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Search pattern in a verbally reported visual scanning test in patients showing spatial neglect

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Abstract

The present study of right hemisphere stroke patients showed that presence of visuospatial neglect in conventional neglect tests at the postacute stage was strongly associated with an aberrant search pattern in a verbally reported visuo-perceptual scanning test. Compared with normal controls, patients with visuospatial neglect showed a greater proportion of repeated readings of the same target, shorter search sequences, more shifts between horizontal, vertical, and diagonal search, and lower proportion of horizontal search. The relation between spatial neglect and a deficient search pattern was strongly influenced by the asymmetric allocation of attention in the scanning test, with the exception for the proportion of repeated reading which was not influenced by this asymmetry. At follow-up, a significant recovery was noted in the neglect group for the proportion of repeated readings and for the asymmetry in the allocation of attention. However, a high number of omitted targets in the search test was still a common finding in the neglect group and it was suggested that a non-lateralized attentional deficit may have played an important role behind the ineffective search at this point of time. (*JINS*, 2002, *8*, 382–394.)

Keywords: Visuospatial neglect, Visual scanning, Scanpath, Right hemisphere stroke

INTRODUCTION

In conventional tests of visuospatial neglect, a high number of omissions of the test stimuli and a bias to the contralesional side in the location of the omissions are typically considered as basic components of neglect (Halligan et al., 1991; Heilman, 1979). Another central component in the neglect phenomenon is an ipsilesional bias of the orientation of attention in tasks requiring visual exploration (Kinsbourne, 1970, 1993).

The asymmetric components of the visual exploration in visual neglect have been confirmed in several eye movement studies. In these investigations, the search performance in patients showing spatial neglect differed in several ways compared to controls or patients without neglect. The neglect patients showed an increased rightward bias in initiation of visual exploration, more fixations and longer inspection time on the ipsilesional right side, and fewer fixations on the left side (Behrmann et al., 1997; Chedru et al., 1973; Ishiai et al., 1987; Karnath & Fetter, 1995; Kim et al., 1997). Further, these patients exhibited slower initiation of leftward saccades, fewer large saccades toward the contralesional left side, and shorter exploration time on this side (Behrmann et al., 1997; Chedru et al., 1973; Girotti et al., 1983; Ishiai et al., 1989; Johnston & Diller, 1986).

There is also evidence to suggest that, beside these asymmetric or directional impairments, patients with neglect may suffer from more general deficits in their visual search behavior. In an eye-movement study, Chedru et al. (1973) found that brain-damaged patients in general and patients with spatial neglect in particular showed an unsystematic and irregular eye-movement pattern during the performance in a visual search task. Weintraub and Mesulam (1988) studied the search strategy exhibited in visual target cancellation tasks by patients showing unilateral hemispheric lesions. A higher frequency of unsystematic search was ob-

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served in patients with a right-sided lesion in contrast to patients with a left-sided lesion. It was suggested that an unsystematic search pattern may constitute an important component of the neglect phenomenon shown by patients suffering from a right hemisphere lesion.

Observations in previous studies of scanning performance in patients showing spatial neglect (Chatterjee et al., 1992; Mark et al., 1988) have led to the suggestion that directional or asymmetric deficits in orienting of attention, may play an important role behind the irregular scanning pattern that these patients show.

Chatterjee et al. (1992) studied the search strategies used by a 73-year-old, right-handed woman who showed spatial neglect after a right-sided frontoparietal lesion. In a series of target cancellation tests the patient used a stereotypic search pattern, consisting of successive vertical sweeps of the page, starting in the top right of the sheet. An impaired ability to move attention or movements horizontally toward the left side in patients suffering from neglect was suggested to result in this vertical search strategy. Mark et al. (1988) reported that patients exhibiting left neglect on a cancellation test (Alberts test) often cancelled the same target repeatedly within the right side of the test page. After successive cancellation of targets, from right to left, the patients typically returned to targets already cancelled on the right hand side. It was suggested that an increased ipsilesional bias in the orienting of attention toward targets on the right side may have lead to a frequent return to targets already cancelled.

Although the importance of directional deficit in allocation of spatial attention is emphasized in the above studies, the specific relationship between this kind of deficit and irregular patterns of visual search, remains to be specified. The knowledge is sparse regarding how patterns of irregular search may relate to the basic components of neglect: ipsilesional bias of the orientation of attention, contralateral inattention, and general inattention. Furthermore, there is spare knowledge of how this relationship may change over time.

The aim of the present study was three-fold: (1) analyzing how the visual search pattern may be altered in patients exhibiting visuospatial neglect; (2) testing if a change of the pattern of visual exploration such as rereading of targets and nonhorizontal search is due to an asymmetric allocation of visual attention; and (3) in a follow-up, analyze if the relationship between visuospatial neglect and an aberrant scanning pattern changes over time. The visual search behavior was classified using a newly developed bedside test of visual scanning.

In addition, a clinical screening of neurological functions, basic intellectual capacity and general alertness provided background data. This assessment was made in order to control for severe deficits of basic functions that may influence the relationship between irregular scanning pattern and presence of visuospatial neglect. A neuroradiological examination was conducted by a neuroradiologist to examine the size and location of the lesion.

METHODS

Research Participants

The study concerns 41 patients who have suffered a first-ever major stroke after a right-sided cerebral infarction (n = 35) or intracerebral hemorrhage (n = 6), admitted consecutively to the Department of Neurology at Sahlgrenska University Hospital, Göteborg. The patients were selected on the basis of a medical chart review, a neurological examination conducted by the staff neurologist and a classification of the lesion from the computerized tomography (CT) scans conducted by a neuroradiologist. Patients not included in the study met at least one of the following criteria: (1) a prior clinically manifested cerebrovascular accident or other cerebral disorder and/or a clinically manifested infarct or hemorrhage not confined to the right hemisphere, (2) minor strokes with a return to normal or virtually normal neurological functions within three weeks, (3) older than 77 years of age, (4) a history of serious substance abuse or psychiatric disturbances, (5) not right-handed, (6) severely ill and not able to co-operate, (7) not Swedish speaking, (8) a severely defective vision in both eyes.

Healthy subjects from the population of Göteborg, matched for age and gender, comprise the control group (n = 34, M age 61.2, range 29–75).

Classification of participants

The Behavioural Inattention Test (BIT) was introduced by Wilson et al. (1987) as a valid test of unilateral visual neglect. The occurrence of visual neglect was determined in the present study using seven slightly modified subtests from BIT (Line Crossing, Letter Cancellation, Star Cancellation, Figure Copying, Representational Drawing, Article Reading, and Sentence Copying).

In each subtest, the cut-off level for visual inattention was represented by the first score below the normative range obtained from the control group (Samuelsson et al., 1996). A laterality index was then computed by measuring the lateral asymmetry in the number of detected targets (Friedman, 1992): the number of detections made at the left side in the test was divided by the total number of detected targets and expressed in per cent. Thus, a laterality index close to 50% means that an equal number of targets are detected at both sides of the test, whereas a lower percentage indicates a bias in the performance with less detections on the left side. To avoid confusion of centrally and laterally located omissions, the mid part of each test form or test figure was excluded from the above measure of laterality (Gainotti et al., 1990). The laterality index in the control group ranged between 44 to 56%.

The following criteria for visuospatial neglect were applied: a score at or below the cutoff level for inattention in at least one of the subtests in the battery and a contralesional asymmetry for the number of targets omitted (that is, a laterality index below 44% in at least one of the tests and no test above 56%).

The patients were tested at 1 to 4 weeks post stroke except for 4 patients who were examined during the 2nd month post stroke. Of 41 patients, 18 showed visuospatial neglect (the *neglect group*, *M* age 62.1, range 45–75) and the remaining 23 formed the *no-neglect group* (*M* age 59.6, range 21–77). Of the 41 patients, 36 were re-examined 6 to 7 months post stroke, at this point of time 6 of the patients showed persisting neglect.

Classification of search pattern

The visual search behavior was studied using a test form (the Visual Scanning Test) consisting of an A4 sheet of paper with 32 numbers and letters scattered across the paper (Samuelsson, 1992; Figure 1). The design of the test was based on results reported in a prior study (Samuelsson, 1988). The test was designed so that the form could be divided into four rows and eight columns, dividing the test page into 32 cells ($4 \times 8 = 32$). Each cell contains a letter or number placed to give a random impression (Figure 1A). The location of the numbers and letters allows the entire sheet of paper to be searched either by reading the four lines (with eight letters and numbers in each line) line by line, or reading the eight columns (with four letters and numbers in each column) column by column.

The test form was placed directly in front of the patient. The instruction was to read all the letters and numbers seen on the page. The test administrator sat directly in front of the patient and noted the order in which the patient read the letters and the numbers.

To analyze the material, the test administrator divided the sheet of paper into four lines and eight columns and then drew arrows between the letters and the numbers in the order in which they were named by the subject (Figure 1B). In this manner, a search pattern was obtained indirectly describing how attention was moved across the material. Those parts of the search pattern (including a sequence of at least two letters or numbers) which were inside a row were marked with a red pen (row search), and those parts inside a column were marked with a green pen (column search). Marking was always carried out successively in the direction of the search, beginning with the first letter or number read. A successive marking with no interruptions was defined as a search sequence. The length of each sequence was defined as the number of targets included.

Those parts of the pattern that were not part of a row or a column as described above, were left unmarked. Each unmarked part of the pattern typically included few targets (i.e., one to three targets) with some part of the pattern running diagonally across the paper, crossing the boundary of at least one column and one row. This form of search was named "diagonal search."

The classification of the search pattern shown by the subjects was based on the observations made in a previous pilot study (Samuelsson, 1992). Further modifications of this classification were based on the performance in the control group in this study. The search behavior of the subjects was classified using the five variables defined below (see Figure 2).

Proportion of row search

Proportion of letters and numbers read that comprised a search by row was calculated using the following formula: (number of letters and numbers read by row)/(number of letters and numbers read by row + by column + diagonally).

Shifts among search forms

Total number of shifts occurring between the three search forms (by row, by column and diagonal search) was counted (Figure 2).

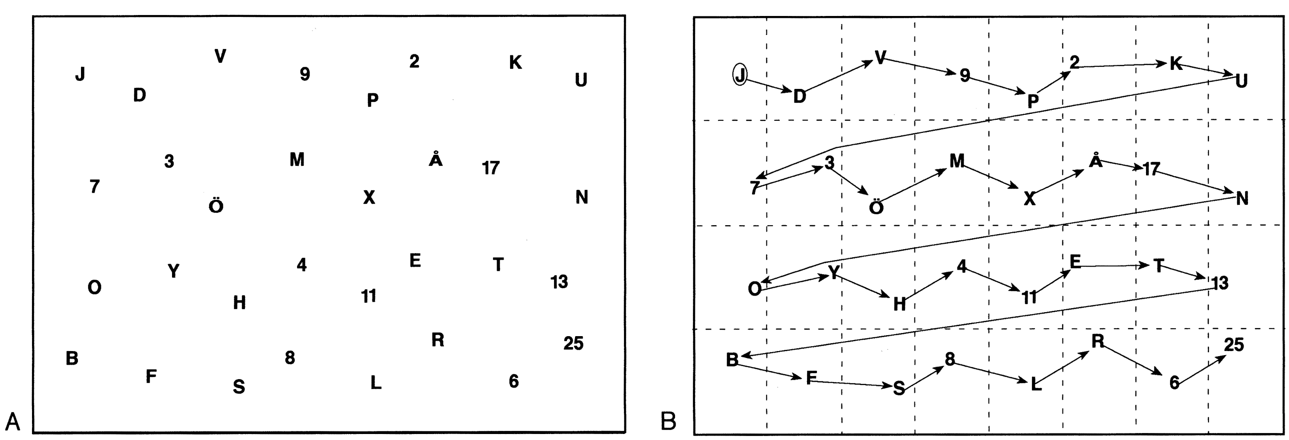

Fig. 1. A: The test sheet. B: The test sheet divided into four rows and eight columns and with lines drawn between the letters and the numbers in the order in which they were named by the subject. Figure B shows a typical search pattern from the subjects in the control group.

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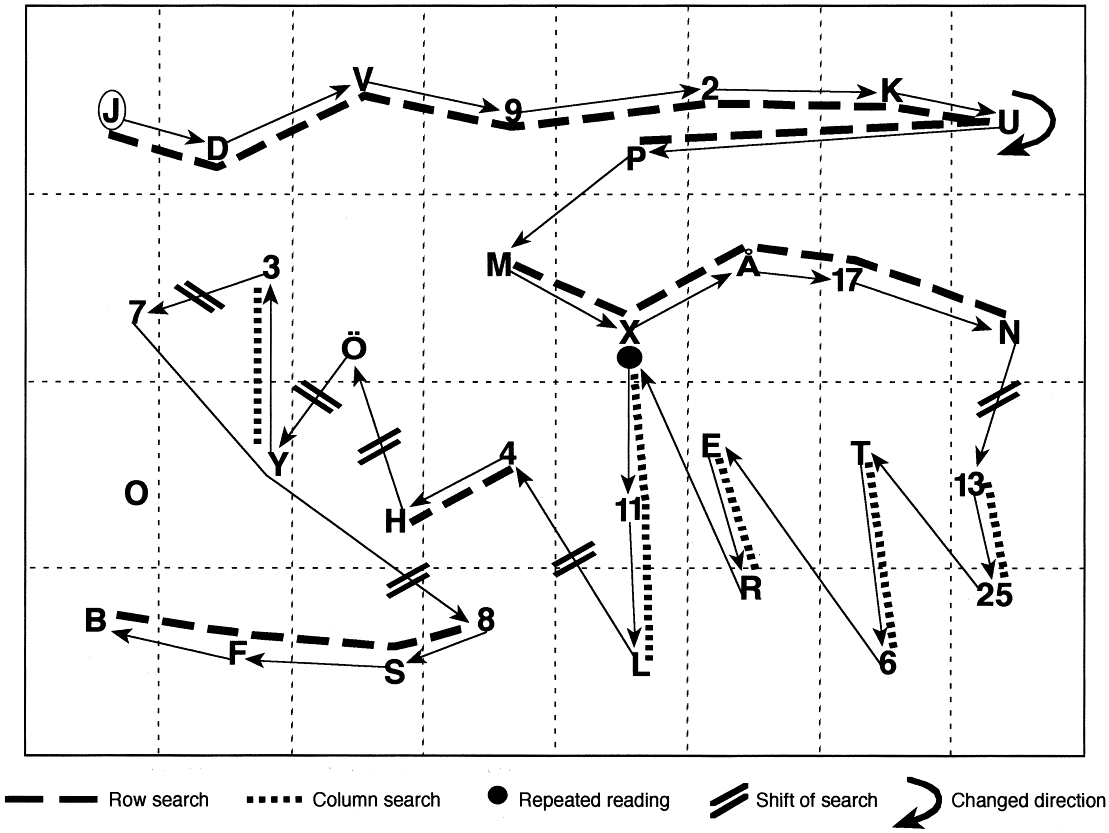

Fig. 2. Example of marking and evaluation of the obtained search pattern. This search pattern consists of 11 search sequences: four by row, five by column and two by diagonal (unmarked parts of the pattern represent "diagonal search," e.g., 7 and Ö in the pattern above). Six shifts among the three search forms were registered. The average length of rows and columns was: $8+5+2+2+2+3+2+2+4/9 = 3.3$. One marking is made for a repetition of a previously read letter as well as for a changed direction within the marking for a row.

Length of search sequences

Average length of search sequences of rows and columns (of all individual sequences of targets marked by the test administrator as row or column search; Figure 2).

Changed direction of search

Number of times that the search changed direction (turned back in the opposite direction) within the marking for a row or column (Figure 2).

Repeated readings

Proportion of readings that were repetitions of previously read letters or numbers.

Omission of targets

The number of letters and numbers not read in the Visual Scanning Test was counted and the percentage of omissions of the total numbers of targets was computed.

Asymmetric orientation of attention

The two variables below were aimed at assessing degree of ipsilesional bias in the beginning of the search in the Visual Scanning Test and degree of contralesional asymmetry in the inattentive behavior in the test. The variables were assessed as follows:

Start column. The columns in the scanning test were numbered 1 to 8 from left to right. The location of the first letter or number read by the subject represented the start column.

Asymmetry index. The number of detected targets on the left side was divided by the total number of detected targets and expressed in per cent. Thus, a laterality index $<50\%$ indicates a bias in the performance with less detections on the left side. The two columns in the center of the sheet were excluded from this analysis.

Supplementary Behavioral Variables

Basic intellectual capacity

An assessment of general intellectual ability was performed using a short form of the Similarities subtest consisting of six word pairs and the forward part of the Digit Span subtest from the Swedish version (the CVB scale) of

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the Wechsler Bellevue Scale (Wechsler, 1944), and the Mini-Mental State Examination (MMSE; Folstein et al., 1975).

Warned simple reaction time

An estimation of warned simple auditory reaction time was included as a behavioral indicator of general alertness (Sturm, 1996). The subjects were instructed to rest their right index finger on a response key and to press the key as rapidly as possible on the appearance of a loud and short pure tone. Auditory stimulus was preferred instead of visual stimulus in order to minimize the effect that visual neglect might have on the reaction times. In addition, the response key and the stimulus box were placed at the right side of the subject, approximately 20 to 25 cm from the subject's body midline. Thus, the location of the stimuli and the manual responses were ipsilesional and accordingly contralateral to the part of space neglected by the patients in the neglect group.

The experimenter started each trial by giving a verbal warning and at the same time initiating the presentation of the target stimulus. Each stimulus appeared after random intervals of 2 to 7 s. The reaction time was the time lapse between the appearance of the target stimulus and the pressing of the key. The time was measured in milliseconds by an internal integrated electronic counter. Individual performance was defined by the median values of 11 valid reaction trials. A more detailed presentation of this assessment has been presented elsewhere (Samuelsson et al., 1998).

Although auditory reaction time was preferred in the present study, an assessment of simple visual reaction time was also conducted for the patients and controls (not reported in this paper). A comparison of the auditory and the visual reaction times resulted in a high correlation between these two sets of data (Spearman rank correlation: $Rho = .83$, $p < .0001$ in the patient group and $Rho = .79$, $p < .0001$ in the control group).

Perseverative responses

Perseverative responses were measured using the Alternating Sequences Task. This task was modified from Christensen (1975) and from Luria (1966). The subjects were asked to draw a sequence of two circles, one cross, and three triangles in the first six squares in a vertical row of 50 consecutive squares. The subjects were then told to continue to draw exactly the same sequence of figures repeatedly until all of the squares in the row were filled. Perseverative (erroneously repeated) drawing of figures within each sequence was recorded.

Neurological and Neuroradiological Variables

Homonymous visual field deficits

Visual field deficit was examined using the customary confrontation technique. The visual stimulus was given from one side at a time. The performance was rated as no, partial, or total visual field deficit (score 0–2). More detailed descriptions have been presented elsewhere (Samuelsson et al., 1997).

Conjugate eye movement deficits

A clinical routine examination of externally induced horizontal eye movements was conducted. Asymmetric defects in the movements were tested by instructing the patient to look at the examiner's moving index finger. The patient had to focus on the finger during slow movements (smooth pursuit eye movements) and during rapid movements (saccadic eye movements) from right to left and the reverse. The examiner, located in front of the patient, inspected the eye movements during the testing. One score was given for each of the following findings: (1) a spontaneous conjugate deviation of the eyes towards the ipsilesional side, (2) defective smooth-pursuit eye movements, (3) defective saccadic eye movements (maximum score = 3).

Neuroradiological examination

CT scans were performed acutely within 2 days after onset of neurological symptoms as well as 4 weeks or later after onset. The evaluation of the CT examinations were carried out by two trained neuroradiologists without knowledge of clinical data. With guidance of the atlas of Kretschmann and Weinrich (1986) the anatomical structures were grouped into six main brain areas (frontal, central grey, insula, temporal, parietal, and occipital). For each patient, the incidence of damaged tissue within each main brain area was noted.

The size of the lesion(s) was defined by using sagittal and transversal measurements (rounded off to the closest 0.5 cm) on the scan where the lesion had its greatest extent. In addition, the size was indicated by the number of main brain areas damaged.

Statistical Methods

Group comparisons of the scores from the search variables, the variables of asymmetric orientation of attention, and the supplementary behavioral variables were performed by the Kruskal-Wallis one-way analysis of variance. The Mann-Whitney *U* test was used for *post-hoc* two-sample comparisons. Comparisons between the neglect and no-neglect group of neurological and neuroradiological variables were made for the nominal variables by the Fisher exact test and for the ordinal or continuous variables by the Mann-Whitney *U* test. Two-tailed levels of significance was used. Multiple two-sample comparisons were corrected by the Bonferroni-Hochberg method (Hochberg, 1988).

Forward stepwise logistic regression analysis (Hosmer & Lemeshow, 1989) was used in order to try to identify the most important correlates of visuospatial neglect among the visual search variables.

The relationship between presence of neglect and the search variables was determined by univariate logistic regression analysis (Hosmer & Lemeshow, 1989). The strength of the relationship was given by odds ratios. In addition, adjusted odds ratios were estimated in order to examine the effect of confounding variables on the relationship between the search variables and the occurrence of neglect. In the latter estimation, only variables showing statistically significant association with neglect in the univariate analyses were included. The adjusted odds ratios were estimated by forcing each of the following variables into the regression model: Asymmetry index, start column, and omission of targets (all three variables were based on the performance in the Visual Scanning Test). Supplementary behavioral variables and neuroradiological variables were also forced into the model. Odds ratios with a confidence interval with the lower limit exceeding 1.00 was considered statistically significant.

Within subject comparisons between the postacute and follow-up examinations were conducted by the Wilcoxon signed rank test. These comparisons were made for the five search variables and the variables of the orientation of attention in the scanning test.

RESULTS

Search Patterns in the Control Group

Of 34 control subjects, 29 (85%) showed a single search strategy (by row or by column) throughout the search. The most common form of search throughout the test was search by row (24/34 subjects, 71%). In those cases in which the entire search was carried out by row, this was always done row by row beginning at the top. In those cases in which the entire search was by column, the search was carried out column by column, beginning from the left. There were two versions of row and column search observed in these cases. Usually, the search was carried out by reading letters and numbers within one marking (for row or column) successively in one direction. In the other version, the search changed direction (turned back in the opposite direction) within the limits of a row or column. Figure 2 shows an example of this type of search. A mixture of search forms was observed in a total of 5 control subjects. Four of these showed a mixture of all three search forms. All subjects except 3 (91%) began the search farthest to the left on the top row of the test form.

Unread letters or numbers were observed in 5 subjects (15%). In all these cases, only one letter or number had been omitted. Repeated reading of the same letter or number was noted in only 3 subjects (9%). Two subjects showed repeated reading only once, and 1 subject demonstrated the phenomenon three times.

Two control subjects deviated from the others by first reading all letters and then all numbers. The same strategy was used by 2 patients in the no-neglect group and by 2 patients in the neglect group. For these patients, the analyses of the search pattern were limited to the reading of the letters.

Search Patterns in the Patient Groups

Table 1 shows that statistically significant group differences were obtained for each one of the search variables. The *post-hoc* analysis indicated that the patients in the neglect group showed significant deviations in all five search variables as compared to the control group (Table 1). Furthermore, the neglect group and no-neglect group differed

Table 1. Visual search pattern at the first assessment

	Group								
	Control (n = 34)		No neglect (n = 23)		Neglect (n = 18)			Significant *post-hoc* comparisons[b]	
Variable	*Mdn*	(IQR)	*Mdn*	(IQR)	*Mdn*	(IQR)	H value[a]		
Search variables									
Proportion row search (1–0)	1	(0.16)	1	(0.22)	0.77	(0.7)	8.78*	1 *vs.* 3*	2 *vs.* 3*
No. of shifts among search forms	0	(0)	0	(1.75)	2.5	(4)	13.34**	1 *vs.* 3**	
Average length of search sequences	8	(3.9)	7.5	(3.9)	3.5	(2.4)	16.45***	1 *vs.* 3***	2 *vs.* 3*
No. of changed direction of the search	0	(1)	0	(1.8)	2	(4)	14.28***	1 *vs.* 3***	2 *vs.* 3*
Percentage repeated readings	0	(0)	0	(0)	8.7	(23.8)	27.96***	1 *vs.* 3***	2 *vs.* 3***
Percentage omitted targets	0	(0)	0	(3.1)	3.1	(21.9)	17.11***	1 *vs.* 3*** 1 *vs.* 2*	2 *vs.* 3*
Asymmetric allocation of attention									
Asymmetry index	50	(0)	50	(0)	48.9	(13.16)	12.11**	1 *vs.* 3*	2 *vs.* 3*
Start column (1–8)	1	(0)	1	(0)	3	(3)	28.03***	1 *vs.* 3***	2 *vs.* 3***

Note. IQR = Interquartile range; *Mdn* = median.
[a]Kruskal-Wallis test with *df* 2.
[b]Two sample *post-hoc* comparisons showing $p \leq .05$ after correction for multiple comparisons.
$*p < .05$, $**p < .01$, $***p < .001$.

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on all variables with the exception of the number of shifts among search forms. No statistically significant differences were obtained between the no-neglect group and the controls for the five search variables.

In order to identify the most important correlates of presence of visuospatial neglect among these five search variables mentioned above, a stepwise logistic regression analysis was undertaken. The five search variables were involved as independent variables and presence or absence of visuospatial neglect constituted the dependent variable. The analysis resulted in a selection of repeated reading as the most important correlate of visuospatial neglect (χ^2: 15.59, *df* 1, $p < .001$). No other variables were selected by the statistical procedure.

Omission of Targets

Table 1 shows that the patients with visual neglect exhibited a greater proportion of unread letters and numbers in the Visual Scanning Test compared to the no-neglect group and the control group. The *post-hoc* comparisons also showed that the no-neglect patients exhibited greater proportion of omitted targets than the control subjects.

Asymmetric Allocation of Visual Attention

It can be seen from Table 1 that statistically significant group differences were obtained both for the asymmetry index and the start column. The patients in the neglect group demonstrated a more pronounced bias in the allocation of visual attention, with a higher proportion of omitted targets on the left side as compared to the no-neglect group and the controls. Furthermore, the patients in the neglect group began the search farther out to the right of the test form than the no-neglect patients and the control group.

Supplementary Behavioral Variables

Table 2 shows that the neglect group differed significantly compared to the no-neglect group and the controls on the MMSE, the simple reaction time, and the number of perseverative responses. The no-neglect group did not differ significantly from the controls.

Neurological and Neuroradiological Variables

It can be seen from Table 3 that a lesion involving the temporal lobe was more common in the neglect group than the no-neglect group. It can also be seen that the neglect group showed more extensive lesions in the transversal plane, and that the lesions involved more lobes in the neglect group compared to the no-neglect group.

The Relationship Between the Search Pattern and Visual Neglect

Unadjusted and adjusted odds ratios for the relationship between neglect and the search variables were computed using logistic regression analysis (Table 4). Presence or absence of spatial neglect constituted dependent variable in these analyses. The three search variables selected for inclusion in Table 4 were those showing a *p* value $< .05$ in univariate logistic regression analysis. The odds ratios for these variables are shown in the first line of the table.

Influence of asymmetric allocation of attention

The adjusted odds ratios in the upper part of Table 4 (Part A) indicates if the relationship between visuospatial neglect and the search variables are influenced by the asym-

Table 2. Supplementary behavioral variables

	Group								
	Control (n = 34)		No neglect (n = 23)		Neglect (n = 18)			Significant *post-hoc* comparisons[b]	
Variable	*Mdn*	(IQR)	*Mdn*	(IQR)	*Mdn*	(IQR)	*H* value[a]		
Digit Span Forward	6	(1)	6	(1)	6	(2)	1.82		
Similarities[c]	9.5	(3)	9.5	(3)	8	(4)	4.06		
MMSE	28.5	(1)	29	(3)	25.5	(3)	15.18***	1 *vs.* 3***	2 *vs.* 3*
Simple RT	217	(62)	251	(114)	343	(155)	29.44***	1 *vs.* 3***	2 *vs.* 3***
Perseverative responses	0	(0)	0	(0)	1	(5)	24.40***	1 *vs.* 3***	2 *vs.* 3**

Note. MMSE = Mini-Mental State Examination; IQR = Interquartile range; *Mdn* = median.
[a]Kruskal-Wallis test with *df* 2.
[b]Two sample *post-hoc* comparisons showing $p \leq .05$ after correction for multiple comparisons.
[c]A short form consisting of six word pairs.
*$p < .05$, **$p < .01$, ***$p < .001$.

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Table 3. Neuroradiological and neurological variables

Variable	No neglect (n = 23)		Neglect (n = 18)		p^a
Damaged area: n (%)					
Frontal lobe	8	(36)	11	(61)	
Central grey	7	(32)	11	(61)	
Insula and adjoining matter	4	(18)	10	(56)	
Temporal lobe	4	(18)	13	(72)	.002
Parietal lobe	7	(32)	10	(56)	
Occipital lobe	6	(27)	4	(22)	
Number of damaged areas: *Mdn* (range)	1	(1–4)	4	(1–5)	.001
Max size of lesion: *Mdn* (IQR)					
Sagittal (cm)	2.5	(2)	4.3	(4)	
Transversal (cm)	1	(1)	3.3	(2)	.001
Visual field deficit: *Mdn* (IQR)	0	(0.75)	0.5	(1)	
Conjugate eye movement deficits: *Mdn* (IQR)	0	(0.75)	0	(1)	

Note. IQR = Interquartile range; *Mdn* = median.
[a]Tested with the Fisher's exact test or the Mann-Whitney U test. Only p values < .05 after adjustments for 11 multiple comparisons are shown.

metric allocation of visual attention in the scanning test. The table shows that after correction for the start column and the asymmetry index, only one of the three search variables, the percentage of repeated reading, still showed a statistically significant association with presence of visuospatial neglect.

Influence of other variables

The odds ratios for the relation between neglect and the search variables in Table 4 were also corrected for the omissions of targets in the scanning test and for a selection of variables from the supplementary behavioral variables and the neuroradiological variables (part B). The selection included those variables showing statistically significant associations with visuospatial neglect in the previous analyses (see Tables 2 and 3).

Table 4 shows that the relationship between the percentage of repeated reading and visuospatial neglect was not influenced by the inclusion of these variables into the regression model. The table also shows, with one exception, that the average length of search sequences still showed a

Table 4. Adjusted and unadjusted odds ratios (OR) for presence of visuospatial neglect

	Search pattern								
	Percentage repeated readings			Length of search sequences			Proportion row search		
		CI			CI			CI	
Variable	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Unadjusted	1.22	1.05	1.42*	1.54	1.10	2.16*	9.59	1.07	86.31*
Adjusted									
A. Asymmetric attention									
Start column	1.21	1.02	1.45*	1.33	.90	1.96	1.71	.10	30.33
Asymmetry index	1.36	1.06	1.75*	1.36	.94	1.97	5.9	.53	65.81
B. Omitted targets	1.22	1.04	1.44*	1.46	1.00	2.11	11.11	.93	133.
Supplementary behavioral variables									
Simple RT	1.26	1.02	1.54*	1.52	1.02	2.28*	12.95	.91	185.
Perseverative responses	1.23	1.04	1.44*	1.58	1.09	2.31*	9.27	.91	94.44
MMSE	1.20	1.03	1.40*	1.57	1.08	2.29*	8.92	.88	90.72
Neuroradiology									
Temporal lobe	1.26	1.04	1.52*	1.53	1.02	2.28*	10.15	.75	137.
No. of damaged areas	1.28	1.04	1.56*	1.68	1.09	2.60*	24.74	1.46	418.*
Max size of lesion: transversal	1.25	1.02	1.53*	1.62	1.04	2.51*	59.56	2.17	1633.*

Note. CI = Confidence interval.
*An odds ratio with a Cl exceeding 1.00 is considered statistically significant.

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statistically significant association with spatial neglect after the adjustments for these variables.

On the other hand, a statistically nonsignificant relationship between visual neglect and the proportion of row search was obtained after the corrections for each of the following variables: the proportion of omissions, the supplementary behavioral variables, and lesions involving the temporal lobe (Table 4). The table also demonstrates great uncertainty (i.e., wide confidence intervals) for the estimations of several of these corrected odds ratios for proportion of row search. Thus, the results from this part of the analysis must be interpreted cautiously.

The Follow-Up

The presence of visuospatial neglect, the search pattern, and the simple reaction time were re-examined at 6 to 7 months post stroke. Of the 41 patients, 36 were examined. At this assessment, 6 patients showed persisting symptoms of visuospatial neglect in the neglect battery. Table 5 shows the results obtained at this assessment. Results are given for patients with and without neglect at this point of time and for the controls. For the controls, no second assessment was made, instead, the data from the first assessment was used in this analysis.

Search Patterns at Follow-Up

Table 5 shows that the group of patients with persisting symptoms of neglect exhibited a higher number of shifts between the three search forms and shorter search sequences compared to the control group. Also, the patients without neglect at follow-up differed from the control group by exhibiting shorter search sequences. However, no statistically verified differences were obtained between the no-neglect group and the neglect group.

A within subject comparison (first assessment *vs*. follow-up) was made in order to analyze if there is a change over time in the search pattern shown by the patients with neglect. The comparison included the group of patients who showed visuospatial neglect at the acute stage (n = 15, 3 patients with missing follow-up). The comparison was made for the five search variables in Table 5, the two variables of asymmetric allocation of attention, and for the percentage of omitted targets. The analysis revealed (1) a marked decrease of the percentage of repeated readings (Wilcoxon signed rank test: $Z = 2.67$, $p < .01$), (2) a decreased asymmetry of the location of the omitted targets on the sheet ($Z = 2.32$, $p < .05$), and (3) a significant shift of the start column towards the outer left side of the sheet ($Z = 2.56$, $p = .01$). A slight improvement was also suggested for the number of changed direction of the search ($Z = 1.82$, $p = .07$).

The improvements of the search performance are indicated in Figure 3. The figure shows that, among the patients who showed neglect at the acute stage, all except 2 started the reading of targets at the first or second column at the follow-up. Furthermore, at the second assessment, most of the asymmetry indexes for the location of omitted targets showed a cluster around the index of 50 (no asymmetry). One patient even showed an ipsilesional asymmetry with an asymmetry index of 60. Repeated reading of the same target, which was highly correlated with visuospatial neglect at the acute stage, was uncommon at the follow-up;

Table 5. Visual search pattern and simple auditory RT at follow-up

Variable	Group: Control n = 34 *Mdn*	(IQR)	No neglect n = 30 *Mdn*	(IQR)	Persisting neglect n = 6 *Mdn*	(IQR)	*H* value[a]	Significant *post-hoc* comparisons[b]	
Search variables									
Proportion row search (1–0)	1	(0.16)	1	(0.53)	0.95	(0.67)	1.49		
No. of shifts among search forms	0	(0)	0	(4)	1.5	(2)	6.92*	1 *vs.* 3*	
Average length of search sequences	8	(3.9)	6.58	(5.18)	6.62	(4.42)	8.98*	1 *vs.* 2*	1 *vs.* 3*
No. of changed direction of the search	0	(1)	0	(1)	1	(2)	1.85		
Percentage repeated readings	0	(0)	0	(3.03)	0	(9.52)	5.12		
Asymmetric allocation of attention									
Asymmetry index	50	(0)	50	(2.17)	48.9	(12.17)	5.32		
Start column (1–8)	1	(0)	1	(0)	1	(1)	3.98		
Percentage omitted targets	0	(0)	0	(4.76)	13.4	(9.38)	25.76***	1 *vs.* 3*** 1 *vs.* 2**	2 *vs.* 3**
Simple RT (ms)	217	(62)	251	(67)	393	(245)	17.85***	1 *vs.* 3*** 1 *vs.* 2*	2 *vs.* 3**

Note. IQR = Interquartile range; *Mdn* = median.
[a]Kruskal-Wallis test with *df* 2.
[b]Two sample *post hoc* comparisons showing p ≤ .05 after correction for multiple comparisons.
*$p < .05$, **$p < .01$, ***$p < .001$.

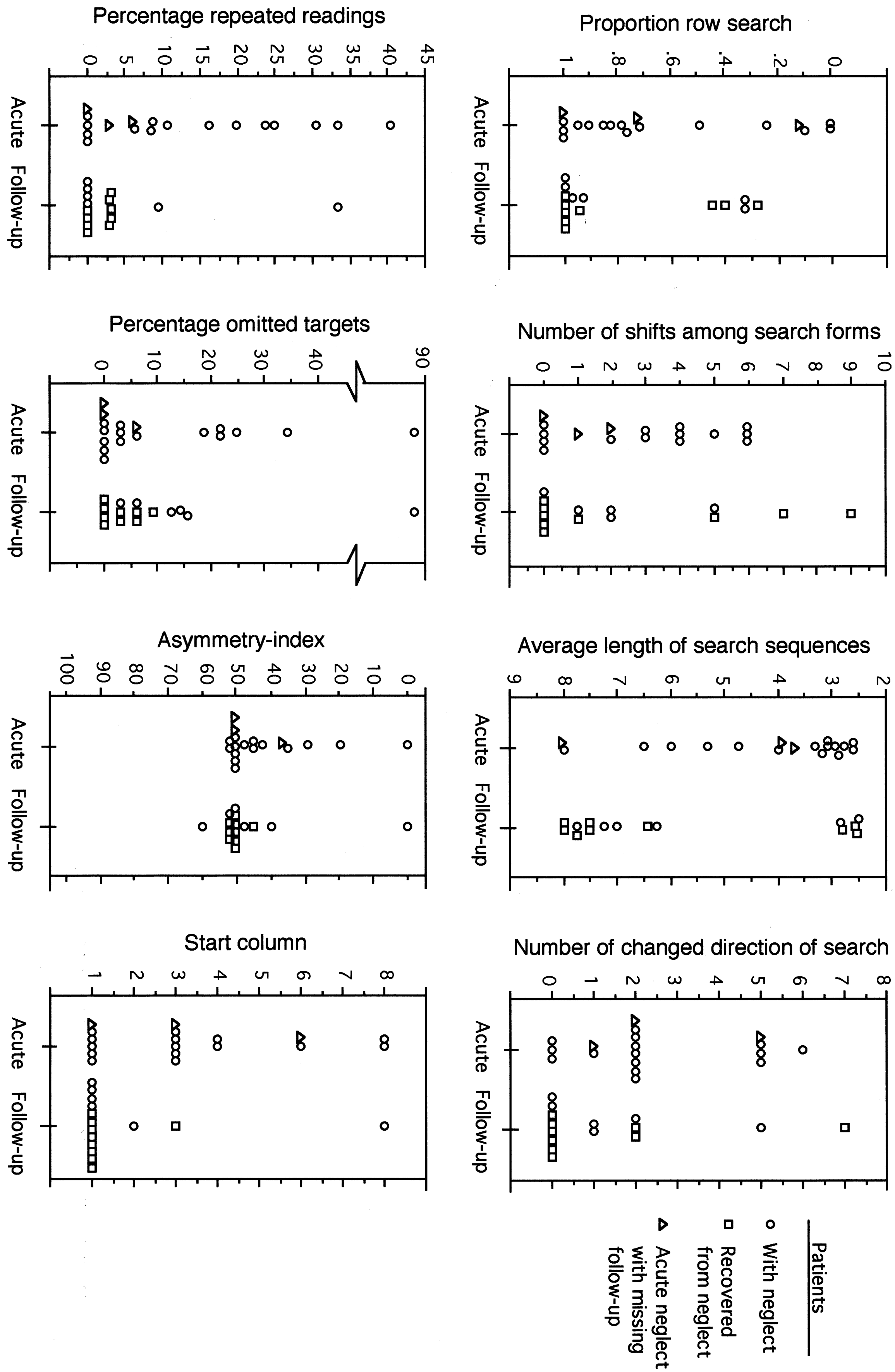

Fig. 3. The search pattern exhibited by the patients who showed visuospatial neglect at the first assessment. Results from the postacute stage and the follow-up are shown.

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only 2 of these patients showed repeated reading more than once (in >3.3% of the readings). On the other hand, an inferior improvement is indicated by Figure 3 for the number of omitted targets and for the number of shifts among the three search forms. No improvement is indicated for the length of the search sequences in 5 of the patients at this follow-up. Finally, the figure shows that, out of the eight variables in the figure, only the percentage of omitted targets showed an obvious relationship with presence of *persisting neglect* at the follow-up.

Visual Attention and Simple Reaction Time at Follow-up

The lower part of Table 5 shows that the patients with persisting neglect differed both from the no-neglect group and the controls by showing a higher proportion of omitted targets and increased reaction times. The no-neglect group exhibited a higher proportion of omitted targets and increased reaction time compared with the controls.

The size of the lesion may represent a confounding variable influencing the relationship between simple reaction time and persisting neglect. The relationship obtained between neglect and proportion of omitted targets may also be influenced by the size of the lesion. Therefore, the relationship between neglect and each of these variables (simple reaction time and proportion of omitted targets) were analyzed respectively, while adjusting for the size of the lesion. A logistic regression analysis was computed. Presence or absence of persisting neglect was the dependent variable. The analysis was corrected by the inclusion of the maximal transversal and sagittal size of the lesion into the logistic regression model. The adjusted regression showed that the relationship between neglect and proportion of omitted targets still persisted after this correction (adjusted χ^2: 6.13, *df* 1, $p < .05$). The same finding was true for the simple reaction times (adjusted χ^2: 9.53, *df* 1, $p < .005$).

DISCUSSION

The Acute Phase

The results show that the patients with visual neglect in the acute phase did not only exhibit omissions of visual stimuli within the test sheet but also demonstrated more general deficits in their visual search performance. Several of these patients showed search patterns with many short search sequences and numerous shifts between searches by column, by row and diagonally. In contrast, the controls exhibited a few long search sequences of the same type. Further, the results indicate that the neglect patients reduced the number of searches by row compared with the no-neglect group and the controls and instead increased the proportion of searches by column and diagonally.

Among the five search variables analyzed in this study, *repeated reading* of the same letters and numbers was the most important correlate of presence of visuospatial neglect. In the multiple regression analyses, repeated reading of targets showed a statistically significant relationship with presence of visual neglect also after the correction for the visual inattention and the asymmetric allocation of attention (i.e., after the inclusion of the number of omissions, start column, and asymmetry index into the regression model).

Mark et al. (1988) have suggested that a tendency to return to previously cancelled targets shown by patients with neglect may be explained by an ipsilesional bias in the explorative behavior. The present results are not in line with such an explanation because the severity of asymmetric allocation of attention in the scanning test did not change the relationship between repeated reading and visuospatial neglect. That is, repeated reading of targets showed a statistically significant relationship with presence of visual neglect also after the correction for the start column and the asymmetry index in the regression analysis.

Chatterjee et al. (1992) suggested that a deficient ability to direct attention horizontally toward the left side may lead to a shift from horizontal to vertical search in patients suffering from neglect. The suggestion that an asymmetric direction of attention may influence the spatial orientation of the visual search is supported by our observations. The inclusion of the ipsilesional bias (in terms of the start column) into the regression analysis resulted in a marked weakening of the correlation between the proportion of row search and presence of visuospatial neglect (see Table 4).

It should be noticed that the statistical power of the various multiple logistic regression analyses used in this study is probably rather weak due to the low number of patients in the neglect group. Consequently, the selection of variables into the regression model during the stepwise regression analyses will in general be conservative. The few patients in the neglect group may also have lead to the rather unstable values and confidence intervals for some of the corrected odds ratios in the analyses of proportion of row search.

To summarize this part of the discussion, a tendency to reread targets was highly correlated with presence of visual neglect at the postacute stage. Rereading was neither explained by the bias in allocation of visual attention nor by the non-lateralized inattention. On the other hand, a bias in the orientation of attention may have played a central role behind the other components of irregular search such as, increased number of short search sequences and reduced number of searches by row.

The Follow-Up

At the follow-up examination the most marked improvement in the Visual Scanning Test was observed for the location of the start column, the asymmetry of the location of the omitted targets, and the proportion of repeated readings. Thus, the components of the search pattern that showed the strongest correlation with visuospatial neglect at the postacute stage, showed no correlation with the same phenomenon at the follow-up. Instead, the most important correlate of persisting neglect among the variables from the scanning test was the proportion of omitted targets. The asymmetric distribution of these omissions was, however, markedly reduced. Accordingly, in this type of search task, most of the patients with neglect managed to compensate for the asymmetry in the inattentive behavior at the follow-up, whereas their visual inattention persisted.

Robertson (1993) suggested that a nonlateralized attentional decline is an important component behind the inattentive performance in space that characterizes the neglect phenomenon. The present results lend support to the above suggestion by indicating that a nonlateralized visual inattention may play an important role in the ineffective visual search that patients with persisting neglect show. Also, if the increased simple reaction time is interpreted as reduced alertness, then the finding that the increased reaction time showed a strong relationship with persisting neglect seems to be in line with the above notion.

As a conclusion, the data obtained in the acute and chronic stage makes it conceivable that at a late stage post stroke, nonlateralized attentional deficits may play a central role in the ineffective visual search, while at an early stage post stroke, lateralized impairments of the orientation of visual attention may represent a more important component.

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