P < 0.05$). The figure shows that the patients performed more poorly overall than they did with the first experimental procedure, but with performance still above floor. The ANOVA for the patient data showed a significant effect of standard/reversed mode of report ($F(1, 9) = 10.99$, $P < 0.01$), a significant effect of side of presentation ($F(1, 9) = 23.65$; $P < 0.001$), and a significant interaction ($F(1, 9) = 8.25$, $P < 0.025$). As for the previous procedure, items described as being on the right, and reported from the right (bar 3 for patients in Fig. 2) were better recalled (Newman–Keuls $P < 0.001$)

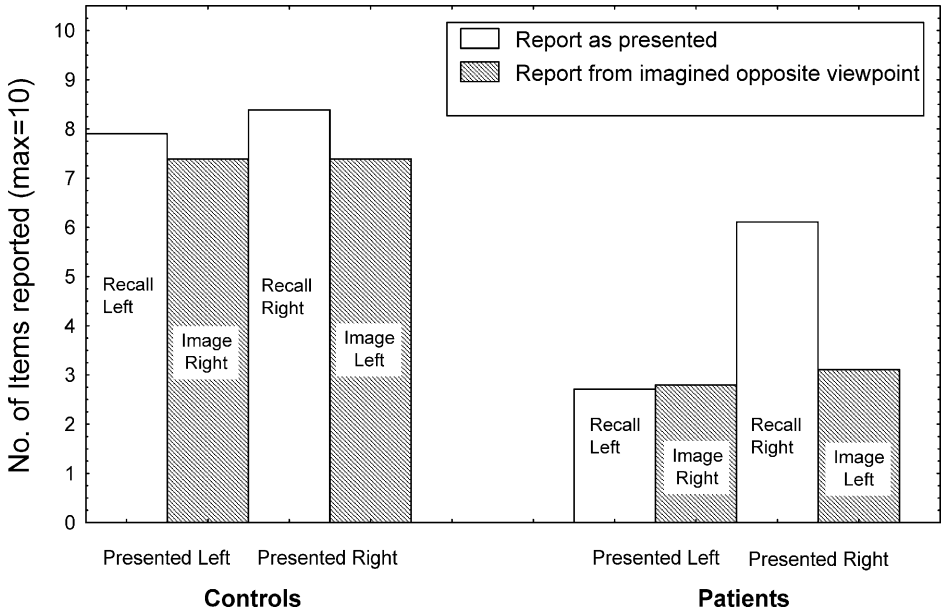

Fig. 2. Number of items correctly reported from the left and right side of orally described (not viewed) object arrays from the described perspective and from the imagined opposite perspective by healthy adult controls and by individuals suffering from unilateral spatial representational neglect.

than were items described on the right and recalled from the imagined left (bar 4 for patients in Fig. 2). Consistent with the findings for the memory following perception condition, for memory following description there was no difference (Newman–Keuls, ns) in recall for items described on the left whether they were reported from the left (bar 1 for patients in Fig. 2) or from the right following mental rotation (bar 2 for patients in Fig. 2). Again, performance for items presented on the right and imagined as if on the left (bar 4 for patients in Fig. 2) was not significantly different (Newman–Keuls, ns) from performance for items actually described on the left and recalled from the left (bar 1 for patients in Fig. 2).

4. Discussion

The converging results from both experimental procedures demonstrated that the patients were capable of carrying out some form of mental rotation of their temporary mental representation of the object array. Several items (see Figs. 1 and 2) that were presented on the right are lost when they are subsequently imagined on the left, as would be predicted from both the visuo-spatial working memory account of neglect and the attentional theory. However, the patients can mentally rotate their representation of the picture array, and whatever information is available to them from the impoverished left of the representation is still available when it is imagined on the right, as predicted only by the visuo-spatial working memory account. Although the system responsible for holding the mental representation is impaired on the neglected side, the process of manipulating information results in no further loss of information from that representation.

The above results suggest that at least some of the processes that can operate on images (e.g. mental rotation) appear to be intact in patients with representational neglect. The results cannot be explained by assuming damage to the process of activating traces in long-term memory (e.g. Meador et al., 1987) because the paradigm involved the use of novel arrays.

One influential candidate theory of an attentional deficit in perceptual neglect has been proposed by D'Erme, Robertson, Bartolomeo, Daniele & Gainotti (1992; reviewed in Bartolomeo & Chokron, 2002). These authors propose a distinction between exogenous attention, which is an automatic response to a stimulus in the environment, and endogenous attention which is a strategy driven, intentional directing of visual or auditory attention. Their argument is that the exogenous, stimulus driven attentional system is impaired in perceptual neglect and this accounts for the patients' lack of awareness of stimuli on the neglected side. However, endogenous attention is thought to be relatively intact in such patients, and this accounts for a mitigation of the impairment when attention is purposefully directed to the neglected side (see Gainotti, 1996 for a review).

In the case of representational neglect, the evidence appears to be more compatible with the hypothesis that cognitive impairments arise from damage to the system responsible for holding temporary mental representations. As suggested in the introduction, a strong candidate for the system that might be damaged is visuo-spatial working memory, conceived as a system providing temporary visuo-spatial representations, and the means for manipulating and interpreting those representations (Logie, 1995, 2003). Lateralized damage to visuo-spatial working memory may therefore give rise to representational neglect (Beschin et al., 1997; Ellis et al., 1996).

The suggestion that representational neglect might reflect damage to the visuo-spatial component of working memory was originally proposed by Baddeley and Lieberman (1980). However, that paper focused on an empirical investigation of visual- and movement-based working memory in healthy adults. The authors presented their suggestion regarding neglect as a speculative hypothesis and reported no evidence from neglect patients. In addition, research on the topic of visual imagery and of visuo-spatial working memory at that time was debating the use of the 'picture metaphor' of a mental image, and Baddeley and Lieberman referred to the metaphor of a 'torn screen', indicating some two dimensional projection onto some kind of 'damaged mural in the mind'. However, subsequent research on mental imagery argued that the picture metaphor was misleading, in that mental images, unlike pictures, are interpreted (for more detailed discussion see Logie & Della Sala, in press). Yet although the 'torn screen' metaphor may not now seem appropriate, the concept of damage to one part of a visuo-spatial mental representation system does offer a coherent account of representational neglect.

The possible role of impaired visuo-spatial working memory in neglect has been explored in a number of recent papers (e.g. Malhotra, Mannan, Driver & Husain, 2004; Pisella, Berberovic & Mattingley, 2004; Wojciulik, Husain, Clarke & Driver, 2001). These authors have argued that non lateralized damage to visuo-spatial working memory adds to the pattern of impairments in perceptual neglect, in that such patients are unable to form an adequate temporary visuo-spatial memory of whatever information they can glean from the impoverished, lateralized perceptual input. Our aim is to account for the pattern of lateralized impairment and sparing of mental representations and their transformations found in patients with representational (rather than perceptual) neglect, and we propose that lateralized damage to the mental representations held in visuo-spatial working memory is itself the source of the deficit from which representational neglect patients suffer, rather than the visuo-spatial working memory impairment adding to a separate deficit in directing attention (see also Beschin et al., 1997; Ellis et al., 1996).

A possible caveat is that the resource required to direct covert attention within a visuo-spatial mental representation may be different from the resource required to carry out mental transformations. However, this account assumes

that there are different forms of attentional resource that can be differentially damaged. In the absence of empirical support, the assumption that attention might take these different forms and be differentially sensitive to damage remains speculative.

In sum, this paper reports evidence that patients with representational neglect appear to have no difficulty in directing their attention to the neglected side of a mental representation in order to mentally transform that representation. The general pattern of results offers new empirical support for an account of representational neglect as an impairment of visuo-spatial working memory.

Acknowledgements

We thank Dr. Francesco Zaro, his colleagues, and the physiotherapists of the Rehabilitation Department of Somma Lombardo, Italy, for allowing us to test some of their patients.

References

Albert, M. L. (1973). A simple test of visual neglect. *Neurology*, *23*, 658–664.

Anderson, B. (1993). Spared awareness for the left side of internal visual images in patients with left-sided extrapersonal neglect. *Neurology*, *43*, 213–216.

Baddeley, A. D., & Lieberman, K. (1980). Spatial working memory. In R. S. Nickerson (Ed.), *Attention and performance* VIII (pp. 521–539). Hillsdale, NJ: Erlbaum.

Bartolomeo, P. (2002). The relationship between visual perception and visual mental imagery: a reappraisal of the neuropsychological evidence. *Cortex*, *38*, 357–378.

Bartolomeo, P., & Chokron, S. (2002). Orienting of attention in left unilateral neglect. *Neuroscience and Behavioral Reviews*, *26*, 217–234.

Berti, A. (2004). Cognition in dyschiria: Edoardo Bisiach's Theory on misconception of space and consciousness. *Cortex*, *24*, 275–280.

Beschin, N., Basso, A., & Della Sala, S. (2000). Perceiving left and imagining right: dissociation in neglect. *Cortex*, *36*, 401–414.

Beschin, N., Cocchini, G., Della Sala, S., & Logie, R. H. (1997). What the eyes perceive, the brain ignores: a case of pure unilateral representational neglect. *Cortex*, *33*, 3–26.

Behrmann, M., & Tipper, S. P. (1999). Attention accesses multiple reference frames: evidence from visual neglect. *Journal of Experimental Psychology Human Perception and Performance*, *25*, 83–101.

Bisiach, E. (1993). Mental representation in unilateral neglect and related disorders. *Quarterly Journal of Experimental Psychology*, *46*, 435–461.

Bisiach, E. (1999). Unilateral neglect and related disorders. In G. Denes, & L. Pizzamiglio (Eds.), *Handbook of clinical and experimental neuropsychology* (pp. 479–495) Hove, UK: Psychology Press.

Bisiach, E., & Luzzatti, C. (1978). Unilateral neglect of representational space. *Cortex*, *14*, 129–133.

Bisiach, E., Perani, D., Vallar, G., & Berti, A. (1986). Unilateral neglect: personal and extrapersonal. *Neuropsychologia*, *24*, 759–767.

Bisiach, E., Ricci, R., Lualdi, M., & Colombo, M. R. (1998). Perceptual and response bias in unilateral neglect: two modified versions of the Milner Landmark Task. *Brain and Cognition*, *37*, 369–396.

Cocchini, G., Beschin, N., & Jehkonen, M. (2001). The Fluff Test: a simple task to assess body representation neglect. *Neuropsychological Rehabilitation*, *11*, 17–31.

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

Coslett, B. (1997). Neglect in vision and visual imagery: a double dissociation. *Brain*, *120*, 1163–1171.

Denis, M., Beschin, N., Logie, R. H., & Della Sala, S. (2002). Visual perception and verbal descriptions as sources for generating mental representations: evidence from representational neglect. *Cognitive Neuropsychology*, *19*, 97–112.

D'Erme, P., Robertson, I., Bartolomeo, P., Daniele, A., & Gainotti, G. (1992). Early rightwards orienting of attention on simple reaction time performance in patients with left-sided neglect. *Neuropsychologia*, *30*, 989–1000.

Ellis, A. X., Della Sala, S., & Logie, R. H. (1996). The bailiwick of visuo-spatial working memory: evidence from unilateral spatial neglect. *Cognitive Brain Research*, *3*, 71–78.

Gainotti, G. (1996). Lateralization of brain mechanisms underlying automatic and controlled forms of spatial orienting of attention. *Neuroscience and Behavioral Reviews*, *20*, 617–622.

Guariglia, C., Padovani, A., Pantano, P., & Pizzamiglio, L. (1993). Unilateral neglect restricted to visual imagery. *Nature*, *364*, 235–237.

Heilman, K. M., Bowers, D., Valenstein, E., & Watson, R. T. (1987). Hemispace and hemispatial neglect. In M. Jeannerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 115–150). Amsterdam: North-Holland.

Kinsbourne, M. (1987). Mechanisms of unilateral neglect. In M. Jeannerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 69–86). Amsterdam: North-Holland.

Logie, R. H. (1995). *Visuo-spatial working memory*. Hove, UK: Lawrence Erlbaum.

Logie, R. H. (2003). Spatial and visual working memory: A mental workspace. In D. Irwin & B. Ross (Eds.), *Cognitive vision: a volume of the psychology of learning and motivation* (vol. 42, pp. 37–78). New York: Academic Press.

Logie, R. H., & Della Sala, S. Disorders of visuo-spatial working memory. In A. Miyake, & P. Shah (Eds.), *Handbook of visuospatial thinking*. New York: Cambridge University Press, in press.

Malhotra, P., Mannan, S., Driver, J., & Husain, M. (2004). Impaired spatial working memory: one component of the visual neglect syndrome? *Cortex*, in press.

Meador, K. J., Loring, D. W., Bowers, D., & Heilman, K. M. (1987). Remote memory and neglect syndrome. *Neurology*, *37*, 522–526.

Nichelli, P., Rinaldi, M., & Cubelli, R. (1989). Selective spatial attention and length representation in normal subjects and in patients with unilateral spatial neglect. *Brain and Cognition*, *9*, 57–70.

Pisella, L., Berberovic, N., & Mattingley, J. B. (2004). Impaired working memory for location but not for colour or shape in visual neglect: a comparison of parietal and non-parietal lesions. *Cortex*, *40*, 379–390.

Rode, G., Rossetti, Y., Perenin, M. T., & & Boisson, D. (2004). Topographic information has to be spatialised to be neglected. *Cortex*, *40*, 391–397.

Spinnler, H., & Tognoni, G. (Eds.), (1987). Standardizzazione e taratura italiana di test neuropsicologici [Italian norms of neuropsychological tests]. Italian Journal of Neurological Sciences, 6 (Suppl. 8), 1–120.

Wilson, B., Cockburn, J., & Halligan, P. (1987). Development of a behavioural test of visuo-spatial neglect. *Archives of Physical Medicine and Rehabilitation*, *68*, 98–102.

Wojciulik, E., Husain, M., Clarke, K., & Driver, J. (2001). Spatial working memory deficit in unilateral neglect. *Neuropsychologia*, *39*, 390–396.