

## Horizontal and Vertical Neglect Dyslexia

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This case study concerns a 25-year-old right-handed male patient (G.G.) with post-traumatic lesions involving the right temporal and occipital lobe as well as the basal forebrain of the same side. G.G., who had a visual field defect almost limited to the upper left quadrant, showed both left horizontal and lower vertical neglect dyslexia, disproportionately severe when compared with left and lower visuo-spatial neglect. This is the first case report of a patient whose neglect dyslexia for vertical stimuli depended upon stimulus orientation, i.e., errors affected the final letters of top-down words and the initial letters of the bottom-up ones. This implies that neglect dyslexia can affect the internal letter shape map not only along the horizontal, but also along the vertical axis. © 1993 Academic Press, Inc.

A reading disorder in which errors fall in one spatial half of each stimulus item is a possible manifestation of abnormal distribution of attention over space. Patients with this kind of deficit, when reading a word or a nonword, produce paralexical responses in which letters at the beginning or at the end of the stimuli are substituted, omitted, or added (Kinsbourne & Warrington, 1962).

Due to its frequent association with unilateral spatial neglect this disorder is named "neglect dyslexia" (Baxter & Warrington, 1983), but the term "positional dyslexia" has also been suggested (Katz & Sevush, 1989) to emphasize that the correlation (in terms of severity and even of side of occurrence) between neglect in reading and neglect in other visual tasks is very loose (Baxter & Warrington, 1983, 1990; Costello & Warrington, 1987; Cubelli, Nichelli, Bonito, De Tanti, & Inzaghi, 1989).

Neglect dyslexic patients provide important information for drawing

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inferences about the normal process of visual word recognition and the role of attention in orthographic processing (Riddoch, 1990).

Caramazza & Hillis (1990a), following the lines of the model of object recognition proposed by Marr (1982) and its extension to reading by Monk (1985), proposed a multistage model of word recognition. According to this model (see also Rapp & Caramazza, 1991) the brain first computes directly from surface-reflected light intensities the relevant discontinuities that define edges in the images (*feature map*). This process is spatially parallel across the entire visual field, so that the representation computed at this stage is a retino-centric description. Thus, for example, the feature map for a word ("Modena") presented vertically in the left upper field will be represented vertically in the upper left quadrant (see Fig. 1).

The second step involves recovering from the feature map the shape properties of contours and the spatial relations existing among parts of the stimulus. The result is a *letter shape map*, i.e., a stimulus-centered description of the shapes and of the spatial relations of the letter forms in the image. In the example the string "Modena" is still vertically arranged but it is represented in the center of the display to signify that its actual position in the visual field is no more relevant at this stage.

Then, from the simple shape properties, the brain computes the abstract letter representations that comprise a letter string. The resulting word-centered *grapheme description* is independent both from simple shape properties (e.g., case, font) and from stimulus orientation and serves to activate lexical-orthographic representations for word identification. In Fig. 1 this representation level is displayed by showing the letters of the word "Modena" in triangular brackets to indicate the corresponding graphemes.

The administration of topographically nonstandard texts (such as vertically presented, rotated, or mirror-reversed words) has been used as a tool to establish the impaired stage of grapheme processing (Caramazza & Hillis, 1990a; Ellis, Flude, & Young, 1987). More specifically, with vertical word reading the assumption is that, since neglect phenomena involve either the left or the right part of an inner map, vertical reading should be errorless in the case of a stimulus-centered disorder, while neglect errors should persist unchanged if neglect involves part of a word-centered grapheme description. Vertical reading should also be unimpaired in case of a retino-centric feature map disorder, provided that the whole word is presented in the sound visual field.

Patients with both kinds of disorders have been described. For instance, V.B. (Ellis et al., 1987), after a series of cerebrovascular accidents which resulted in a left homonymous hemianopia, left-sided hemiplegia and hemianaesthesia, and neglect of left hemispace, made errors affecting the left half of a horizontal stimulus independently on the direction of

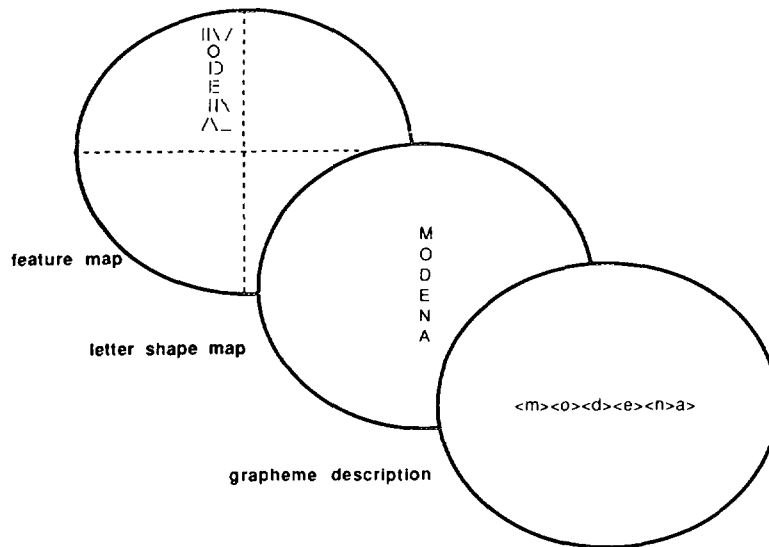


FIG. 1. Schematic description of the levels of representation that allow visual recognition of the word "MODENA," when the word is presented in the right upper quadrant of the visual field. The model (Caramazza & Hillis, 1990b) assumes three levels of representation before lexical access. The first level of analysis consists of a retino-centric feature map, the second level consists of a stimulus-centered, letter-shape map, and the third level consists of a word-centered, grapheme description.

reading: i.e., errors involved the (leftmost) initial letters of normally oriented words and nonwords and the (leftmost) last letters of mirror-reversed and upside-down stimuli. As in this case errors also were uninfluenced by the position of the word with respect to the visual field, the functional deficit must be located at a level operating on actual stimuli (Caramazza & Hillis, 1990a). When the opposite is true (i.e., errors depend on the position of the string in the visual field) a deficit at the level of the retino-centered, feature map has been postulated (Rapp & Caramazza, 1991).

In other patients errors involve the same half of the words, independently of the spatial orientation of the presented stimuli. N.G. (Caramazza & Hillis, 1990b), suffering from left parietal damage, misread the rightmost (ending) letters of normally oriented words, the lower (ending) letters of vertical words, as well as the leftmost (ending) letters of mirror-reversed words. The functional deficit appears here to be at the level of a word-centered grapheme description.

In this paper, we describe the unexpected pattern of reading performance of a brain-damaged subject, G.G., who presented both left horizontal and lower vertical neglect dyslexia and discuss it in the framework

of a multiple-representation word recognition model. Since neglect dyslexia was also apparent in reading vertically arranged words, his reading disorder might have been judged to be at the level of the "graphemic representation." However, a thorough analysis of his reading behavior led us to conclude that the deficit was confined at a more peripheral level of representation and involved both the horizontal and the vertical axis.

### CASE REPORT

G.G. is a 25-year-old right-handed male with 10 years of schooling. His native language is Italian. On September 23, 1989, while working as a painter, he fell from a scaffolding and was found unresponsive. A large subdural hematoma involving the right temporal lobe was drained off. He remained comatose for 20 days. A CT scan, 4 months after the trauma, showed a large hypodense area involving the right temporal and occipital lobe and a smaller hypodense area in basal right forebrain (Fig. 2). The EEG showed normal alpha activity at 8 Hz over the left hemisphere and a slow theta activity at 6–7 Hz over the right hemisphere, with delta waves at 3 Hz over the right temporal region.

At the same time, the neurological examination disclosed minor reaching difficulties with both hands in the left hemisphere and severe left-sided neglect phenomena in searching tasks. Neglect was so severe as to affect G.G.'s everyday life: for instance, he switched wearing the watch from the left to the right arm because, when he wore it on the left arm, he behaved as if he could not check the time by himself. Goldman perimetry (Fig. 3) showed a visual field defect in the left-upper quadrant of both eyes. The deficit was somewhat more extended in the lower left field of the right eye. There was no extinction of double simultaneous stimulation in the lower field, even for small stimuli. We could not examine the upper field for extinction, since he also missed single stimuli.<sup>1</sup>

When asked to look straight ahead, G.G. tended to shift his gaze toward the right after a while, but on verbal command he did not show any difficulty in looking to either side as well as up and down. A continuous series of postcards moving to the right evoked an optokinetic nystagmus, whose jerks were however of less amplitude and frequency compared with those obtained by stimuli moving to the left. The remainder of neurological examination was normal.

G.G.'s verbal IQ on the Italian standardized version of the WAIS (Fer-

<sup>1</sup> Extinction on double simultaneous stimulation is not an all-or-none phenomenon: in order to assess it, one should administer stimuli of different sizes to corresponding portions of the visual fields on both sides (i.e., both the right and the left visual fields). Lack of extinction for a portion of space that the patient neglected in visual search task is a further support to the notion that extinction and visuo-spatial neglect are two distinct phenomena (De Renzi, Gentilini, & Barbieri, 1989).

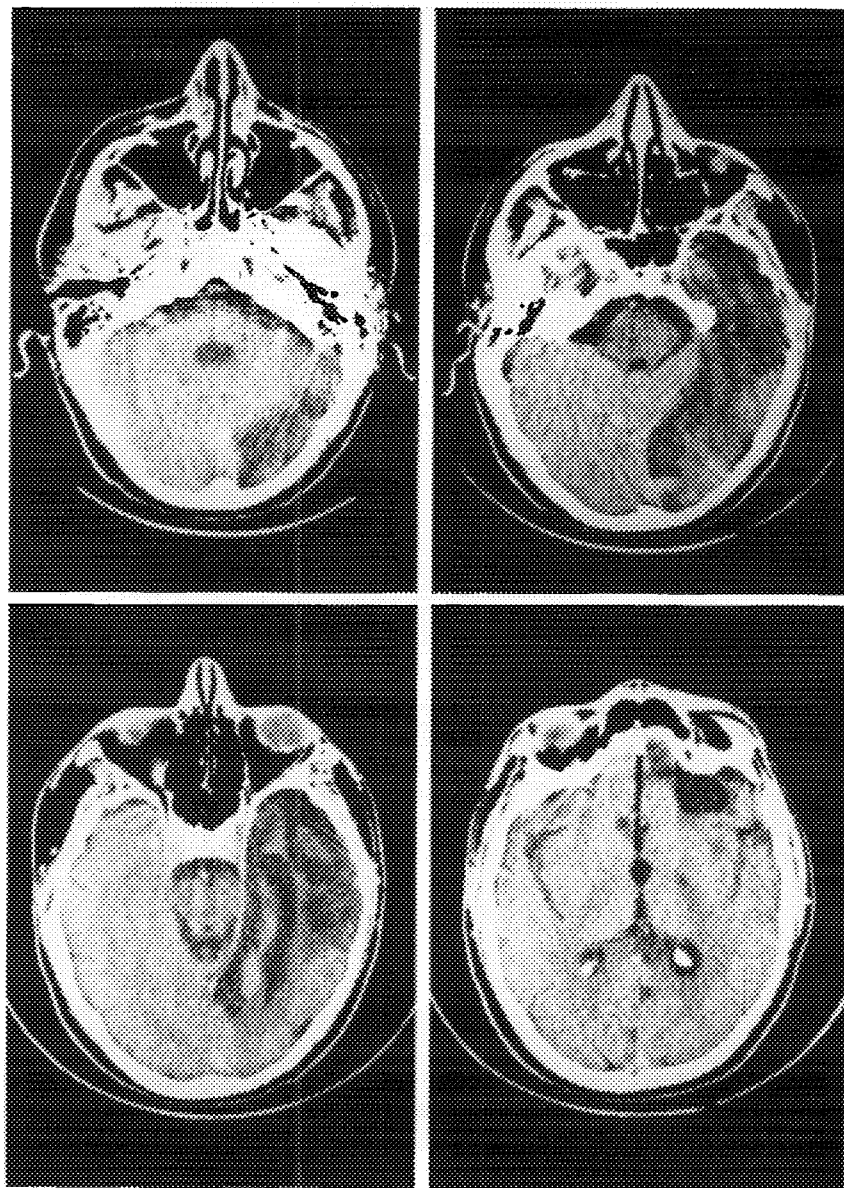
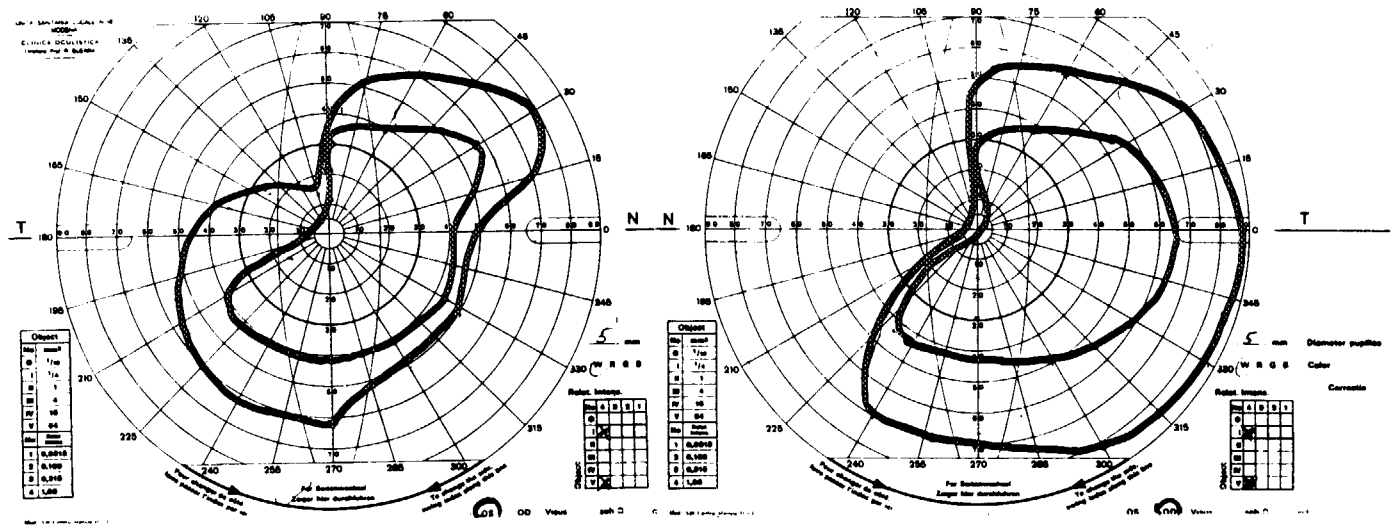


FIG. 2. CT scan, 20 February, 1990.



radini & Vassena, 1974) was 87. He performed within the normal range on a standardized test battery for memory evaluation including auditory digit span (Orsini, Grossi, Capitani, Laiacona, Papagno, & Vallar, 1987), prose memory, and paired associate learning (Novelli, Papagno, Capitani, Laiacona, Cappa, & Vallar, 1986a). Verbal fluency with both phonemic and semantic cues was normal (Novelli, Papagno, Capitani, Laiacona, Vallar, & Cappa, 1986b).

On a standard copying drawings test (Spinnler & Tognoni, 1987), G.G. omitted to copy the left half of stimuli (Fig. 4). His left spatial neglect was quantitatively assessed with a line bisection test and two cancellation tasks.

#### *Line Bisection*

Lines of five different lengths (80, 120, 160, 200, and 240 mm) were drawn horizontally, one line per sheet, at the center of a 420 × 298 (A3) plain paper. Each line appeared three times for a total of 15 trials. Lines of various lengths were presented randomly. The subject's task was to mark the center of the line with a pencil. Errors in line bisection were measured in millimeters and averaged across the three repetitions. Figure 5 shows the mean performance of G.G. for the different lengths compared with  $\pm 2$  standard deviations of the mean bisection error by 10 normal subjects at the same task (Nichelli, Rinaldi, & Cubelli, 1989). A bisection task using vertical lines was not administered to G.G., because the patient failed to show up the day we had planned this control.

#### *Line Cancellation Task*

This modified version of the Albert's Cancellation Test (Nichelli, Rinaldi, & Cubelli, 1989) consists of 20 lines, each of 30 mm in length, arranged in four columns of 5 lines each on a 215 by 320-mm sheet of paper. By that way 10 lines are to the left and 10 are to the right of the center of the paper sheet. The task of the subject was to cross out all the lines of the page. All normal subjects perform this test without errors (Nichelli et al., 1989). G.G. missed 1 out of 10 lines on the right side and 5 out of 10 lines on the left side. Two of the omitted lines were in the upper half of the display, while 4 were in the lower one.

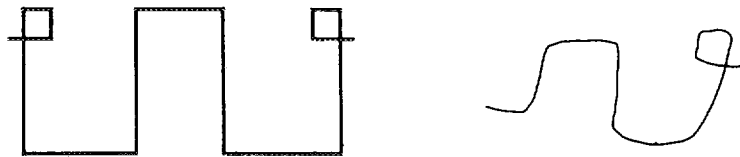


FIG. 4. Copying drawings test showing omission of the left part of the pattern.

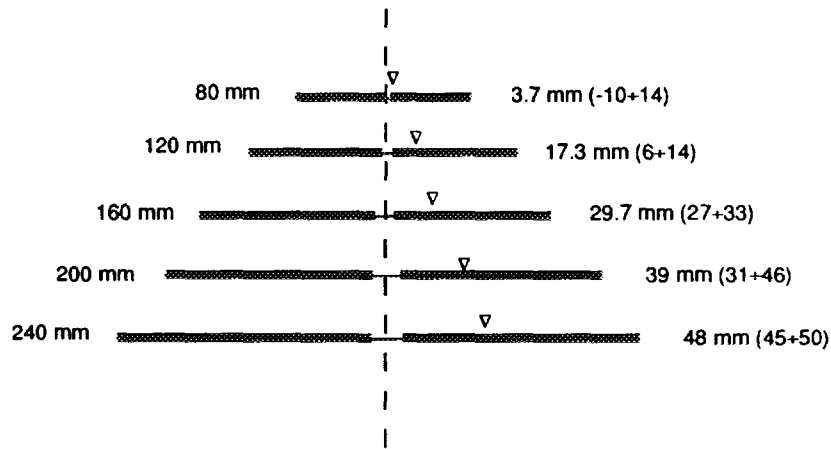


FIG. 5. G.G.'s performance at line bisection of lines ranging from 80 to 240 mm, compared with the performance of 10 normal controls (Nichelli et al., 1989). The thin line at the center of each line represents the range between  $\pm 2$  standard deviations of the mean bisection error by normal subjects. The triangle points to the mean G.G.'s bisection across three trials. On the right of each line mean bisection error (minimum  $\div$  maximum) are given in mm. Positive values indicate displacement to the right, negative values indicate errors to the right.

#### *Bells' Cancellation Task*

The Bells' Test (Gauthier, Dehaut, & Joanette, 1989; Vanier, Gauthier, Lambert, Pepin, Robillard, Dubouloz, Gagnon, & Joanette, 1990) requires the subject to search for the silhouette of a bell among 280 distractors that are randomly arranged on a 215 by 320-mm sheet of paper. This task, much more than the previous one, requires the subject to adopt a systematic scanning strategy for effective performance. Normal subjects do not omit more than 3 bells at this test (Vanier et al., 1990). G.G. omitted 1 target item out of 15 on the right side, 1/5 in the center, and 11/15 on the left side. Five out of 18 bells (28%) were omitted in the upper part of the display, while 8/17 (47%) were omitted in the lower part.

#### *Single Word Reading*

To evaluate reading abilities with topographically standard text, we administered both a list of 40 Italian words and 40 pronounceable non-words (pseudowords) prepared by Sartori (1984) and a list of 96 Italian words prepared by Job (1987). Both lists are balanced by frequency and length. For both of them normative values for Italian native speakers are available in the referenced papers. Sartori's list also has an equal number of concrete and abstract words, while Job's list is balanced by imagery



value. To these lists we added 90 more words and 14 pseudowords of different lengths that were only used to evaluate the length effect. All the words were printed on white cards in 18 pt Geneva bold upper-case fonts.

G.G. made reading errors in response to 105/225 (47%) words and to 33/55 (60%) pronounceable nonwords (pseudowords);  $\chi^2 = 3.143$ ,  $df$  1,  $p = .0762$ . In response to pseudowords, G.G. produced 40% of words and 60% of pseudowords, while with words he produced 91% of words and 9% of pseudowords ( $\chi^2 = 72.67$ ,  $df$  1,  $p < .0001$ ). Errors did not vary as a function of word frequency: G.G. made 25/68 (37%) errors with high frequency words and 32/68 (47%) errors with rare words ( $\chi^2 = 1.48$ ,  $df$  1, n.s.). Word concreteness did not affect his performance: G.G. made 9/20 (45%) errors with concrete words and 8/20 (40%) errors with abstract words ( $\chi^2 = .102$ ,  $df$  1, n.s.). Word imagery value also did not affect performance: G.G. made 17/48 (35%) errors with "high imagery" words and 23/48 (48%) errors with "low imagery" words ( $\chi^2 = 1.5$ ,  $df$  1, n.s.). As shown in Table 1, G.G. tended to make more reading errors with long as compared with short words ( $\chi^2 = 10.611$ ,  $df$  4,  $p < .031$ ). Accordingly, the mean length of correctly read stimuli was significantly shorter than the mean length of incorrectly read words (5.32 letters vs. 5.94 letters;  $t_{(278)} = 3.11$ ,  $p < .0021$ ).

Following Hillis and Caramazza (1990), we assumed that left neglect dyslexia resulted in two kinds of errors: (a) true neglect errors (omissions), i.e., responses that were identical to the stimulus on the right, but omitted all letters to the left of the shared portion [e.g., *mezzaluna* (half-moon) → "una" (one)]; (b) backward completion errors, i.e., any response that satisfied all the following criteria: (1) the response was identical to the target by at least two letters from the right end; (2) there was at least one unshared letter on the left; (3) the error did not contain 2 or more letters in the same relative order on the left of the shared position [e.g.: *margin* (margin) → "vergin" (virgin); *dio* (God) → "stipendio" (salary)].

Using these criteria, 93% of G.G.'s reading errors could be attributed

TABLE 1  
Topographically Standard (Left-to-Right) Text: Reading Errors as a  
Function of Stimulus Length

Stimulus length	No. of errors	%
3 letters	8/22	36.4
4 letters	32/85	37.6
5 letters	16/31	51.6
6 letters	13/25	52
≥7 letters	69/117	59

to neglect dyslexia. All his non-neglect errors in our experiments were classifiable as visual.

## EXPERIMENTAL INVESTIGATIONS

After having ascertained that G.G. made a large number of neglect errors, we investigated the characteristics and the extent of his deficit more deeply.

### *Experiment 1: Reading Words with a Red Digit Appended to the Left*

There are several theoretical reasons for doubting that neglect dyslexia can be a direct by-product of a visual field defect (Ellis et al., 1987). However, we wanted to further exclude the possibility that G.G.'s neglect errors arose because the initial letters of a word he was trying to read fell into his left superior blind field.

For this purpose we used the technique of positioning a red digit to the left of the target word. G.G. had to report the digit before reading the word. When he was reading the red digit all the word fell entirely within his right visual field, with the initial letters closest to the point of fixation.

Sixty stimulus cards were prepared. Each card had a single red digit positioned 3 mm to the left of a word printed in black, upper-case letters (18 pt geneva bold laser print). There were 10 words and 10 pseudowords for each of 6, 8, and 10 letter length. Words were selected from those rated with a frequency greater than 25 in the Italian Language (Bortolini, Tagliavini, & Zampolli, 1971).

*Results.* G.G. made a total of 27 errors (45%) after correctly reporting the red digit to the left of the target. Errors involved 36.6% left half letters and 5.8% right half letters. Fifteen (56%) were left neglect errors. These error rates were compared with those obtained when reading a subset of 141 stimuli selected from the standard reading test as having more than 5 letters. At this subset G.G. made 82 (58%) errors. Seventy-four of these errors (90%) were classified as neglect errors.

Therefore, reading a red number at the left end of the stimulus did not affect the total number of reading errors ( $\chi^2 = 2.935$ ,  $df 1$ , n.s.) but caused a decrease in the rate of neglect errors ( $\chi^2 = 16.314$ ,  $df 1$ ,  $p < .001$ ).

It can be concluded that as for line bisection (Nichelli et al., 1989; Riddoch & Humphreys, 1983), directing attention to the neglected side can decrease, but may not prevent, neglect phenomena.

### *Experiment 2: Reading Unconventional Orientation Stimuli*

To assess the level at which neglect dyslexia impaired G.G.'s reading process, we asked him to read right-to-left and vertical words.

*Right-to-left reading.* We administered 30 words and 30 pseudowords for each of the following 3 sets of stimuli:

- reversed (e.g., ANEDOM)
- mirror-reversed (e.g., MODENA)
- upside down (e.g., VNƆDOW)

All groups included an equal number of items of 6, 8, and 10 letter length. Stimuli were laser printed on 15 × 30-cm white cards with 18 pt geneva bold capital letters. The upper panel of Table 2 presents the cumulative number of reading errors at the three right-to-left reading conditions as a function of letter position in words and pseudowords of different lengths. It is immediately apparent that G.G.'s errors occurred almost exclusively on the left (final) end of the words, irrespective of their length.

*Results.* Total errors were 22/60 (37%) with reversed, 29/60 (48%) with mirror-reversed, and 22/60 (37%) with upside-down stimuli. The rate of neglect errors was respectively 86%

TABLE 2  
Number of Reading Errors as a Function of Letter Position in Words and Pseudowords of Different Lengths

Horizontal stimuli (right-to-left reading)										
Stimulus length	Left half					Right half				
6			5	6	3	3	0	0		
8		20	21	12	3	1	0	0	0	
10	35	34	31	16	9	2	0	0	0	0
Total			195				6			

Vertical stimuli				
Stimulus length	6	8	10	Total
			1	
		3	4	
Upper half	2	2	4	44
	1	3	1	
	6	6	11	
	9	1	9	
	8	8	19	
Lower half	22	13	16	173
		19	24	
			25	

*Note.* The upper panel (horizontal stimuli) shows the number of errors cumulated across reversed, mirror reversed, and upside-down stimuli; the lower panel (vertical stimuli) shows the errors cumulated across top-down, rotated to right, bottom-up, rotated to left conditions.

with reversed, 83% with mirror reversed, and 91% with upside-down stimuli. In conclusion, reading from right to left caused a decrease of the total number of errors in comparison with standard left-to-right reading (compared with the subset of similar length:  $\chi^2 = 9.809$ ,  $df 1$ ,  $p < .002$ ). The decrease was possibly due to the fact that the initial part of the word, which in the case of right-to-left reading fell in the sound hemisphere, could provide a cue for correct completion of the total word. However, the rate of neglect errors was unaffected by reading direction ( $\chi^2 = .585$ ,  $df 1$ , n.s.).

With this set of stimuli, G.G. made 26/90 (28.8%) errors when reading words and 47/90 (52.2%) errors when reading pseudowords ( $\chi^2 = 10.163$ ,  $df 1$ ,  $p < .002$ ). However, the rate of neglect errors was not different for words (22/26 = 84.6%) and pseudowords (41/47 = 87.2%).

*Vertical reading.* We administered 30 words and 30 pseudowords for each of the following 4 sets of vertical stimuli:

- top-down;
- rotated 90° to the right;
- bottom-up;
- rotated 90° to the left.

All groups included an equal number of items of 6, 8, and 10 letter length. Stimuli were laser printed on 15 × 30-cm white cards with 18 pt geneva bold capital letters.

Figure 6 reports an example for each of the different kinds of vertical stimuli.

*Results.* The lower panel of Table 2 presents the cumulative number of reading errors at the four vertical reading conditions as a function of letter position in stimuli of different lengths. G.G.'s errors occurred almost exclusively on the lower end of the stimuli, irrespective of their length. Total errors were 29/60 (48%) with bottom-up and 36/60 (60%) with rotated to left, 21/60 (35%) with top-down, and 23/60 (38%) with rotated to right.

There were 25/120 (20.8%) errors with words and 82/120 (56.1%) errors with pseudowords ( $\chi^2 = 54.793$ ,  $df 1$ ,  $p < .0001$ ), but, as with horizontal stimuli, the rate of neglect errors was uninfluenced by the lexical status (14/25 = 56% with words; 46/82 = 56.1% with non-words).

With vertical as well as with horizontal stimuli the initial part of the word was more helpful than the final part in producing correct completion of the entire word. In fact, there were significantly more errors when the lower end of the word corresponded to the first letters (bottom-up and rotated-to-left conditions) as compared with top-down and rotated-to-right items where the last letters fell in the neglected field ( $\chi^2 = 7.142$ ,  $df 1$ ,  $p < .007$ ). On the contrary, the rate of neglect errors was not significantly different in bottom-up/rotated to left vs. top-down/rotated to right conditions ( $\chi^2 = 1.597$ ,  $df 1$ , n.s.).

Lower neglect errors were more frequent in top-down (57%) and bottom-up (83%) reading, as compared with stimuli rotated 90° to the right (39%) or to the left (42%;  $\chi^2 = 5.365$ ,  $df 1$ ,  $p = .02$ ). Rotated stimuli were shorter than top-down and bottom-up ones and hence occupied a more limited portion of the lower hemisphere.

In conclusion, reading conditions which can bias the spatial distribution of attention (the stimulus length or reading words and pseudowords preceded by a red digit) affected the rate of neglect errors, whereas the total number of errors was reduced if the final, instead of the initial, part of the word fell within the neglected hemisphere.

*Experiment 3: Assessing Visuo-Spatial Neglect along the Vertical Axis*

Since some case reports (Costello & Warrington, 1987; Cubelli et al., 1989) have documented that neglect dyslexia can dissociate itself from visuo-spatial neglect, we decided to further investigate vertical neglect with two tasks aimed to assess visuo-spatial exploration along the vertical axis.

*Vertical letter search.* We prepared 30 different 29.6 × 10.5-cm displays each composed by 6 large font (112 pt times bold) capital letters, arranged vertically. The display was placed

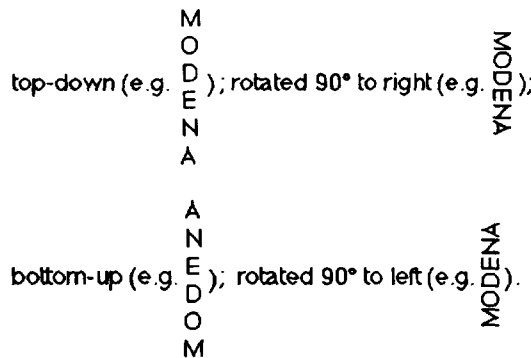


FIG. 6. Examples of vertical stimuli.

covered on the table, in front of the subject, aligned with his body midline. After the examiner had said the name of a letter, the display was shown to the subject, and he had to indicate the letter on the display as quickly as possible. The time to find the target letters was averaged according to three spatial positions (upper, middle, and lower space), each comprising two letter positions.

*Vertical picture search.* The test was similar to the Vertical Letter Search. With a set of 180 pictures of common objects we prepared 30 different  $28 \times 7$ -cm vertical displays each composed by 6 different pictures. On each trial the examiner named the object of the target picture and measured the time the subject took to find it.

*Results.* G.G. correctly indicated all the letters, but he misidentified one target picture in the lower space.

Figure 7 shows the mean searching times of G.G. according to the three spatial positions at Vertical Letter Search (Fig. 7a) and at Vertical Picture Search (Fig. 7b) compared with the mean performances of a group of 7 subjects matched for age, sex, and educational level.

Kruskal-Wallis's non-parametric analysis of variance was performed to compare G.G.'s searching times as a function of the three spatial position. Results showed that G.G. was significantly slower to reach for the target in the lower space both at the Vertical Letter Search ( $H = 8.689$ ,  $df = 2$ ,  $p < .02$ ) and at Vertical Picture Search ( $H = 6.134$ ,  $df = 2$ ,  $p < .05$ ) task.

Neither normal controls as a group, nor any single control subject, showed any significant

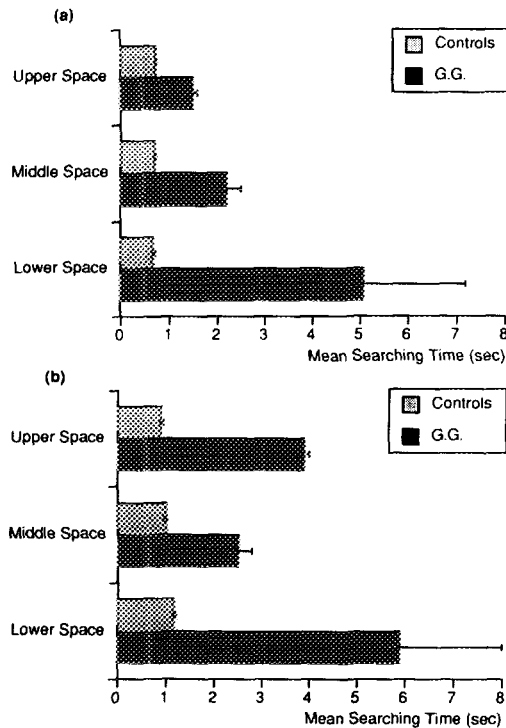


FIG. 7. Mean (and standard error) of searching times for each spatial position (upper, middle and lower space) obtained by G.G. and by seven matched control subjects at letter (a) (vertical letter search) and picture (b) (vertical picture search) searching tasks.

difference in response times to target according to the three spatial positions at both vertical search tasks.

## DISCUSSION

G.G., a right-handed man with a left superior quadrantanopsia, showed left visuo-spatial neglect and left neglect dyslexia. Furthermore he was less accurate or slower in searching for a given letter (or a given picture) in the lower part of a display and, when reading vertical words, he tended to misread letters falling in the lower (less affected) visual field, i.e., he showed a lower neglect both in reading and in searching tasks.

On reading normally oriented words, he also made errors when forced to attend to the leftmost part of the word. Neglect errors always involved the left part of the stimulus, i.e., initial letters of normally oriented words and final letters of words written from right to left. On vertical reading, errors involved the lower part of the stimulus, i.e., initial letters of bottom-up and rotated-to-left stimuli and final letters of top-down and rotated-to-right items.

Lower neglect dyslexia has not been reported before. However, reading rotated prose passages or vertical words was not errorless in a small number of neglect dyslexic patients whose deficit appeared to be at the level of stimulus-centered letter shape representations. Kinsbourne and Warrington (1962) presented 6 neglect dyslexic patients text rotated 90° clockwise, so that printed lines ran from above downwards. They reported that under these conditions paralexia errors nearly completely disappeared, but omitted to specify whether the few errors that occurred involved the last words in a row, the final part of the affected words, or if they were non-neglect errors. V.B. (Ellis et al., 1987) made a few reading errors with a 90° counterclockwise rotated prose passage, and her errors were not indicative of vertical neglect at the beginning of lines.

Behrmann, Moscovitch, Black, & Mozer (1990) examined vertical single word reading in two left neglect dyslexic patients. They presented 60 words and 60 pseudowords and found that reading accuracy of the two patients was 84 and 80%, respectively. The authors omit to give details about their patients' errors but claim that there was no neglect on vertical reading. However, as they were looking for errors on the initial part of the word, one cannot eliminate the possibility of lower neglect errors.

Hillis and Caramazza (1991) also examined vertical reading in a left neglect dyslexia patient (R.W.). R.W. made a few errors, that occurred without any specific spatial pattern and that, unlike errors in normal reading, were most often due to substitution of visually similar letters (e.g., h/n, b/d, a/o).

Neglect dyslexia has been classified according to a multistage model of word recognition (Caramazza & Hillis, 1990b). This model hypothe-

sizes that the first level of analysis is a retino-centric description of letter features. Then, a stimulus-centered letter shape map is computed. The third level consists of a word-centered grapheme description and provides information to be used by the orthographic input lexicon and by the phonologic conversion mechanism.

As G.G.'s errors depended on the topographical layout of the stimulus, we conclude that his reading disorder was confined to a relatively peripheral level of representation. Furthermore, since the reading disorder was present in any part of the patient's visual field (i.e., also when a red digit is placed left to the word thus forcing the subject to put the entire word in the right visual field), we claim that it involved a stimulus-centered description and not a retino-centric one.

The fact that a patient with a neglect dyslexia at this level also might be impaired in reading vertical stimuli posits a caveat to the use of vertical reading as a tool to specify the level of analysis at which the reading process is affected. Indeed, assuming that neglect dyslexia can result from the disruption of an inner map only along the horizontal axis, vertical reading should be errorless in the case of a stimulus-centered disorder, while errors should persist unchanged if neglect involved part of word-centered grapheme descriptions. On the contrary, the pattern of G.G.'s errors suggests that when the representation levels of features and letter shapes are concerned, neglect can affect both the horizontal and the vertical dimension of space. Therefore, only inverting reading direction along the same axis can help to determine the level of representation which is affected in the single patient.

So far there has been no systematic study of vertical reading in neglect dyslexia patients. In the only group study of vertical visuo-spatial neglect (Halligan & Marshall, 1989), 18 out of 23 patients with left unilateral neglect also showed a lower neglect at a line cancellation task. A few single cases have been reported where neglect was disproportionately affected along the vertical axis (Rapsack, Cimino, & Heilman, 1988; Shelton, Bowers, & Heilman, 1990). A perhaps simplistic explanation of lower neglect in search and cancellation tasks relates it to "fatigue" consequent upon the serial order in which the patient cancels the lines. However, this hypothesis cannot account for lower neglect dyslexia, where omission and completion errors affect the end of top-down and rotated-to-right words, but the beginning of bottom-up and rotated-to-left stimuli.

A more likely explanation is that the parietal lobe is involved in the control of attention not only along the horizontal, but also along the vertical axis. Based on the greater "cost" of attending to lower space when upper stimuli are presented, Gawryszewski, Riggio, Rizzolatti, and Umiltà (1987) proposed that in most subjects visuo-spatial attention is biased toward the lower visual space. This imbalance might depend upon a larger neural space devoted to the representation of the lower space as

compared to that devoted to the representation of the upper portions of space. As a consequence, a parietal lesion would more likely cause a neglect for the lower portions of the space (Previc, 1990). Alternatively, the neural system mediating attention in the upper parts of extrapersonal space may have a different cerebral location, not so close to that for lateral attentional shifts as the neural system mediating attention to the lower parts of the space.

The experimental evidence on several patients (Ellis et al., 1987; Behrman et al., 1990; Riddoch, Humphreys, Cleton, & Fery, 1990; Young, Newcombe, & Ellis, 1991; Hillis & Caramazza, 1991) is consistent with left neglect dyslexic patients showing spatially specific deficits either at the level of the stimulus centered, letter-shape map, or at the level of the retino-centric, feature map. Only three patients with right neglect dyslexia have been described so far: T.S. (Warrington & Zangwill, 1957), N.G. (Caramazza & Hillis, 1990b), and R.Y.T. (Warrington, 1991). The performance of two of them (N.G. and R.Y.T.) can be explained by assuming a spatially specific deficit at the level of the word-centered, grapheme description (Caramazza & Hillis, 1990b; Warrington, 1991). The remaining case report (T.S.) was not worked out well enough to allow inferences about the impaired processing level. A fourth patient (D.H., Hillis & Caramazza, 1989) showed right visual dyslexia together with a pattern of spelling errors that was consistent with a spatially selective damage to the graphemic map. Interestingly enough, two more patients (O.R.F., Baxter & Warrington, 1983; M.L., Hillis & Caramazza, 1989) had left neglect dyslexia after right hemisphere lesions that seemed to affect the graphemic map. However, both of them were left handed and had aphasic disturbances after their strokes.

One might hypothesize that the right hemisphere is mainly involved in evenly distributing processing resources over space within both the feature and the letter-shape maps, while the left hemisphere is mainly responsible for doing the same with the word-centered grapheme description.

Direct evidence for this hypothesis is still lacking. However, some data are in agreement with this theory. Marsolek, Kosslyn, and Squire (1992) demonstrated that both within-modality and case-specific priming for words are greater when stimuli are presented initially to the right hemisphere. They suggested that the right hemisphere is more effective in representing a visual word-form that encodes form-specific information. On the other hand, Petersen, Fox, Snyder, and Raichle (1990) found that certain areas in the left, medial extrastriate visual cortex were activated by visually presented words and pseudowords, a finding that points to an abstract word-form system relatively more effective in the left hemisphere than in the right.

We further hypothesize (see Fig. 8) that the feature map is bilaterally



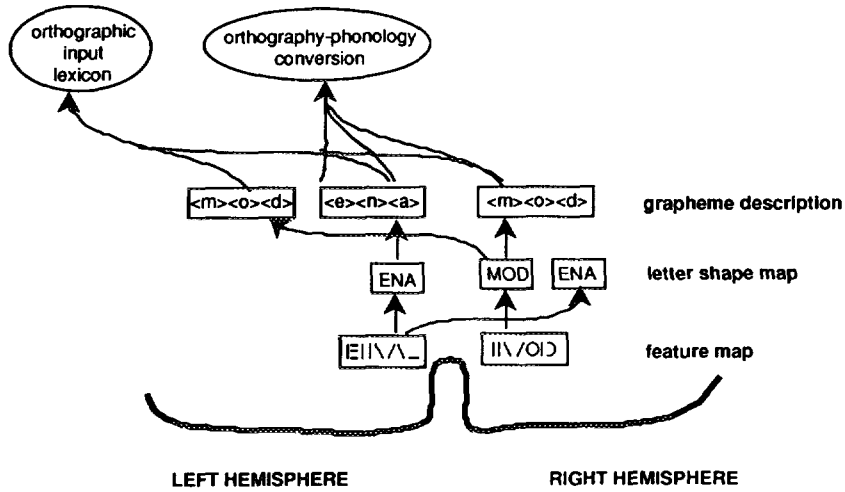


FIG. 8. Schematic view of the putative arrangement of the neural substrate subserving the different steps of the visual word recognition system.

and symmetrically distributed in the visual areas of the two cerebral hemispheres, while the neural arrangement of the system distributing processing resources over the letter shape map is somewhat similar to that described by means of positron emission tomography (PET) for the neural systems involved in shifting visuo-spatial attention. These PET studies (Corbetta, Miezin, Shulman, & Petersen, in press) showed that in the right superior parietal lobule there are the two distinct representations for separately directing attention into the left or right visual field, while only one representation in the left superior parietal lobule is devoted to direct attention into the right visual field.

The consequence of a similar arrangement of the letter shape map would be neglect dyslexia for the left part of the stimulus (i.e., for the initial part of normally oriented words and for the final part of the mirror reversed ones) after a right hemisphere impairment at this level. On the contrary, a unilateral lesion at the level of the feature map should cause a reading deficit that the subject could compensate by moving the stimulus in the sound visual field. An opposite arrangement might occur for right-handed individuals at the grapheme description level: two neural systems, one for the right and one for the left half of the word in the left hemisphere, and a single system for the left half of the word in the right hemisphere. A lesion involving the left hemisphere at this level could explain neglect for the right part of the word. Opposite lesions of the right hemisphere system that distribute processing resources over the left half of the graphemic map or of the left hemisphere system dealing with

the right half of the letter shape map could be easily compensated by intact systems in the opposite hemispheres.

While we admit that our assumption of a right hemisphere system that distributes processing resources over the left half of the word lacks of any direct support, we claim that such an arrangement can better explain the occurrence of patients with spatially specific deficits at the level of graphemic map. Indeed, if the only neural system responsible for distributing processing resources over the graphemic map were in the left hemisphere, we would expect spatially specific deficits involving either one, or the other end of the word, or the part in between. On the contrary, all the patients described so far showed a graphemic map neglect dyslexia involving the side of the word opposite to the cerebral hemisphere dominant for language.

A few patients also have been described that show left neglect dyslexia following a left hemisphere lesion (Costello & Warrington, 1987; Katz & Sevush, 1989; Cubelli et al., 1991; Binder, Lazar, Tatemiki, Mohr, Desmond, & Ciecierski, 1992). However, there is no evidence that any of these patients had a deficit at the level of the graphemic map. Binder et al. (1992) pointed out that these patients might have lesions that impair the normal callosal transfer of information originating from the more peripheral parts of the left visual field to the regions of the left hemisphere involved in the subsequent analysis of visually presented words. Their hypothesis easily fits the model of neural arrangement we are suggesting.

In conclusion, although such an arrangement is no more than conjectural, it seems able to explain most of the pattern of deficit that has been described in neglect dyslexia patients. Furthermore, it allows specific predictions for future observations. More systematic studies, both on neglect dyslexia patients and on normal subjects (with neuroimaging activation techniques) will be required to investigate the brain substrates for early stages of visual word recognition processing.

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