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LEVELS OF IMPAIRMENT IN UNILATERAL NEGLECT

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OUTLINE

Unilateral brain lesions may induce signs of lateralized spatial bias, whereby patients show a preference for responding to events occurring on the side of space ipsilateral to the lesion, as compared to events occurring on the other, contralesional side. This bias can range from a mild asymmetry of response latencies to lateralized events to situations in which patients seem to act as if the contralesional half of the world did not exist anymore. The resulting peculiar patterns of performance in everyday life and in paper-and-pencil tests are collectively described as unilateral neglect (Jeannerod, 1987; Robertson and Marshall, 1993; Weinstein and Friedland, 1977). It is now generally accepted that unilateral neglect is more common, severe and long-lasting after lesions in the right hemisphere than after left brain damage; in this chapter, we will thereby primarily focus on neglect for left-sided events after right-hemisphere lesions. Left neglect is often dramatic enough as to constitute a major handicap for neurological patients, who may repeatedly bump into objects on their left side, hurt themselves and get lost in familiar environments.

"Peripheral" sensory or motor processing is usually preserved in unilateral neglect; hence, neglect might stem from an impairment situated at one of the many levels of processing that go from primary sensory processing to action. In this chapter, we describe the most common behavioral signs of neglect and the neuropsychological tasks used to determine its presence and severity; we then review some of the putative levels of impairment involved in neglect, with the functional mechanisms that have been proposed to account for neglect. The chapter is concluded by a short overview of rehabilitation techniques.

Clinical description

Signs of left neglect usually emerge after large lesions involving the temporo-parietal junction of the right hemisphere. In the acute phase, patients lie in bed with their head and eyes turned toward the right. They typically do not answer if questioned from the left side, and cannot pay attention to the left even if summoned to do so. The tendency to rightward orienting is so compulsive and pervasive in this stage, that it is usually impossible to administer neuropsychological tests.

After a few days, patients usually recover the ability to maintain head and eyes straight. However, the mere appearance of any visual object either on the right side or bilaterally induces an immediate orientation of the head and the eyes toward the right-sided object. For example, in testing the visual fields by means of the confrontation technique, as soon as the examiner outstretches his or her hands, patients may look at the hand on their right, before the actual administration of the stimuli ("magnetic attraction" of gaze, see Gainotti et al., 1991). At this stage, when questioned from the left side patients may answer to another person standing on their right. Other behavioral signs of left neglect include eating from only the right side of the dish, shaving or making up only the right half of the face, and reading only the right extremity of newspaper titles. Patients may forget to wear the left sleeve or slipper and leave hanging the left earpiece of their spectacles. Neuropsychological tests (see below for an overview) reveal the presence of a severe left unilateral neglect, with patients' performance often confined to a restricted region of the right hemispace, without reaching the sagittal midline.

Subsequently, patients may recover from gross behavioral signs of neglect in everyday life. In this phase, diagnosis of neglect rests on appropriate neuropsychological testing, in which patients may be able to attend to information from the right half of the display sheet, but still show defective performance on the left side.

After a period ranging from weeks to months since lesion onset, patients may learn to compensate for neglect both in everyday life and in paper-and-pencil tasks. Even in this phase, however, subtler signs of spatial bias can be demonstrated. Patients continue to begin their exploration from the right side (Mattingley et al., 1994b), whereas most normal individuals use a left-to-right scanning technique, possibly on account of their reading habits (Chokron and Imbert, 1993). When producing a manual or vocal response to lateralised visual targets, patients respond more slowly to left than to right targets, especially at the beginning of the test (Bartolomeo, 1997), as if a residual initial attraction for right-sided objects were at work (Mattingley et al., 1994b).

A number of patients do not recover from behavioral signs of neglect. For these patients, the presence of neglect may affect negatively motor recovery (Denes et al., 1982). Thus, neglect does not only have important implications for understanding the brain mechanisms of space processing; it also constitutes a major clinical problem.

1.1. Diagnostic tests

Several neuropsychological tasks can be used to demonstrate the presence and the amount of unilateral neglect. Here we briefly describe three visuomotor procedures simple enough as to be administered at the bedside. Other tasks that can be used for the assessment of particular aspects of neglect will be discussed in section 3. Care should be taken in the proper positioning of the test sheet; in the usual clinical conditions, the midline of the sheet should correspond to the trunk midline of the patient.

1.1.1. Drawing tasks

In drawing figures, whether from memory or by copying them, neglect patients omit or distort the details on the left side (Gainotti et al., 1972) (Fig. 1).

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Fig. 1 about here

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When copying patterns composed of several elements aligned horizontally, some patients neglect the whole left part of the model, while others copy all the items but leave unfinished the left part of each (Gainotti et al., 1972; Marshall and Halligan, 1993) (Fig. 2). These different patterns of performance have been respectively defined as scene- (or viewer-)based and object-based neglect (see Walker, 1995, for review).

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Fig. 2 about here

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In copying drawings, patients may sometimes displace to the right side of their copy details situated on the left side of the model (Fig. 3) (Halligan et al., 1992). These transposition errors are often referred to as allochiria or allesthesia, by analogy with the behavior of patients who report as occurring on the good side of their body a tactile stimulus given to the affected side (Critchley, 1953).

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Fig. 3 about here

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1.1.2. Cancellation tasks

In cancellation tasks, patients are asked to cross out items scattered on a paper sheet, such as lines (Albert, 1973), letters (Mesulam, 1985) or shapes (Gauthier et al., 1989; Halligan et al., 1991). Patients typically begin to scan the sheet from the right side, unlike normal left-to-right readers, who start from the left side (Bartolomeo et al., 1994). Patients omit a number of left-sided targets, sometimes without even crossing the midline; they may continue to cancel the same rightmost items over and over again (Fig. 4).

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Fig. 4 about here

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A monetary reward for each canceled item can dramatically reduce neglect on cancellation tasks (Mesulam, 1985); this finding underlies the importance of motivational factors in neglect behavior, and the possibility of circumventing neglect by manipulating task conditions apparently unrelated to space.

1.1.3. Line bisection

In line bisection tasks, patients have to mark the midpoint of a horizontal line; neglect patients deviate the subjective midpoint to the right of the true center of the line (Schenkenberg et al., 1980). The amount of deviation depends on several factors. The longer the line, the more rightward the bisection point; for the shortest lines there may be a paradoxical leftward deviation (the "crossover effect", Marshall and Halligan, 1989b). The location in space of the line with respect to the patient's trunk midline also influences performance; rightward deviation increases when lines are located in the left hemispace and decreases when they are in the right hemispace (Heilman and Valenstein, 1979; Schenkenberg et al., 1980). Another factor that influences line bisection performance is the direction of exploration of the line. In a passive version of the task, in which patients had to observe a dot or pen moving along the line and to say "stop" when it crossed the perceived middle, neglect patients' rightward error decreased when the pen traveled from the left to the right, as opposed to the right-to-left condition, which increased the amount of rightward shift (Chokron et al., 1998; Mattingley et al., 1994a; Reuter-Lorenz and Posner, 1990). Reading habits seem also to influence line bisection, presumably through the induction of preferential exploratory strategies. Chokron and Imbert (1993) demonstrated that whereas left-to-right French readers deviated toward the left in a visuo-motor line bisection task, right-to-left Israeli readers shifted the subjective middle toward the right. This effect of reading habits on line bisection performance occurs not only for school-children (8 years old) and adults but also for pre-school children, indicating that reading habits may influence the visual exploration of non-linguistic stimuli even before formal reading begins (Chokron and De Agostini, 1995).

How many neglects?

The peculiar issues that unilateral neglect raises concerning space processing and consciousness, together with the puzzling fact that neglect occurs preferentially after right-hemisphere lesions, have stimulated a large body of research in the last decades. A number of theories have been advanced to explain neglect, but a unitary explanation has up to now proved elusive, and there is no consensus about its causal mechanisms (see Halligan and Marshall, 1994).

The shift in neuropsychological research from group studies to single-case studies has led to the description of several dissociations in neglect. Thus, patients have been described who neglect left-sided events in near (peripersonal), but not far space (Halligan and Marshall, 1991a), or vice-versa (Cowey et al., 1994), or who show neglect on some tests but not others (Halligan and Marshall, 1992), or even opposite patterns of neglect (left vs. right) depending on the task administered (Costello and Warrington, 1987; Halligan and Marshall, 1998; Humphreys and Riddoch, 1994). This apparently “unmanageable explosion of dissociations” (Vallar, 1994) has understandably led to the consideration of neglect as a highly heterogeneous disorder (see, e.g., Chatterjee, 1998; Stone et al., 1998), if not “a meaningless entity” (Halligan & Marshall, 1992).

It is certainly possible that different causes lead to similar neglect behavior through different routes (see, e.g., Barton et al., 1998). However, it must be noted that the status of some neglect dissociations as diagnostic of qualitatively different impairments has been questioned. Neglect has a unique position in neuropsychology, in that the same event can elicit different behaviors depending on which side of space it occurs. But the left/right border, and consequently the border between attended and neglected objects, is not a fixed border but a dynamic one (Gainotti, 1994), and can be influenced by several factors, including patients' exploratory strategies and compensatory mechanisms.

Spatial exploratory tasks, such as those used to investigate neglect, are particularly sensitive to changes in strategy. For example, changing the direction of exploration of a horizontal line can reverse the direction of the bisection error, both in normals and in neglect patients (Chokron et al., 1998). In a similar vein, although the dissociation of scene- and object-based neglect does suggest that they reflect different underlying impairments (see Walker, 1995), any firm conclusion in this sense is rendered difficult by the finding that the same patients can show scene- or object-based neglect depending on the nature of the task (see below, section 3.3.3). Analogous considerations can be made for the distinction between visual and imaginal neglect (section 3.2.2) and for the dissociation between perceptual and premotor forms of neglect (section 3.5). Moreover, the well-established evidence that lesions determining neglect tend to cluster over the temporo-parietal junction of the right hemisphere seems to suggest that some core deficit, or some peculiar association of deficits (as suggested by the generally large size of the lesions, which may indicate damage to several functional systems), is at work in a large majority of neglect patients. Thus, at this stage any conclusion about the heterogeneity or a (relative) homogeneity of the neglect syndrome seems premature. In view of these considerations, multiple single-case studies, in which individual performance of several patients are explored in detail, seem at present the best way to constrain theoretical models of neglect, and to determine the real clinical importance of the deficits at issue.

The peculiarities of neglect behavior have fostered several explanations of neglect. These hypotheses were often inspired by a particular aspect or symptom, that was isolated and considered to account for the other manifestations of the syndrome. Thus, one hypothesis may consider one aspect as the cause and the other aspects as its consequences; another explanation may revert the putative cause-consequence relationship in a chicken-and-egg fashion. For example, a rightward deviation in line bisection has always been seen as a consequence of left neglect, but a rightward deviation in judging the position of the “straight ahead” has been interpreted as a shift of the egocentric reference leading to neglect (see below, section 3.2.4). It is thus perhaps no wonder that the explanatory value of the existing theories of neglect has been considered to be very low, if not “essentially zero” (Marshall and Halligan, cited by Bisiach et al., 1994).

Unilateral neglect: From sensation to action

Various levels of impairment from primary sensory processing to motor programs have been invoked to explain neglect. Acting in the environment continuously demands visuomotor transformations. Perceptual representations and motor plans mutually update each other as action changes the perceived environment (action-perception cycles, (Arbib, 1981). For example, the mere fact of crossing out lines in a cancellation task modifies the visual scene, so that patients' performance in this task may differ from performance in an equivalent task where lines are to be erased rather than crossed (Mark et al., 1988) (see section 3.3.1).

One could thus conceive that patients show left neglect signs as illustrated in Figures 1-4 because: (1) they do not see the left part of the test sheet; (2) their representation of the space array is amputated, distorted or deviated; (3) they suffer from an attentional bias favoring the right side or penalizing the left side; (4) their exploration of space is biased toward the right; (5) they have problems in programming movements of the arm or the hand toward the left. It is also possible that any combination between these impairments determines neglect. In the following sections, we will review and discuss the possible contribution of each of these putative levels of spatial bias to neglect.

1.2. Elementary sensory processing

The first possible level of spatial bias in neglect could logically be an elementary sensory impairment. For example, patients could neglect the left side of their world just because they do not see it, possibly in the context of altered mental functioning (Battersby et al., 1956). This hypothesis has long been falsified by the reports of double dissociations between hemianopia and neglect (Gainotti, 1968; McFie et al., 1950). Importantly, hemianopic patients without neglect try to compensate for their deficit, often to the point of a paradoxical contralesional deviation in line bisection (Barton and Black, 1998), whereas patients with hemianopia and neglect deviate ipsilesionally[1]. Moreover, neglect has been shown not only in the visual space, but also in auditory (Bisiach et al., 1984; De Renzi et al., 1989a), tactile (Bisiach et al., 1985b; Chedru, 1976) and imagined space (Bisiach et al., 1981; Bisiach and Luzzatti, 1978). Thus, unilateral neglect can be a supramodal disorder. A third argument that challenges the hypothesis of an important role of primary sensory impairment in neglect is that the early stages of visual perception, such as figure-ground segregation, can be preserved in neglect (Driver et al., 1992). These considerations call for a more abstract of a level of impairment than primary sensory representations. For example, Denny-Brown, Meyer and Horenstein (1952) surmised that the parietal cortex is concerned with the perceptual synthesis of multiple sensory data (morphosynthesis), achieved through spatial summation. The loss of visual and tactile components of this integrative process would result in

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[1] The hypothesis of a primary sensory impairment as the origin of neglect has been somewhat reversed by the demonstration that neglect can be so profound as to simulate a non-existent hemianopia (Kooistra and Heilman, 1989; Walker et al., 1991) or hemianesthesia (Vallar et al., 1991).

neglect behavior (amorphosynthesis). This putative level of sensory integration is still close to perceptual processes. Levels of impairment further away form perception have also been hypothesized, such as a difficulty in building or in exploring an internal representation of space.

1.3. Space representation

1.3.1. Neglecting mental images

Accounts of neglect based on a disturbed mental representation of space stem from the observation that neglect may not only occur during activities requiring the processing of sensory input, but also during tasks less directly involved with perception, such as the description from memory of places. Brain (1941) reported on a patient who, “when asked to describe how she would find her way from the tube station to her flat she described this in detail correctly and apparently visualizing the landmarks, but she consistently said right instead of left for the turning except on one occasion (p. 259)”. McFie et al. (1950), commenting upon Brain’s study, observed that “not uncommonly, loss of topographical orientation can be traced to massive neglect of the left half of visual space... This symptom (...) undoubtedly accounts for the greater part of the topographical disability observed by Russell Brain (p. 170, note 1)”. These authors described a patient with topographical disorientation who showed “no evidence of neglect of left half of space apart from his own admission that he thought most of the turnings which he missed when he became lost were on his left (McFie et al., 1950, p. 176)”. When the patient reported by Denny Brown et al. (1952) was asked to describe the ward two months after discharge form hospital, she “began by describing all the patients and the windows which had been on her right, mentioning them from right to left. She made no mention of the patients on the left until pressed and then was able to recall 2 out of 5 (Denny-Brown et al., 1952, p. 438-439)”.

The issue of mental representation of space in neglect assumed theoretical significance in the work of Bisiach and his associates (see Bisiach, 1993, for review). In their seminal paper, Bisiach and Luzzatti (1978) reported two left neglect patients who, when asked to imagine and describe from memory familiar surroundings (the Piazza del Duomo in Milan), omitted to mention left-sided details regardless of the imaginary vantage point that they assumed, thus showing representational, or imaginal, neglect. Bisiach, Capitani, Luzzatti and Perani (1981) replicated this finding in a group study with 28 neglect patients, of which 13 had to be excluded from analysis because they misplaced the imagined details (e.g., they said that a left-sided detail was on the right side); the remaining 15 patients showed a bias toward mentioning more right-sided than left-sided details of the Piazza del Duomo. Bisiach and coworkers interpreted these findings as evidence that neglect patients suffer from "a representational map reduced to one half (Bisiach et al., 1981, p. 549)".

Bartolomeo, D'Erme and Gainotti (1994) reasoned that, if such a representational deficit were at the base of neglect, patients should show comparable neglect signs in imaginal (i.e., description from memory of known places) and visuospatial tasks. They assessed quantitatively the amount of neglect in 30 right brain-damaged (RBD) and 30 left brain-damaged (LBD) patients, tested consecutively. RBD patients showed a significant ipsilesional (rightward) bias in both sets of tasks, while LBD patients, taken as a group, performed not differently from controls. For RBD patients, the amount of spatial bias in imaginal tasks correlated with that in visuospatial tasks, thus supporting the idea of a relationship between the two impairments. However, analysis of individual performance revealed that only five of the 17 RBD patients with visuospatial neglect also showed neglect in the imaginal domain, contrary to the predictions of the representational hypothesis. Furthermore, only in the visuospatial tasks, and not in the imaginal tasks, RBD patients consistently showed the right-to-left scanning procedure typical of left neglect. The greater frequency of left neglect in visuospatial than imaginal tasks may thus result from the fact that visual objects are more likely than imagined details to attract RBD patients' attention toward the right (see section 3.3.1 below). Of the 30 LBD patients, two showed signs of right visuospatial neglect, none of right imaginal neglect. That left visuospatial neglect often stands unaccompanied by imaginal neglect was also confirmed by another group study (Halsband et al., 1985), by the detailed report of two cases (Anderson, 1993), and by a study conducted during intracarotid injection of amobarbital (Manoach et al., 1996).

A problem with the description from memory of known places is that abilities other than visual imagery might be used to perform this task. In the Bartolomeo et al.'s (1994) study, patients were invited to imagine the places "as if they were before their eyes". Despite these instructions, some of them might simply have produced a list of details from verbal semantic memory. If so, imaginal neglect would be underestimated in these tasks, and might thus ultimately appear to be less common than visuospatial neglect (although it is unlikely that the two thirds of left neglect patients of the Bartolomeo et al.'s series did not comply with the test instructions). A different paradigm to study lateralized defects of mental representation was devised by Bisiach, Luzzatti and Perani (1979), who had 19 RBD patients with left neglect perform same/different judgements over pairs of cloud-like shapes that moved horizontally and could only be seen while passing behind a narrow slit. Performance was particularly impaired when the shapes differed on the left side. Because the overall shape had to be mentally reconstructed to perform the same/different judgement, Bisiach et al. (1979) concluded that a representational disorder was of primary importance in neglect. However, since patients without neglect were not examined in this study, the results simply indicated that an imaginal defect could be present in neglect. In a similar task, Ogden (1985) also found impaired accuracy for contralesional details in four RBD (of whom three had left visuospatial neglect) and five LBD patients (of whom two had right visuospatial neglect; five other RBD and four LBD patients could not complete the task). The status of the slit experiment as a test of imaginal neglect was, however, later questioned by Bisiach and Rusconi (1990), who found that the left part of a drawing may continue to be neglected even when patients correctly follow the contour of the drawing with their finger. This finding suggested to Bisiach and Rusconi a reinterpretation of the slit experiment results, as “a defective pick-up of information from the leftmost part of the stimuli in the short lapse of time in which this part was shown in central vision (p. 647)”.

The interpretation of imaginal neglect depends on the development of theories of mental imagery. The possibility that patients who neglect visual objects could also neglect visual mental images was easily explained within the general framework theories considering mental images as functionally similar to visual percepts. If visual perception and visual imagery share a number of mental operations (Kosslyn, 1994), and rely upon common neural structures, including early visual cortices (Damasio, 1989; Kosslyn, 1994), then an association of visual and imaginal neglect is indeed to be expected. However, there is now robust evidence that patients with severe perceptual impairment can conjure up vivid mental images of the very items that they cannot perceive (Bartolomeo et al., 1998a; Behrmann et al., 1992). This evidence calls into question the hypothesis of too strict an equivalency between the act of perceiving and that of imagining, and seems to relate imagery to more abstract abilities than perception. If so, imaginal neglect is an even more striking phenomenon, perhaps akin to forms of “conceptual” bias such as the one demonstrated by occasional neglect patients who seem unwilling even to utter the word “left”.

1.3.2. Imaginal neglect in isolation

Neglect for the left part of mental images has been described in the absence of neglect for visual objects (Beschin et al., 1997; Coslett, 1989 (abstract); Coslett, 1997; Guariglia et al., 1993). The most straightforward interpretation of this dissociation is that different mechanisms mediate visuospatial and imaginal neglect. A more parsimonious account would be that these patients have learned with time (and possibly the help of people around them) to compensate for their neglect in the visuospatial domain, but not in the less ecological imaginal domain. As a matter of fact, neglect patients are often reminded by relatives and hospital staff to explore the visual scene thoroughly, and could learn to appreciate the consequences of their omissions (e.g., while eating or reading a newspaper), but this cannot happen in the imaginal space. The follow up of a patient with a severe visuospatial and imaginal neglect seems to support this idea. Eight months after the first testing, this patient had recovered from visuospatial neglect, but still showed imaginal neglect (Bartolomeo et al., 1994). Patient M.N. described by Coslett (1989; 1997) also showed a similar pattern of selective recovery from visuospatial, but not from imaginal, neglect. Another patient (D'Erme et al., 1994) did not show clinical signs of neglect eight days after the stroke; he had, however, mild but definite left neglect signs on visuospatial testing and on imaginal tasks. Two weeks after the stroke, visuospatial neglect had resolved, leaving an isolated imaginal neglect, which disappeared in turn 22 days after onset (Fig. 5). In this patient, visuospatial neglect at the initial assessment was so mild, that it would have probably passed undetected without proper testing, thus leaving the impression that neglect was exclusive for visual imagery from the beginning.

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Fig. 5 about here

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Thus, follow-up studies can disentangle residual deficits from compensatory mechanisms, and they can possibly contribute to reduce the confusing variety of neglect dissociations to a number of component mechanisms[2].

[2] By this account, it remains of course to be elucidated why some patients develop effective strategies for certain domains, whereas other patients do not.

1.3.3. Anisometry of mental coordinates

Other explanatory accounts of neglect focus on a dysfunction of the left part of a mental representation of space in neglect. These accounts, however propose that this part of the representation is not destroyed, but distorted. Evidence relevant to this issue was collected by Gainotti and Tiacci (1971, Experiment 2), who had 75 RBD patients (of which 31 with left neglect) compare the size of two geometrical figures presented on the left and the right sides of a sheet. Neglect patients tended to overestimate right-sided as compared to left-sided figures. Also seven right neglect patients (out of a group of 62 LBD patients) showed a similar, albeit less marked tendency to overestimate the size of ipsilesional figures. Drawing on evidence showing that normal individuals overvalue the dimensions of those items on which their gaze is mostly fixed (Piaget, 1961), Gainotti and Tiacci (1971) attributed the perceptual bias of neglect patients to an asymmetrical exploration of space favoring ipsilesional over contralesional objects (see section 1.4.1 below). More recently, a similar experimental paradigm was employed by Milner and Harvey (1995), who reasoned that a “shrinkage” in object size perception in the left hemispace could explain neglect patients’ rightward error in line bisection. They asked 15 RBD patients (of whom three had left neglect) to compare pairs of horizontally arranged shapes (horizontal rectangles, vertical rectangles, or nonsense shapes). Neglect patients consistently underestimated items presented on the left side, with the exception of the vertical rectangles, for which they were accurate. Milner and Harvey (1995) concluded that horizontal size is miscomputed in the left parts of the visual array. Bisiach et al. (1996) had neglect patients mark the left and right endpoints of a virtual horizontal line on the basis of a given midpoint. Patients misplaced the left endpoint leftwards, as if mimicking their biased performance in line bisection. Bisiach et al. (1996)

concluded that space representation in neglect is characterized by a horizontal anisometry, with spatial coordinates progressively relaxing from the right to the left side (Fig. 6).

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When placing the endpoints of a virtual line, patients should travel further leftward than rightward to equalize the amount of perceived spatial extent. It has also been shown, however, that only patients with an association of neglect and complete left hemianopia seem to show this peculiar behavior, whereas neglect patients without visual field defect do not demonstrate consistent asymmetries in placing the endpoints (Doricchi and Angelelli, 1999); this finding limits the generality of the anisometry account. Moreover, performance of one left neglect patient would rather suggest a *compression* of left-sided spatial coordinates (Halligan and Marshall, 1991b). When this patient saw rows of numbers (from 1 to 15), and had to identify the number aligned with an arrow presented either at the top or bottom of the monitor, she often indicated a number to the right of the target. The more the target was on the left, the more the response was shifted rightward. Halligan and Marshall (1991b) concluded that in this patient points in left space were compressed rightward[3].

While the accounts based on a horizontal anisometry of space representation may explain relatively easily patients' behavior in line bisection and related tasks, they fare less well for visual search paradigms, in which it is not clear why neglect patients should *omit* left-sided targets. Moreover, further assumptions are necessary for the model to explain why neglect patients deviate much more when bisecting a line than when bisecting an empty space between two points (see

[3] Another possible explanation of these results is that patient's attention was attracted by the digits to the right of the target digit (see below, section 1.4.1), thus biasing her responses toward right-sided digits.

Bisiach et al., 1996). More generally, models of neglect based on a dysfunction of space representation are not able to account for the dramatic effect exerted on neglect signs by variables such as the presence or absence of visual guidance (see section 1.4). For example, when two horizontally arranged LEDs are presented in otherwise complete darkness, neglect patients can accurately adjust their position to a prespecified distance, independent of the hemispace of presentation (Karnath and Ferber, 1999). In this case, the absence of other visual stimuli or of a visual background seems to nullify the error of horizontal length estimation induced by neglect. This appears in turn to underline the importance of the presence of competing visual events to elicit neglect.

1.3.4. Shift of the egocentric frame of reference

On the basis of the observation of asymmetric compensatory eye movements after lesions in the cat parietal cortex and superior colliculus, Ventre and colleagues (Ventre and Faugier-Grimaud, 1986; Ventre et al., 1984) hypothesized that a body reference frame that allows a reconstruction of body position in space with respect to external objects is built as an internal representation of body midline or longitudinal axis. This internal representation was assumed to be a result of symmetric activity of associative neural structures. Unilateral lesions of these structures would produce permanent asymmetric activity inducing a displacement of the egocentric coordinates to a new position located in the ipsilesional hemispace, thus inducing a contralesional neglect (Fig 7).

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Fig. 7 about here

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One way of improving neglect patients would thus be to restore the position of their egocentric reference. Several authors assumed that this was indeed the reason explaining the positive, if temporary, effect on left neglect signs of a number of vestibular and proprioceptive experimental stimulations. Thus, caloric vestibular stimulation, optokinetic stimulation, vibration of neck muscles on the left side, leftward trunk rotation and transcutaneous electrical stimulation of the left hand would reduce left neglect signs by temporarily inducing a leftward deviation of the egocentric reference, thus counteracting the pathological ipsilesional deviation of this reference and replacing it at the mid-sagittal plane as observed in normals (Fig. 8) (Karnath, 1997; Karnath et al., 1993; Karnath et al., 1991; Rode et al., 1992; Rode and Perenin, 1994; Vallar et al., 1993a; Vallar et al., 1993b; Vallar et al., 1997; Vallar et al., 1995; Vallar et al., 1990).

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Patients would then become temporarily aware of otherwise neglected stimuli delivered to the affected side.

This theoretical set implies three distinct assertions. First, it takes for granted the existence of an ipsilesional deviation of the egocentric reference in left neglect patients. Second, this deviation is considered as the cause of the neglect behavior. Third, the above-cited stimulations are seen as a means to restore the position of the reference. If some physiological and clinical evidence seem to support these assertions, other experimental findings challenge them.

The vestibular system is a component part of cerebral circuits including cortical and sub-cortical structures. Its main cortical projections are on the parietal cortex (Fredrickson et al., 1966), which in turn projects to the vestibular nuclei in the brainstem (Ventre & Faugier-Grimaud, 1986). According to these anatomical data, the vestibular system could be involved in maintaining orientation in egocentric space. Other neurophysiological studies (reviewed by Stein, 1992) suggest that the vestibular system project to the posterior-superior temporal region. This area is adjacent to the infero-posterior parietal cortex, which is frequently damaged in patients with contralateral neglect

In neglect patients, a constant “directional” error, which would fit the hypothesis of an ipsilesional deviation of the egocentric reference, has been repeatedly described. The usual way of testing the perceived direction of the egocentric reference is to ask subjects to point straight ahead while blindfolded and to record this subjective position (Jeannerod and Biguer, 1987). Heilman, Bowers and Watson (1983) reported in five left neglect patients a large deviation of the subjective straight-ahead to the right ipsilesional hemispace. Heilman and coworkers interpreted their results in neglect patients in terms of a directional motor disorder ("hemispatial akinesia"; see below, section 1.5). The finding of an ipsilesional shift of the subjective sagittal middle in left neglect was replicated in one patient with a proprioceptive straight-ahead pointing task (Chokron and Imbert, 1995) and in three patients with a visual straight-ahead pointing task (Karnath et al., 1993). Perenin (1997) found a mean rightward deviation of about 9° in a group of 25 left neglect patients using a straight-ahead pointing task performed in darkness (see Perenin, 1997, Fig. 5). It was also recently suggested that the presence of an extensive right parietal lesion correlated with a rightward shift of the egocentric reference (Chokron and Bartolomeo, 1999; Hasselbach and Butter, 1997).

However, others have found no correlation between left neglect signs and either the presence or the side of a deviation of the egocentric reference position recorded during a straight-ahead pointing task (Bartolomeo and Chokron, 1999; Chokron and Bartolomeo, 1997; Chokron and Bartolomeo, 1998; Farnè et al., 1998; Hasselbach & Butter, 1997; Perenin, 1997). The absence of a direct causal link between the position of the egocentric reference and the presence of neglect signs is confirmed by several experimental data. First, there is evidence for a significant deviation of the egocentric reference in patients with hemianopia (Fuchs, 1920), ataxia (Perenin, 1997) or primary motor deficit (Chokron & Bartolomeo, 1997), but without any signs of neglect. Second, neglect signs may arise in frames of reference other than the egocentric one (e.g., object-based: see section 1.4.3 below). Third, visual guidance seems to exacerbate the neglect behavior with respect to conditions in which visual control is minimized (see section 1.4). The reference shift hypothesis would on the contrary predict that the absence of visual control worsened patients' performance, because the egocentric reference is not defined in retinotopic coordinates but in body-centered ones (Jeannerod & Biguer, 1987; Karnath et al., 1991).

It follows from these considerations that the positive effect of the experimental stimulations mentioned above cannot come from a restoration of a normal egocentric frame of reference. This notion was confirmed by evidence showing that optokinetic stimulation may not always restore normal performance in neglect (Bisiach et al., 1996). As reported in section 1.3.3, when required to set the endpoints of an imaginary horizontal line of a given length on the basis of its midpoint, left neglect patients can misplace endpoints leftwards, thus reproducing the usual rightward deviation of the subjective middle found in line bisection. When the task was executed during leftward optokinetic stimulation (known to temporarily improve left neglect), the disproportion increased instead of vanishing. Bisiach and coworkers (1996) concluded that manipulations such as optokinetic stimulation may remove neglect without normalizing the representational medium itself. In a similar vein, imposing a left-to-right scanning of a to-be-bisected line may induce a pathological leftward deviation of the subjective middle in neglect patients, thus reversing left neglect behavior without reducing it (Chokron et al., 1998). Several data suggest that these stimulations could act by allowing an orientation of attention to the left hemispace (see section 0 below). These considerations strongly suggest an important role of attentional processes in the determinism of left neglect.

1.4. Orienting of attention

The basic fact of left neglect is that an event on the right side is more likely to attract patient's attention than an event occurring on the left. This is particularly true when the two events are in competition, for example when they appear at the same time. The phenomenon of omitting to report a contralesional stimulus only when a concurrent ipsilesional stimulus is presented is called *extinction*. Left visual stimuli are usually extinguished in neglect patients (Gainotti et al., 1991); extinction may persist after clinical signs of neglect have subsided (Kaplan et al., 1995; Karnath, 1988). Thus, the fact of putting stimuli in competition is a powerful means of eliciting signs of spatial bias (Di Pellegrino and De Renzi, 1995). This observation naturally leads to explanations of neglect based on an attentional bias, because attention is considered the basic mechanism used to deal with multiple competing stimuli.

The concept of attention refers to a heterogeneous set of phenomena, whose goal is to maintain coherent behavior in the face of irrelevant distractions. William James (1890) already observed that "my experience is what I agree to attend to… Without selective interest, experience is an utter chaos (James, 1890, p. 402)". James distinguished among different "varieties of attention"; for example, he separated "passive, reflex, non-voluntary, effortless" attention from "active and voluntary" attention (James, 1890, p. 416). In a recent review, Parasuraman (1998) identified at least three independent but interacting components of attention: (1) *selection*, that is, systems determining more extensive processing of some input rather than another; (2) *vigilance*, or the capacity of sustaining attention over time; (3) *control*, the ability of planning and coordinating different activities. Most attentional accounts of neglect postulate a problem of spatial selective attention. Spatial selective attention refers operationally to the advantage in speed and accuracy of processing for objects lying in attended regions of space as compared to objects located in non-attended regions (Posner, 1980; Umiltà, 1988). The scope of attentional selection need not be confined to perception, but can be functional to coherent control of action (Allport, 1989). Goal-directed behavior results from an orderly sequence of a limited number of actions; sensory information irrelevant to current behavioral scopes has to be filtered out to prevent interferences.

Attention can be oriented in space *overtly*, when eye and head movements align the fovea with the attended region, or *covertly*, in the absence of such movements. Posner and coworkers (see Posner, 1980, for review) developed a manual reaction time (RT) paradigm to study the covert orienting of attention. Subjects are presented with three horizontally arranged boxes. They fixate the central box and respond by pressing a key to a target (an asterisk) appearing in one of two lateral boxes. The target is preceded by a cue indicating one of the two lateral boxes. The cue can be either an arrow presented in the central box, or a brief brightening of one peripheral box. *Valid* cues correctly predict the box in which the target will appear, whereas *invalid* cues indicate the wrong box. Often, a large majority (usually 80%) of cues is valid; in this case, cues are said to be *informative* of the future emplacement of the target. The experimental paradigm may require the cue to be *non-informative*; in this case, the target will appear with equal probabilities in the cued or in the uncued location. For informative cues, normal subjects usually show an advantage of valid cue-target trials as compared to invalid trials. This suggests that the cue prompts an attentional orienting toward the cued location, which speeds up the processing of targets appearing in that region and slows down responses to targets appearing in other locations.

Other studies highlighted the fact that attention can not only be directed to a region of space, but also (and perhaps more importantly) to visual objects in space. For example, when normal subjects see a rectangle with a line struck through it, they can more easily report two attributes if they belong to the same object (e.g., if the line is dashed and tilted), than if they belong to two different objects (e.g., if the rectangle has a gap and the line is dotted), notwithstanding the fact that the two objects appear in the same spatial region (Duncan, 1984). In such a view, objects would be preattentively defined in the space array, and attention would then prompt selection of an entire object, and not of its spatial location. The demonstration that attention is directed to objects in space has since been confirmed by many studies (see Egeth and Yantis, 1997, for review). As a matter of fact, normal observers find it extremely difficult, if not impossible, to covertly attend to a 'blank' region of space, where no object is present (see Nakayama and Mackeben, 1989, Experiment 2).

Before proceeding with an overview of attentional accounts of neglect, it is worth examining some of the reasons why attentional processes can be considered more relevant than others for explaining unilateral neglect. Consideration of the sensory modalities of expression of neglect may prove useful. For example, costs and benefits provided by cues are maximal for visual targets and decrease for tactile and even more for acoustic targets (Posner, 1978/1986). This is perhaps related to the topographical organization of the visual system, which might emphasize the spatial aspects of cueing (see Reuter-Lorenz et al., 1996). Moreover, the organization of the oculomotor system, with the possibility of rapidly bringing into foveal vision objects to be identified, calls for an efficient interface with the perceptual system. Seeing an object "out of the corner of the eye" typically induces movements of the eyes and of the head to align the object with the retinal fovea, the region with the highest spatial definition for visual identification. Attentional orienting is often triggered by the sudden appearance of an object in the retinal periphery (Yantis, 1995). As we have seen, orienting one's attention toward a visual object means being able to process it with increased speed and accuracy. This clearly represents an advantage when a quick decision is to be taken about which objects are to be approached (e.g. food) and which to be avoided (e.g. dangers). Thus, the anisometry of the sensory surface, with a region (the fovea) much more sensitive than others, prompts the need for orienting movements to align the sensory input with this region. These characteristics are much less evident in other sensory systems.

If neglect, then, can be shown to occur more in the visual modality than in other domains, it would parallel an important characteristic of visual attention. As mentioned before, neglect is not exclusive to visually presented material, but can be apparent in auditory, tactile and imagined space. However, when patients' performance in tactile or imagery tests is directly compared with their performance in visuospatial tests, neglect often results more common and severe for visual than for nonvisual stimuli (see Bartolomeo et al., 1994, for imagined space; Fujii et al., 1991; Gentilini et al., 1989; Hjaltason et al., 1993, for tactile space). Also for auditory neglect, it has been shown that blindfolding improves the ability of neglect patients to localize correctly sound stimuli originating on the left (Soroker et al., 1997). Thus, one can conclude that visually-presented stimuli exacerbate neglect (Hjaltason and Tegnér, 1992), as Fig. 9 dramatically demonstrates.

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Fig. 9 about here

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These considerations are strong arguments in favor of the role of attentional processes in the determinism of neglect. For example, a defective conceptualization of an hemispace (see section 1.3.1), or a shift of the egocentric frame of reference (section 1.3.4), would have little reason to express themselves more in the visual than in the tactile or in the acoustic space.

1.4.1. A rightward attentional bias in left neglect

A well-articulated account of neglect based on orienting of attention is the opponent processor model (Kinsbourne, 1970; 1977; 1987; 1993). This model draws upon the very general biological evidence that reciprocally inhibiting opponent systems are an evolutionary advantageous way of solving the problem of deciding whether to turn right or left. The dominant system would achieve its goal of turning the organism by progressively inhibiting its contralateral counterpart. A first assumption of the opponent processor model is that each hemisphere shifts attention toward the contralateral hemispace by inhibiting the other hemisphere. A second assumption is that in the normal brain there is a tendency to rightward orienting supported by the left hemisphere, which has a stronger orienting tendency than the right hemisphere. Right hemisphere lesions, by disinhibiting the left hemisphere, exaggerate this physiological rightward bias, thus giving rise to left neglect. Left neglect does not reflect an attentional deficit, but an attentional bias consisting of enhanced attention to the right. The verbal interaction between patient and examiner would further enhance left neglect by further activating the already disinhibited left-hemisphere. Furthermore, left neglect patients would suffer from an abnormally tight focus of attention, which would deprive them of the possibility of a more general overview of the visual scene (Kinsbourne, 1993). Right neglect would rarely be observed because much larger lesions of the left hemi sphere are needed to overcome its stronger tendency to rightward orienting, and because the verbal exchanges with the examiner would now work in the opposite direction, thus minimizing right neglect. This latter aspect of the model seems at variance with the common observation of neglect signs in everyday situations, when no verbal exchange takes place. Moreover, a task of visual matching of letters to auditorily presented samples has been shown to disclose right neglect in LBD patients, but it was not able to elicit left neglect in RBD patients (Leicester et al., 1969). This finding is contrary to the predictions of opponent processor model; it is, however, consistent with the idea that verbal tasks may induce a left-to-right exploratory strategy (see Chokron et al., 1998), and that attention is thus preliminarily driven to the leftmost stimulus, thereby increasing right, but not left, neglect.

Despite these problems, other aspects of the opponent processor model appeared to be confirmed by subsequent empirical evidence. For example, a patient who showed a severe left neglect following a first right-sided parietal infarct abruptly recovered form neglect ten days later, when he suffered from a second, left side infarct in the dorsolateral frontal cortex (Vuilleumier et al., 1996). However, inferences from this case report must be prudent. All the case history took place in the acute phase of the disease, when transient phenomena of neural depression in areas remote from the lesion (diaschisis: see Meyer et al., 1993) render difficult any firm conclusions about the effect of anatomical damage. As the authors reported, the second stroke induced a tonic leftward deviation of head and gaze; this occurrence might have contributed to minimizing left neglect signs, similarly to the effects of vestibular or optokinetic stimulations (see section 1.3.4).

Also the basic assumptions of the opponent processing model about the functional organization of the brain hemispheres have been questioned. First, while the concept of mutually inhibitory lateral structures appears adequate to describe the mode of functioning of subcortical structures like the superior colliculi, it looks as an excessive simplification of the relationship of structures much more complex as the cerebral hemispheres (among other considerations, callosal connnections seem prevalently excitatory, and not inhibitory, in nature, see Berlucchi, 1983). Second, the assumption of a left hemispheric dominance for attentional orienting seems challenged by PET data showing a preferential involvement of the right parietal lobe for both left- and right-sided attentional shifts, whereas the left parietal lobe is only activated by shifts in the right hemifield (Corbetta et al., 1993), and by ERP results suggesting that the right hemisphere is activated earlier than the left in visual perception (Compton et al., 1991).

The crucial mechanisms of left neglect according to the opponent processor model is a rightward attentional bias. That patients do not simply neglect left objects, but are attracted by right ones has been repeatedly shown. In an ingenious variant of the line cancellation task, Mark, Kooistra and Heilman (1988) had ten patients with left neglect erase lines or draw over them by a pencil mark, and found lesser neglect in the 'erase' than in the 'draw' condition. Mark et al. concluded that right-sided lines attracted patients' attention when they were crossed by a pencil mark; rendering these lines invisible by erasing them obviously nullified this effect, thus decreasing neglect. Similarly, Marshall and Halligan (1989a) reported that targets could be omitted in a shape cancellation task independently of their position with respect of the midsagittal plane, and concluded that "right attentional capture" might be a better description of patients' performance than "left neglect".

An important marker of the direction of attention is the position of gaze. While attention can be shifted while maintaining fixation (Posner, 1980), a gaze shift usually correspond to an analogous shift in visual attention (Hoffman and Subramaniam, 1995; Kowler et al., 1995; Shepherd et al., 1986). Brain lesions often induce a conjugated shift of gaze toward the side of the lesion. De Renzi et al. (1982) importantly demonstrated that gaze deviation does not occur with equal frequency after left- and right-hemisphere lesions, but preferentially occurs after posterior lesions of the right hemisphere, and is often associated with left neglect, again suggesting that a rightward attentional bias is an important component of left neglect. Neglect patients are indeed prone to orient their gaze toward the rightmost stimulus as soon as the visual scene unfolds (De Renzi et al., 1989b). This observation is reminiscent of the "magnetic attraction" of gaze, originally described by Cohn (1972) in hemianopic patients. This phenomenon can be observed during the clinical test of the visual fields by the confrontation method; as soon as the examiner outstretches her arms in the patient's visual fields, before the actual administration of stimuli, the patient compulsively look at the hand on the right. Also this phenomenon, which can be considered as a lesser degree of tonic gaze paresis, is strictly associated with right hemisphere lesions and left neglect (Gainotti et al., 1991, Experiment 1). Moreover, RBD patients typically begin from the right side their exploration of a complex stimulus array (Gainotti et al., 1991, Experiment 2), again suggesting an initial rightward attentional orienting, whereas normal controls and LBD patients start from the left. This set of phenomena may easily explain why neglect, even if it is not exclusive for visually presented material, is nevertheless exacerbated by the presence of visual stimuli. Under visual control, attention might be captured and maintained in the right hemispace by visual objects, thus increasing neglect for the left side. The absence of visual control would improve performance by eliminating this attentional capture exerted by right-sided visual stimuli. In this sense, right-sided external percepts might be more "sticky" than, for example, internal images (Anderson, 1993).

An important question raised by these findings is: does the rightward bias reflect enhanced attention to the right (resulting from a left hemisphere released from right-hemisphere inhibition), as postulated by the opponent processor model? Làdavas, Petronio and Umiltà (1990) found that patients with left neglect responded faster to right-sided than to left-sided targets, even when all the stimuli were presented in the right visual field. RBD patients without neglect, on the contrary, were faster for left-sided than for right-sided stimuli, probably because left targets appeared closer to the fovea. This finding is consistent with the opponent processor model, which holds that there is no special status for the patient's sagittal midline for dividing the attended from the neglected parts of space; independent of its absolute position, any object is likely to be neglected if it is 'left of' some other object that attract patients' attention (see also Marshall & Halligan, 1989a). Of particular interest was the finding by Làdavas et al. (1990) that neglect patients' response times for right targets were faster than those of RBD patients without neglect. Neglect patients' attention for right targets seemed thus enhanced with respect to RBD control patients, consistent with the opponent processor model. As Làdavas et al. (1990) pointed out, according to this model neglect patients should be faster for right-sided stimuli even with respect to normal individuals without brain damage; this, however, would be an unlikely result, given that right brain lesions cause a deficit in arousal (Howes and Boller, 1975). Indeed, subsequent RT studies (Bartolomeo, 1997; Bartolomeo et al., 1998b; D'Erme et al., 1992; Smania et al., 1998) invariably found that left neglect patients were slower than normal controls when responding to right (ipsilesional) stimuli. Recent evidence (Bartolomeo and Chokron, 1999) indicates that this slowing for ipsilesional targets does not simply reflect a nonspecific arousal deficit, but is strictly related to the severity of left neglect. The manual response times to lateralized visual stimuli of 24 left neglect patients were plotted against a laterality score measuring their neglect independent of the overall level of performance. That is, for example, right-sided omissions in cancellation tests with equal number of left omissions would decrease the amount of the score; thus, a non-lateralized pattern of omissions in paper–and-pencil tests, such as the one expected with a nonspecific arousal deficit, would not inflate the score.

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Fig. 10 about here

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Results (Fig. 10) showed that not only RTs to left targets, but also RTs to right targets increased with increasing neglect, contrary to the predictions of the opponent processor model. The two regression lines were not, however, parallel. With increasing neglect, responses to left targets increased more steeply than those to right targets did, suggesting that a rightward attentional bias participates in left neglect. However, this rightward bias seems one of defective, and not enhanced, attention.

That left neglect does not result from a hyperactive left hemisphere is also suggested by functional brain imaging studies of diaschisis in left neglect (Fiorelli et al., 1991; Pantano et al., 1992; Perani et al., 1993), which demonstrated a widespread hypometabolism in both the lesioned and the intact hemisphere. Recovery from neglect seems to correlate with restoration of normal metabolism not only in the unaffected regions of the right hemisphere, but also in the left hemisphere (Pantano et al., 1992; Perani et al., 1993). An increase of neural activity, metabolism and perfusion in the unaffected hemisphere seems indeed a general mechanism of prolonged recovery from neurological and neuropsychological impairments after unilateral strokes (Meyer et al., 1993).

1.4.2. A deficit of disengagement

Posner et al. (1984) had six RBD and seven LBD patients with predominantly parietal lesions perform the cued detection task described on p. 21. Patients were disproportionally slow when a contralesional target was preceded by an ipsilesional (invalid) cue. This RT pattern was present in both RBD and LBD patients, but considerably larger in RBD patients, and evident with both central cues (arrow) and peripheral cues (brightening of the box). Posner et al. (1984) argued that this effect, reminiscent of extinction of contralesional stimuli in double visual stimulation, resulted from an impaired disengagement of attention from the ipsilesional side. The amount of the observed RT effect correlated significantly with the extension of lesion in the superior parietal lobe[4]. Because control patients with frontal or temporal lesions did not present this pattern of performance, the authors concluded that an important role of each parietal lobe was one of disengaging attention from previously attended locations in the ipsilateral hemispace. A problem of disengagement from

[4] In a subsequent study, Friedrich et al. (Friedrich et al., 1998) compared patients with chronic lesions of the superior parietal lobe with patients with lesions of the temporal-parietal junction (involving the superior temporal

ipsilesional stimuli could in principle explain some aspects of neglect, such as the failure to explore the contralesional parts of a cancellation test. However, the parietal patients in the Posner et al.'s (1984) study showed little or no contralesional neglect (no neglect in five patients, minimal neglect in two, mild in five and moderate in one). Thus, in this study there was no direct evidence for a relationship between the observed extinction-like RT pattern and neglect.

This issue was addressed more directly by Morrow and Ratcliff (1988), who tested 12 RBD and ten LBD patients using a RT paradigm with peripheral cues. All patients had lesions including the parietal lobe, contralesional neglect, or both. Only RBD patients showed a significant extinction-like RT pattern (though LBD patients' results did go in the same direction, see Morrow and Ratcliff, 1988, Fig. 1). For RBD patients, the cost for invalid contralesional targets correlated with a measure of left neglect, thus suggesting a causal relationship between the two phenomena.

However, for such a right-disengagement deficit to produce clinical left neglect, attention must logically have been engaged to the right *before* the occurrence of the disengagement problem (see Gainotti et al., 1991; Karnath, 1988). D'Erme et al. (1992) produced evidence for such an early rightward engagement by manipulating the Posner RT paradigm. In this paradigm, targets appear in boxes displayed to facilitate position expectancy. D'Erme et al. (1992) reasoned that, by analogy with the magnetic attraction phenomenon (see above, p. 26), the mere appearance on the computer screen of the positional expectancy boxes should elicit a shift of patients' attention toward the rightmost box. D'Erme et al. (1992) contrasted the traditional RT paradigm in which targets appeared in boxes with a condition in which targets appeared in a blank screen, not surrounded by boxes. The presence of the boxes considerably increased the left/right RT difference

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gyrus), all without clinical signs of neglect or extinction, and found an extinction-like RT pattern only for the temporal-parietal group.

for neglect patients, as if the right-sided box acted as an invalid cue for left targets (the boxes were indeed more powerful than actual right-sided cues to induce an extinction-like RT pattern, Fig. 11).

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Fig. 11 about here

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Because the boxes were not informative about the future location of the targets, the type of orienting elicited by the boxes could best be characterized as reflexive, or exogenous, as opposed to the voluntary, or endogenous orienting elicited by central cues or by peripheral informative cues[5] (Müller and Rabbitt, 1989). Thus, D'Erme et al. (1992) proposed that the attentional imbalance in neglect was primarily one of exogenous attention, in keeping with previous similar suggestions based on the apparent "automaticity" of rightward attentional attraction in left neglect (Gainotti et al., 1991).

The early rightward orientation of attention may be observed as a residual sign of spatial bias in patients who had recovered form left neglect (Bartolomeo, 1997; Karnath, 1988; Mattingley et al., 1994b). Thus, to produce clinical neglect, either the initial rightward orienting must be present in a certain critical amount, or it must be accompanied by other component deficits. Concerning this last possibility, the disengagement problem (Morrow & Ratcliff, 1988; Posner et al., 1984), subsequent to the early ipsilesional engagement, would seem a good candidate. Patients would be initially attracted by a right-sided object, and would subsequently be unable to rapidly remobilize their attention from that location (see D'Erme et al., 1992; Gainotti et al., 1991). However, the disengagement problem has been demonstrated in patients without clinical signs of neglect (Friedrich et al., 1998). It remains to be understood therefore under which conditions these impairments do or do not produce clinical neglect. Perhaps it is a matter of quantitative amount of deficit, as suggested by the correlation between the amount of extinction-like RT pattern and the severity of neglect (Morrow & Ratcliff, 1988). Alternatively or in addition, other deficits could add to those described in order to produce a clinically evident spatial bias. For example, preliminary results seem to suggest that a mechanism which purportedly promotes the exploration of the visual scene by inhibiting repeated orientations towards the same locations (Posner and Cohen, 1984) does not work properly in neglect. Left neglect patients seem to show facilitation, instead of normal inhibition, for repeated events occurring on the right side (Bartolomeo, Chokron and Siéroff, 1999). A persisting, unopposed attentional facilitation for right-sided items could explain why neglect patients cannot explore the remaining portions of space once their attention has been captured by a right-sided object.

Accounts of neglect based on orienting of attention seem thus consistent with several neglect phenomena, provided that these accounts are articulated as an association of a number of concurrent deficits. However, on some occasions neglect patients do seem to orient toward neglected stimuli, yet fail all the same to produce the correct response. For example, Bisiach et al. (1994) observed neglect patients who occasionally followed with their index finger the complete contour of a drawing, but failed to notice the details on its left side. When bisecting lines, some patients with left neglect and hemianopia can look at the left part of the line, but this leftward search does not influence the final bisection decision, which remains rightward-biased (Barton et al., 1998; Ishiai et al., 1996). Similarly, neglect patients may fail to produce the appropriate manual response to left-sided stimuli despite having looked at them (Làdavas et al., 1997). These puzzling patterns of behavior are reminiscent of the possibility that some patients may show an implicit (or "covert") knowledge of otherwise neglected details (see, e.g., D'Erme et al., 1993; Marshall and Halligan, 1988; Volpe et al., 1979). Future research should compare more closely the

[5] A distinction reminiscent of that, proposed by James, between "passive" and "voluntary" attention, see p. 23.

characteristics of ineffective exploratory behavior with those of orienting behavior associated with "normal" responses.

1.4.3. Object-based attentional bias

As mentioned above, spatial attention can perhaps be better conceived as orienting towards objects in space than towards "blank" regions of space. If neglect results from an attentional bias, then, it should be possible to observe instances of neglect of the left part of objects, independent of the absolute location of these objects in space. The "piecemeal" copy of complex drawings shown in Fig. 2 is an example of such an object-based neglect (Gainotti et al., 1972). Consistent with the possibility of an object-based, and not solely space-based, neglect, a patient was found to be impaired in reporting the left-sided details of a vertically elongated shape both when the shape was upright but also when it was tilted by 45° toward the right, so that these details were now on the right with respect to the patient's sagittal midline (Driver and Halligan, 1991). Three other patients showed similar effects when reporting gaps on one side of triangles whose perceived principal axis was manipulated by context (Driver et al., 1994). Also, a left-handed patient with left-hemisphere damage and right neglect produced errors on the final part of words, irrespective of whether the words were presented in a horizontal, vertical, or mirror-reversed format (Caramazza and Hillis, 1990). However, Farah et al. (1990) found no evidence of object-based neglect in a group of ten left neglect patients. When identifying single letters scattered over drawings of familiar objects, patients failed to report left-sided letters when the objects were upright, but they correctly reported these same letters when the objects were tilted[6]. Behrmann and Moscovitch (1994) reasoned that object-based neglect might emerge only for those objects which have an

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[6] A subsequent reanalysis of Farah et al.'s data examined individual performances and indicated that three patients did omit more letters printed on the left side of the object, even when the object was rotated, thus showing evidence of object-based neglect (Hillis and Rapp, 1998).

intrinsic handedness, where a vertical reference axis allows the definition of left and right with respect to the object itself (see Driver & Halligan, 1991). Consistent with this prediction, they demonstrated object-based neglect with upper-case letters presenting a left-right asymmetry (e.g. B, E), but not with symmetrical letters (A, X).

Using another paradigm to demonstrate object-based effects, Behrmann and Tipper (1999) had left neglect patients respond to targets appearing inside one of two horizontally aligned circles of different colors. As expected, patients responded faster to right than to left targets (space-based neglect). However, this effect was reversed when the two circles were connected by a line, like a barbell (thus forming a single perceptual object), and the barbell rotated by 180° just before the target appeared. In this case, RTs for the targets now on the left side, but appearing in a previously right-sided circle, were faster than RTs for the targets appearing on the right, thus suggesting object-based neglect. In other words, the *same* neglect patients could show either space- or object-based neglect depending on the experimental conditions. The implication of these findings is that, once again, a dissociation in performance of neglect patients do not necessarily indicate different impairments, but perhaps different strategies evoked by the experimental conditions. Although not suitable to explain the Behrmann and Tipper’s (1999) findings, a study by Buxbaum et al. (1996) provide some hint about what these different strategies might look like. These authors described a patient that showed object-based neglect with tilted shapes and asymmetrical letters only when he mentally rotated the stimuli to restore their canonical, upright position; when instructed to refrain form mental rotation, neglect was only relative to his sagittal midline.

1.4.4. Non-lateralized attentional impairments

Other component deficits of neglect might not necessarily be lateralized or directional problems. For example, it has been suggested that neglect results not only from a bias in selective spatial attention, but also from impairments in other, non-lateralized attentional components (see the taxonomy on p. 21), such as arousal or vigilance (Robertson, 1993). Such non-lateralized deficits may be invoked to explain the fact that neglect patients are slower than normal individuals when responding to visual targets even in the ipsilesional, non-neglected space. Indeed, this ipsilesional slowing might disappear with recovery of neglect (Bartolomeo, 1997). The normal timing of attentional events also seems to be disrupted in neglect for centrally presented visual stimuli. When normal individuals have to identify two visual events appearing one shortly after another in the same spatial location, the second event goes undetected if presented in a time window of 100-450 ms after the first event (“attentional blink”: Raymond et al., 1992). Husain et al. (1997) had 8 left neglect patients perform this dual identification task, and found that neglect patients needed about 1.5 s of interstimulus interval to detect the second target, thus showing an important slowing of the time to select visual information. Non-lateralized impairments interact with lateralized spatial bias in neglect, as demonstrated by the fact that a warning “beep”, which arouses vigilance, is able to decrease visuospatial bias in neglect patients (Robertson et al., 1998). Phenomena of transcallosal diaschisis (Feeney and Baron, 1986; Meyer et al., 1993) might constitute the anatomo-functional basis for such non-lateralized impairments.

1.5. Space exploration

When patients with neglect search for a target in a cluttered environment, they explore asymmetrically the visual scene, favoring the ipsilesional side (Chedru et al., 1973). The objective correlate of this tendency is an increased number of saccades (with increased fixation times) to the ipsilesional side. As discussed in the previous section, this could depend on the fact that patients’ attention is attracted by the visual objects lying in the ipsilesional part of space. However, an alternative view might be that this asymmetry of exploratory movements reflects in fact an ipsilesional shift of the whole frame for exploratory behavior. If so, patients should explore the visual space in a symmetrical way around a new center, which would be deviated in the ipsilesional space by a given angle.

Hornak (1992) had five neglect patients search for a (non-existent) visual target in darkness. The frequency of patients' eye fixations peaked about 15° right of objective midline. Karnath and Fetter (1995) subsequently replicated this finding with five other neglect patients. These authors concluded that in neglect patients the represented spatial frame of reference used for exploratory behavior is shifted toward the right side, due to a corresponding deviation of the egocentric frame of reference (see section 3.2.4). However, a potential confounding factor could have influenced these results. During the calibration phase of the eye movement recording, patients were asked to detect a series of light spots presented individually in each visual field. The experimental phase began when, unknown to the patient, no spots were presented, but the patient was anyway asked to detect a spot. It is reasonable to assume that patients were biased to explore those regions of space where they had most easily detected a spot during the calibration phase. For left neglect patients, the most likely localization of these regions was in the right hemispace. A deficit of visual short-term memory for left-sided stimuli (D'Erme and Bartolomeo, 1997) might also have added to patients' unwillingness to explore the left hemispace, by decreasing the possibility of exploring around space locations in which the presentation of calibration spots was soon forgotten.

Karnath, Niemeier and Dichgans (1998) recorded the gaze and head positions of neglect patients exploring an array of letters to search for a non-existent target. In these conditions, the maximal exploration time occurred around 30° to the right of the objective midline (see Karnath et al., 1998, Fig. 2). That is, the mere presence of visual stimuli led to a twice stronger shift of the center of visual exploration with respect to the condition in darkness, where it shifted by about 15° (see Hornak, 1992; Karnath & Fetter, 1995), as if patients' attention were attracted by right-sided letters. Moreover, if, as the authors propose, the distribution of gaze and head exploration time was just shifted rightward in neglect patients compared to controls, one could expect that the neglect patients behave at their center of exploration as controls do at their mid-sagittal plane. In fact, it appears that whereas controls showed a flat distribution of gaze positions up to 130° left and right of the body's sagittal middle, without spending more time to explore the midsagittal plane, neglect patients exhibited a narrow peak of their exploring time at their so-called "centre of exploration" that is at a position around 30° in the right hemispace (see Karnath et al., 1998, Fig. 2). Also, neglect patients seemed to spend about the same time around their actual sagittal midline than controls did.

Therefore, instead of exhibiting a shift of their center of exploration, neglect patients in the Karnath et al.'s (1998) study showed a peak of exploration in the right hemispace. By contrast, controls were neither particularly biased towards a specific location, nor around their midsagittal plane, where they actually spent less time than in the more lateral parts of the display.

Thus, rather than confirming a general deviation of the exploratory behavior as the authors propose, Karnath et al.'s (1998) results strongly suggest that right-sided stimuli exerted a "magnetic attraction" on neglect patients' attention (see section 1.4.1).

1.6. Directional arm movements

The last possible level of impairment in the action-perception cycle is the programming of arm movements in or towards the neglected hemispace. This pre-motor deficit would express itself as a reluctance or a slowing in performing movements towards left-sided targets. It is important to distinguish directional motor disorders of limbs, which involve left-directed movements independent of which arm (left or right) perform the movement, from motor neglect (Laplane and

Degos, 1983), the unwillingness of moving the contralesional limbs in the absence of primary motor deficit.

Drawing on previous work on monkeys with lesions in the frontal lobe or in the brainstem reticular formation (Watson et al., 1978), Heilman and Valenstein (1979) proposed that left neglect patients have a deficit in programming movements in the right hemispace (hemispatial hypokinesia). Such a “pre-motor” deficit was proposed because rightward error in line bisection was not ameliorated by forcing patients to explore the leftmost extremity of the line. As an alternative explanation, however, Heilman and Valenstein (1979) argued that patients could have ‘forgotten’ the left part of the line when placing the bisection mark, because of a lateralized deficit of short-term visual memory (see also D'Erme & Bartolomeo, 1997). In subsequent work, Heilman et al. (1985) asked six left neglect patients to move a handle as quickly as possible along a fixed horizontal pathway in the frontal plane, either rightward or leftward. Patients were slower to initiate hand movements towards the left side of space than rightward-directed movements. Once the movement was initiated its speed did not vary, regardless of the direction. Heilman et al. termed the described impairment "directional hypokinesia". The possibly related concept of directional hypometria, i.e. insufficient amplitude of contralesionally directed movements, was originally introduced to define hypometric leftward saccades in a patient with right frontal lesion (Butter et al., 1988), and subsequently used to describe the performance of a patient showing rightward line bisection errors in the absence of other signs of left neglect (Marshall and Halligan, 1995). Mesulam (1981) proposed that the motor aspect of neglect reflects involvement of the frontal component of an attentional network including the posterior parietal and cingulate cortices and the brainstem reticular formation.

Bisiach et al. (1985a) recorded the accuracy of 16 left neglect patients when pressing left- or right-sided buttons in response to lateralized visual stimuli. Crossed and uncrossed conditions were performed, in which the side of stimulation and the side of motor response were respectively the opposite or the same. Most errors concerned left-sided responses, irrespective of the side of stimulation. Bisiach et al. concluded that an "output neglect" was present in their patients. However, in the right stimulus/left response condition, crucial for demonstrating the output component, the ipsilesional stimulation could have captured patients' attention (see section 1.4.1 above), thus decreasing accuracy on contralesional responses.

Other attempts to isolate the motor aspects of neglect include a line bisection test, in which a pointer could be moved by a pulley in the direction opposite to the hand movement (Bisiach et al., 1990), and a line cancellation test where left and right sides could be reversed using a mirror (Bisiach et al., 1995; Tegnér and Levander, 1991), an epidiascope (Nico, 1996) or a TV monitor (Coslett et al., 1990; Na et al., 1998). These studies demonstrated instances of "motor" and "perceptual" forms of neglect. While perceptual factors prevailed in most neglect patients, motor factors seemed more pronounced in patients with lesions involving the frontal lobes, which appeared consistent with evidence coming from case reports (Bottini et al., 1992; Coslett et al., 1990; Daffner et al., 1990; Liu et al., 1992). However, Na et al. (1998) found that the patterns of performance on line bisection and line cancellation were not always coherent; three out of their ten patients showed a “perceptual” pattern on cancellation and a “motor” pattern on line bisection. This finding casts doubts on the capacity of paradigms which contrast a perceptually congruent with a perceptually incongruent condition to reliably distinguish between “motor” and “perceptual” forms of neglect. As Na et al. (1998) note, these paradigms frequently disclose a decrease of accuracy in the incongruent condition with respect to the congruent condition. This seems to underline the particularly demanding situation faced by patients asked to perform a motor task with visual feedback being artificially reversed with respect to the proprioceptive feedback. These characteristics could render the task particularly difficult for patients with frontal lobe damage, thus explaining their impaired performance in the non-congruent condition (Mattingley and Driver, 1997).

More "ecological" paradigms devised to study directional motor disorders have sometimes produced negative results. Mijovic' (1991) asked 40 right brain-damaged patients to find a target among distractors by moving the stimulus display board under a panel until the target appeared in a window (e.g., to bring a right-sided target into view, the board was to be moved towards the left). Patients were fast and accurate in this task, thus not showing any evidence of directional hypokinesia. Ishiai et al. (1994a; 1994b) asked neglect patients to extend a line leftwards to double its original length. The presence of a directional motor disorder should have shortened the left part of the line, but this was neither observed in patients with parietal lesions, nor in patients with frontal lesions. Patients as a group performed in the range of controls, with occasional patients showing a tendency to overextend lines. Chokron, Bernard and Imbert (1997) presented two neglect patients with either the left half or the right half of a line on a computer screen. The line could be extended by pressing a key, and patients were asked to complete the half-line to obtain a whole line with two equal halves (there was always a mark indicating where the midpoint should be). Thus, no directional motor component was present in this task. Both patients showed a significant underconstruction of the right half with respect to the left one and a significant overconstruction of the left half from the right one, for both patients. The final midpoint was deviated to the right, thus mimicking the usual performance of neglect patients in line bisection. It might then be that the overall accuracy of leftward line extension found by Ishiai et al. (1994a; 1994b) resulted from a tradeoff between directional hypokinesia, leading to reduced leftward extension, and perceptual bias, determining a tendency to overconstruct the left half of the line. Bisiach, Ricci and Neppi Mòdona (1998b) examined 91 left neglect patients and 43 RBD patients without neglect on a line extension task similar to that of Ishiai et al. (1994a), but with an additional condition consisting in the rightward extension of the line. The principal findings of this large-scale study were as follows. First, 27 neglect patients out of 91 showed a tendency to leftward overextension, but 14 other neglect patients showed an opposite rightward overextension. Second, the tendency to a relative leftward overextension was greater in RBD patients without neglect than in those with neglect. Third, the severity of neglect was higher in patients showing a relative right overextension than in those showing a relative left overextension.

In a similar vein, Perri, Bartolomeo and Gainotti (in press) compared line bisection with paper-and-pencil extension either toward the left or toward the right side. Perri and her coworkers reasoned that a predominant role of motor factors in neglect should determine a reduced leftward extension with normal rightward extension, whereas a predominant left perceptual underestimation should produce the opposite pattern, namely normal (or excessive) leftward extension with reduced rightward extension. They studied 25 right-brain damaged patients (of whom 16 had left neglect) and eleven controls. Neglect patients deviated rightward on line bisection, but they performed no differently from controls or patients without neglect when extending lines in either direction. Inspection of individual performances revealed that two neglect patients performed as predicted by the hypothesis of a directional motor disorder (reduced leftward with normal rightward extension). One patient without signs of neglect presented the opposite pattern of performance (normal leftward with reduced rightward extension), as if left perceptual underestimation were at work. Other patients performed abnormally in an unpredictable manner, more often in the sense of an overextension. One tentative explanation of these contrasting pattern of results obtained with line extension tasks is that line extension evokes different attentional mechanisms than the perceptual evaluation of a visual scene or of a to-be-bisected line. As Ishiai et al. (1994a; 1994b) note, neglect patients rarely look at the left end of a line when bisecting it; on the other hand, when extending a line patients' attention may follow the leftward movement of the pencil tip. Thus, line extension could be a spatial task which forces neglect patients to continuously monitor their spatially-oriented activities, thereby reducing or eliminating signs of neglect.

In the *landmark test* (Harvey et al., 1995), subjects have to point to either of the ends of a mid-transected line which they judge closer to the transection, under the (perhaps unwarranted) assumption that leftward hypokinesia would force patients to point predominantly to the right extremity, independent of their perceptual judgement. Of eight patients tested by Harvey et al., (1995), seven pointed consistently leftward, thus showing perceptual forms of neglect. Only one patient pointed predominantly rightward, a pattern suggestive of directional motor deficit. Bisiach et al. (1998a) tested 121 neglect patients on a similar task. Patients had either to manually point to the shorter segment of a black pre-bisected line, or to name the color of the shorter segment of lines composed of two segments, one black and the other red. Instances were found of “perceptual bias” (i.e. patients pointing to or defining the left segment as shorter) and of “response bias” (the opposite pattern of performance). Both forms of bias correlated with each other across the two task conditions (pointing vs. verbal responses). However, perceptual bias was mainly associated with anterior brain lesions, whereas response bias was more frequently associated with subcortical damage, contrary to the prevalent theoretical framework. In some cases, the authors found the two type of bias to be present in the same patients.

Mattingley, Bradshaw and Phillips (1992) requested brain-damaged patients to press buttons which were horizontally arranged and illuminated in sequence from left to right or in the opposite direction. RBD neglect patients were slower when executing leftward movements than when moving rightward. In particular, patients with retro-rolandic lesions were slowed when initiating movements toward a button illuminated on the left side, whereas patients with anterior or subcortical lesions showed a decreased speed of leftward movements. Nevertheless, in Mattingley et al.’s paradigm the slowing of the initiation time exhibited by neglect patients with posterior lesions is not unambiguously interpretable in terms of directional hypokinesia, since patients had to detect the occurrence (lighting) of a left-sided stimulus before moving to reach it. The confounding effect of this perceptual-attentional component might thus have added to the motor component in slowing down patients' performance. In a subsequent study, Mattingley et al. (1998b) tried to clarify this potential confound. They asked six left neglect patients (three with lesions centered on the inferior parietal lobe, three with inferior frontal lobe lesions) to reach for lights appearing right or left of fixation with their hand starting at the body midline (i.e., between the targets) or left or right of both targets. Results showed that all patients responded slower to left than to right targets. Parietal, but not frontal, patients showed an effect of the hand start position; starting from the extreme left position, so that left targets now required a rightward movement, reduced the disadvantage for left targets. Somewhat surprisingly, initiation of these rightward movements to attain left targets was ~600 ms faster than responses to the same targets with the hand already positioned below them, without the need of any reaching movements (compare Fig. 3 and Fig. 4 in Mattingley et al., 1998b). This finding led the authors to conclude that the advantage for rightward reaching movements to left targets was not due to a cueing effect of visual or proprioceptive inputs from the hand situated in the left hemispace. When the hand started form the extreme right, left targets were again responded to more slowly than right targets, thus suggesting that the impairment did not concern leftward movements *per se*, but leftward movements directed to left-sided targets. In other words, a perceptual component seemed again to play a role in directional motor disorders. More specifically, the position of the effector (in this case the hand) could contribute to the patients' perception of right (non-neglected) and left (neglected) sides, perhaps by affecting the coding of 'right' vs. 'left'. If so, one could indeed expect a decrease of the disadvantage for left targets when the hand is positioned at their left, thus rendering the targets more 'righty'. Another study by Mattingley et al. (1998a) further strengthens the conclusion that at least some instances of directional motor disorder in neglect do not stem from a purely output mechanism. Using a procedure similar to that of Mattingley et al. (1992), they found that leftward movements were slowed in neglect patients only in the following conditions: (1) when the movement path could not be predicted in advance, and (2) in the presence of a concurrent right distractor.

Bartolomeo et al. (1998b) tried to disentangle the perceptual from the directional motor aspects of unilateral neglect by contrasting patients' performance on two RT tasks. The "perceptual" task consisted of lateralised visual stimuli and central motor responses, whereas the "motor" task consisted of the same visual stimuli presented on the vertical midline (like a traffic light) and hand responses to be produced in either hemispace. Thirty-four RBD patients (of whom 14 showed signs of left neglect) and 15 controls participated in the study. Results showed that patients showed a clear spatial bias (in the sense of a right over left target advantage) when responding centrally to lateralized targets. However, neither the neglect nor the non-neglect group of patients showed any evidence of directional slowing of performance with lateralized responses. Inspection of individual performance revealed that only two RBD patients (showing no signs of severe neglect) were consistently slowed in producing leftward motor responses. Thus, the results of this study suggest again that, when lateralized visual feedback is minimized, a slowing of leftward arm movements does not play a crucial role in left unilateral neglect.

Conclusions and perspectives on rehabilitation

Although we are still far from understanding the precise mechanisms leading to neglect, the evidence reviewed thus far seems to suggest that a large majority of neglect patients suffer from an association of lateralized and non-lateralized attentional problems. These could include an early orientation of attention towards objects (or object attributes) lying in the ipsilesional side of space, a deficit in reorienting attention toward the contralesional side, and a non-lateralized deficit in rapidly dealing with sensory events. Impairments at other levels of space processing might add to these problems in individual patients. Follow-up studies of recovery from neglect support the idea of a multi-component syndrome, in that they show the apparent recovery of some component deficits and the persistence of others (Bartolomeo, 1997; Mattingley et al., 1994b).

Insight on the nature of neglect is also offered by the study of the effects of the various rehabilitation techniques that have been devised for its treatment. Interestingly, very different approaches appear to decrease neglect, regardless of the theoretical background they stem from. The diverse sort of maneuvers that have been shown to improve neglect include: training visual (Pizzamiglio et al., 1992; Seron et al., 1989; Weinberg et al., 1977; Wiart et al., 1997) or tactile (Weinberg et al., 1979) exploration, actively or passively moving the contralesional arm (Robertson and Hawkins, 1999) , imagining mental scenes (Smania et al., 1997), wearing optical prisms shifting the visual scene toward the right (Rossetti et al., 1998), receiving appropriate vestibular, optokinetic, somatosensory or proprioceptive stimulation (see section 1.3.4 above).

From a clinical point of view, the notion of the success of such disparate techniques in reducing neglect seems reassuring and suggests that an effective strategy for rehabilitating neglect might be to vary the techniques used. From a theoretical standpoint, this multiplicity of apparently successful maneuvers suggests two conclusions. First, this evidence may be considered as another, if indirect, proof that neglect is a multi-component syndrome. Second, one could hypothesize that far from acting at different levels, all of these techniques are in fact attentional in nature. For example, visual exploration training implies an explicit orientation of attention (recall that directing the eyes to a specific location usually triggers an attentional orientation in the same direction). Also mental imagery training might reduce left neglect by training patients to mentally orient their attention to the neglected part of space. Even in the domain of vestibular and proprioceptive stimulations, one could surmise that what is at work is not a restoration of the position of the egocentric reference (see section 1.3.4), but an orientation of attention to the left neglected hemispace by the way of the induced optokinetic nystagmus or of the stimulation itself. Indeed, not only a shift in gaze direction, but also head or trunk turning could be involved in orienting of attention (Gainotti, 1993). These arguments need of course empirical confirmation. Nevertheless, elucidating at which level these different rehabilitation techniques operate, as well as exploring the possibilities of transiently created neglect signs by applying experimental stimulations to normal individuals, could offer important insight on the mechanisms leading to neglect behavior.

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