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Assessment of neglect reveals dissociable behavioral but not neuroanatomical subtypes

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Abstract

In the current study, we investigated whether standard assessment techniques of visuospatial neglect are sensitive to detecting dissociable subtypes. We administered a battery of tasks commonly used to detect the presence of visuospatial neglect to 120 patients with unilateral right hemisphere infarcts and, in most cases, performed a systematic analysis of their lesions to quantify and localize brain damage. Using a factor analysis, we discovered seven relatively independent constructs, three of which were specifically related to the presence of left hemispatial neglect: *Left Attentional Processing, Line Bisection,* and *Word Reading.* Impairments in two of these factors, *Left Attentional Processing* and *Line Bisection,* occurred together in most cases but also occurred independently in 38 cases. There were no cases in whom *Word Reading* was present without concomitant deficits in one or the other two factors. These three factors could not be distinguished neuroanatomically; that is, lesions were equally likely in the temporal/parietal cortex, dorsolateral frontal cortex, or in deep frontal structures. These data confirm the notion that hemispatial neglect is a complex and multifaceted disorder composed of cognitively independent processes. These processes, however, cannot be dissociated neuroanatomically based on currently available assessment techniques. (*JINS*, 1996, *2*, 441–451.)

Keywords: Hemispatial Neglect, Visual search, Line bisection, Neglect dyslexia, Behavioral dissociation

INTRODUCTION

Unilateral visuospatial neglect is an acquired disorder that dramatically affects an individual's ability to acknowledge and/or respond to stimulation on the side of the body contralateral to a brain lesion. It is generally accepted that this disorder can take on a number of different forms that can occur in relative isolation from one another. For instance, dissociations have been reported depending on the modality of information processing (DeRenzi et al., 1989), the space in which information is processed (near *vs.* far) (Halligan & Marshall, 1991), and the perceptual (attentional) *versus* motoric (intentional) requirements of a task (Daffner et al., 1990; Tegner & Levander, 1991; Watson et al., 1978). However, whether further dissociations exist within the more restricted domain of visuospatial processing in near space is still being debated.

Halligan et al. (1989) administered the Behavioral Inattention Test (BIT) (Wilson et al., 1987) to 80 unilateral stroke patients. They reported that the six subtests of the BIT were highly intercorrelated and that a single factor could account for almost 73% of the variance. Accordingly, they concluded that "visuospatial neglect is, to a large extent, a single phenomenon." Based on a series of single case studies, however, Marshall and Halligan have more recently argued against this position. In one report (1992) they described a double dissociation between line bisection and cancellation performance in two patients (H.D. and W.S.), both of whom had temporo-parietal lesions. In a subsequent report (Marshall &

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Halligan, 1995), they described a patient who had a thalamic and right internal capsule infarct (J.B.) who was impaired on the line bisection task but not the cancellation task. Based on these dissociations, they concluded that visuospatial neglect is "not an impairment of any known discrete, encapsulated psychological processes" but rather "a crude description of the behaviors that stand in need of explication."

Evidence regarding what mechanisms may be dissociated in visuospatial neglect was provided by Kinsella et al. (1993). They administered a battery of six tests to 40 unilateral right hemisphere stroke patients: three tests that assessed visual scanning and three that assessed the internal representation of space. Two factors were revealed in a Principal Components Analysis that accounted for approximately 82% of the total variance explained. The first factor loaded most heavily with tasks chosen to assess the scanning of stimuli in space (cancellation tasks, line bisection) and the second factor loaded most heavily with the internal representation measures (tactile maze, spontaneous drawings, landscape scenery).

In another study, Binder et al. (1992) administered a letter cancellation task and a line bisection task to 34 right hemisphere stroke patients. Not only did they report that the two tasks were not correlated with one another, but they also found that the tasks were dissociated in some individuals, as earlier reported by Halligan and Marshall (Halligan & Marshall, 1992, 1995). Specifically, 10 of their patients who were impaired on the cancellation task performed normally in the bisection task, and 11 patients who were impaired on the bisection task performed normally on the cancellation task. Examination of the lesion data further revealed that the patients who were impaired only on the cancellation task tended to have frontal or deep lesions, whereas those who were impaired only on the line bisection task had posterior lesions. Binder et al. (1992) concluded that "separable components of neglect may be associated with damage to discrete areas of the nondominant hemisphere."

A number of case reports have indicated that word reading may also be a dissociable aspect of visuospatial neglect. When reading, some patients fail to read the left side of a word or sentence, often making substitutions to form alternative words or sentences of approximately equal length as those presented (Behrmann et al., 1990; Ellis et al., 1987; Kinsbourne & Warrington, 1962; Patterson & Wilson, 1990; Riddoch et al., 1990; Tegner & Levander, 1993). Although in most cases neglect dyslexia occurs in the context of a more generalized attention deficit, there have been reports of isolated neglect dyslexia (e.g., Baxter & Warrington, 1983; Siéroff et al., 1988). An even more striking dissociation was reported by Costello and Warrington (1987), who described a patient who made letter substitutions on the initial letters of words (indicating a left neglect dyslexia), but made errors on tasks such as line bisection, drawing, and visual search that indicated a right hemispatial neglect. A similar dissociation has also been observed by Katz and Sevush (1989), and Cubelli et al. (1991).

Thus, commonly used tasks in the assessment of visuospatial neglect may tap more than one neuropsychological construct. One disorder may be associated with the scanning of space, a second with the internal representation of space, a third with processes required in the line bisection task, and a fourth with word reading. This conclusion, however, is complicated by the fact that the tasks used have not generally been standardized and have differed in their presentation and in their intended purpose. For example, the cancellation task used by Binder et al. (1992) used letter stimuli, whereas Kinsella (1993) used shapes. Furthermore, the current neuroanatomical evidence supporting the notion of dissociable aspects of visuospatial neglect is contradictory. Binder et al. (1992) found impaired line bisection following posterior damage and impaired visual search following cortical or subcortical frontal damage, whereas Marshall and Halligan (1995) found the opposite pattern.

The primary aim of the current study was to determine whether dissociable patterns of performance can be observed in visuospatial neglect by systematically examining the performance of a relatively large sample of postacute patients who suffered unilateral right hemisphere damage. Their performance was examined with a battery of tasks that samples the five types of measures commonly used to assess hemispatial inattention. These measures include line bisection, four search tasks (letters, symbols, line tracing, and line erasure), three construction tasks (figure copy, hidden figure copy, and figure recall), detection of single and double simultaneous stimulation ("extinction" tasks), and single word reading (noncompound and compound words). Factor analysis was conducted to reveal behavioral constructs underlying these measures. The second aim of this study was to investigate the relationship between performance on these measures and the distribution of brain lesions. For this purpose a careful analysis of the patients' lesions was conducted using MRI or CT scans performed at least 3 weeks postinfarct to determine both the extent and location of the lesion. The relationship between these two factor structures was examined to determine the incidence of behavioral impairment as a function of lesion site and the incidence of lesions in different locations as a function of different patterns of behavioral impairment.

METHOD

Research Participants

The research participants were 120 patients admitted to the Braintree Rehabilitation Hospital over a three-year period who had unilateral right hemisphere damage, which was confirmed by CT or MRI scans (in most cases). Fifty-eight patients were male and 62 were female. Lesions resulted from either stroke ($n = 93$) or hemorrhage ($n = 27$). Most patients were assessed in the acute phase of their injury (median = 16 days), although time postinjury ranged between 6 and 397 days. The patients were given our battery of tests upon admission to the rehabilitation center as part of their more extensive neuropsychological workup.

The mean age of the patients was 65 years (SD = 11.72; range = 21 to 80) and they had a mean of 12 years of education (SD = 2.86; range = 4 to 18). All but seven patients were right-handed. As none of the left-handed patients showed signs of aphasia or right-sided inattention, they were assumed to have a normal pattern of laterality and were therefore included in the database. Based on neurologists' ratings, approximately 43% of the patients had a hemianopia, ranging from a partial field cut (70%) to complete loss (30%). Also, hemiplegia was noted in most cases (81%): 9% face only, 11% face and hand, 11% proximal weakness, 32% predilection pattern, and 18% of the patients suffered complete motor loss. Left-sided hemispatial neglect was specifically noted in 62% of cases for which this measure was specified (n = 91) and ranged in severity from mild (18%), to moderate (16%), to severe (26%).

Seventeen normal control subjects were also evaluated on our battery to determine the range of normal performance. The normal control subjects were recruited from the Harvard Cooperative Program on Aging and were carefully screened to ensure that they were free from neurological disease or damage. The mean age of the control subjects was 72 years (SD = 3.06; range = 66 to 77) and they had a mean of 15 years of education (SD = 2.13; range = 12 to 18). All were right-handed. Data from these individuals were collected solely for normative purposes and are used in the analysis only to classify right hemisphere patients as either "normal" or "impaired" on any one particular subtest based on 95% confidence limits.

Behavioral Assessment

Each subject was tested in a quiet, softly lit room with no interruptions. If the subject became fatigued, testing was terminated and was resumed at a later date. Testing was completed within a one-week period in all cases, which meant that, in some cases, the entire battery was not completed. The reasons for this were in no way related to the capability of the patient, but were due to scheduling conflicts and hospital discharges. The examiner was seated directly across the table from the subject and all test materials were presented to the subject at midline. The measures included several tests.

Line Bisection

Three line lengths were used in the line bisection task (25 cm, 19 cm, and 14 cm) and each was approximately 1 mm in width. The subjects were presented two lines of each length preceded by one demonstration line provided by the examiner. Lines were presented on separate pages and appeared in random order. The subjects were asked to "cut the line in half by placing a small pencil mark through the line as close to the center as possible" (Bisiach et al., 1983; DeRenzi, 1982; Schenkenberg et al., 1980). This task was scored as the amount of deviation from true center with left-sided errors scored as negative deviations and right-sided errors scored as positive deviations.

Scanning and Search Tasks

Line Tracing. The lines in this task were composed of 28 33-mm lines distributed in random orientations across the four quadrants of the page, as in Albert's task (1973). There were seven lines in each quadrant and one horizontally oriented line in the center of the page that was used to illustrate the task. Subjects were asked to trace each line on the page until he or she was satisfied that all of the lines were traced. The task was scored as the number of lines on each half of the page that was not traced.

Line Erasure. The same stimuli comprising the line tracing task were presented on a transparency sheet in water-based, nonpermanent ink. The subjects were asked to erase each line individually with a dampened cotton tipped swab (Mark et al., 1988). This task was scored identically to the Line Tracing task.

Letter Search. The stimuli for this task consisted of an array of 64 letters that appeared on a sheet of paper in uppercase. The individual letters were oriented horizontally on the page but were presented in nonsystematic rows and columns so that they appeared randomly dispersed. There were four target letter A's in each quadrant of the page. The subjects were asked to "make a slash" through all of the letter A's until they were satisfied that all of the A's had been identified. This task was scored as the number of A's in each half of the page that were not identified by the subject.

Symbol Search. The stimuli for this task consisted of an array of 72 nonlinguistic symbols. Similar to the Letter Cancellation task, there were four targets in each quadrant of the page and the individual symbols appeared randomly dispersed about the page. One target symbol appeared in the center, which served both as a model and as a demonstration stimulus. The subjects were asked to make a slash through each target until they were sure they had crossed out all of the targets on the page. Scoring on this task was identical to the Letter Cancellation task.

Visuo-Constructive Tasks

Figure Copy. The subjects were presented a figure of a cross (resembling the symbol of the Red Cross) and instructed to copy it without lifting their pencil off the page. A score of 1 was given if there was evidence of hemi-inattention in the drawing (e.g., the figure was distorted or elements were missing). The left and right side of the figure was scored separately.

Hidden Figure Copy. The subject was instructed to copy the same cross again using a stylus rather than a pencil and with carbon paper placed over a blank sheet of paper. This arrangement does not produce a visible result to the subject, but does produce a drawing on the underside of the blank sheet of paper that was exposed to the carbon paper, thus allowing the drawing to be evaluated later. This task was intended to assess copying performance that is unaffected by the appearance of increasing amounts of visual information by which attention may be captured. This task is scored identically to Figure Copy.

Figure Recall. Approximately 10 min following the administration of the Hidden Figure Copy, the subjects were asked to "draw the figure I asked you to copy just a few minutes ago." If subjects were unable to recall the drawing, the cross was described to them. This task was scored identically to Figure Copy.

Extinction Tasks

Visual. The examiner was seated directly in front of the subject, who was asked to stare directly at the examiner's nose. The examiner's arms were outstretched so that they spanned approximately 20 in. to each side of the subject and his or her hands were clenched so that no digits were visible. On single stimulation trials, the examiner wiggled either the left or right index finger; on double simultaneous trials, the examiner wiggled both index fingers synchronously. The subjects were instructed to respond verbally "left," "right," or "both" to indicate the presence of a target. There was a total of 20 randomly presented trials: 8 single stimulation trials and 12 double simultaneous stimulation trials. The trials were counterbalanced with equal numbers of trials in the upper and lower quadrant of each visual field. One point was scored for each target that was missed as a function of visual field.

Auditory. The examiner stood behind the subject and rubbed his or her fingers together, either in the left, right, or both ears together. There were a total of 16 trials: 8 single stimulation trials (4 left, 4 right) and 8 double simultaneous stimulation trials. Scoring was identical to the visual extinction task.

Word Reading

Subjects were asked to read aloud 12 multisyllabic words that ranged in length from six to eight letters. All of the words were presented on one page, but each appeared on a separate line that was double-spaced and centered. Half of the words were compound (e.g., cowboy) and half were noncompound words of similar length (e.g., machine). The task was scored as the number of errors for each word type.

Anatomical Ratings

In 83 cases, a CT or MRI scan was available, which allowed us to localize and quantify lesions. This analysis was performed by a neurologist who was blind to the patient's behavioral assessment. Table 1 lists the structures and brain regions that were evaluated. A nominal scale based on the extent of damage was used. A specific region or structure was given a score of 1 if damage was observable in less than 25% of its total area; a score of 2 was given if damage was observable in 25–75% of its total area; and a score of 3 was given if damage was seen in more than 75% of its area. While somewhat coarse, this measure provided a reliable quantitative estimate of the extent of brain damage.

Table 1. Neuroanatomical regions and structures evaluated

Cortical regions	Subcortical/deep structures
Lateral frontal	Caudate
Dorsolateral frontal	Thalamus
Medial frontal	Putamen
Orbital frontal	Temporal isthmus
Frontal operculum	Anterior periventricular white matter
Motor cortex	Posterior periventricular white matter
Sensory cortex	
Lateral temporal	
Superior temporal	
Medial temporal	
Angular gyrus	
Superior parietal	
Inferior parietal	
Lateral occipital	
Medial occipital	

RESULTS

Our battery of tasks was first evaluated with regard to its reliability and validity as a tool with which to assess hemispatial neglect in a sample of right hemisphere damaged patients. Internal consistency, as determined by coefficient alpha, was 0.89. The item-total correlation coefficients ranged from .33 to .72 (mean $r = .50$). The reliability index, which is a standardized coefficient of reliability, showed consistent coefficient values from .33 to .74. These reliability data indicate that our battery of tasks was made up of items that each contribute some unique piece of information to the overall assessment of neglect. Criterion validity was estimated with a logistic regression in which the dependent, dichotomous outcome variable was whether or not the neurologist judged the patient to have hemispatial neglect, and the predictor variables were the subscores of the various measures. This analysis indicated that we could correctly classify 84% of those right hemisphere patients that were judged by the neurologist as not demonstrating symptoms of neglect, and 89% of those patients who were judged by the neurologist as having at least a mild hemispatial neglect.

Behavioral Factor Structure

All subscores were normalized and the z-scores were entered into a factor analysis with varimax rotation using a listwise deletion of variables. Some individuals were not

Table 2. Behavioral factors and their factor loadings

Factor 1: Left Attentional Processing	
Left Auditory double simultaneous stimulation	.73267
Left Letter Search	.72050
Left Hidden Copy	.71121
Left Copy	.66159
Left Symbol Search	.65200
Left Visual double simultaneous stimulation	.63744
Left Line Trace	.58003
Factor 2: Line Bisection	
19-cm lines	.94411
25-cm lines	.93167
14-cm lines	.90624
Factor 3: Visual Construction	
Right Figure Recall	.75579
Right Hidden Copy	.74589
Right Figure Copy	.67301
Left Figure Recall	.57996
Factor 4: Word Reading	
Compound Words	.84324
Multisyllabic Words	.83988
(Left Line Erase	.52885)
(Right Symbol Search	.50552)
Factor 5: Right Attentional Processing	
Right Line Erase	.91431
Right Visual double simultaneous stimulation	.55949
Right Letter Search	.49880
Right Line Trace	.48192
Right Visual single stimulation	.45237
Factor 6: Right Auditory Processing	
Right Auditory double simultaneous stimulation	.84895
Right Auditory single stimulation	.83165
Factor 7: Left Unilateral Sensory Processing	
Left Auditory single stimulation	.77490
Left Visual single stimulation	.70368

assessed on some measures (as mentioned above), thus the factor analysis was performed based on the dataset of 99 right hemisphere patients who had received the entire battery. Varimax converged in 11 iterations and extracted 7 factors that accounted for 73% of the total variance explained. Individual subtests that loaded on each factor are presented in Table 2. Factor 1, labeled *Left Attentional Processing*, included subtests that are the benchmark indicators of hemispatial neglect: search tasks, construction tasks, and double simultaneous stimulation. The mean residual loading for Factor 1 was 0.17. Factor 2, *Line Bisection*, comprised the three line lengths that were included in the test battery. Each of these line lengths loaded exceptionally high, suggesting that performance on this task was very distinct from any of the other test measures (mean residual = 0.02).[1] Factor 3, labeled *Visual Construction*, included the subscores on the right side of the three figure tasks as well as the left figure recall (mean residual = 0.13). All of these tasks require visuo-constructive abilities. Two other scores that measure this ability, left figure copy and left hidden figure copy, did not load on this factor. Factor 4, *Word Reading*, suggests that single word reading probably reflects distinct processing components that are not shared by the other subtests (mean residual = 0.11). The other two subscores included in this factor, left line erasure and right symbol search, are not easily interpreted within the context of word reading. However, the magnitude of the difference between factor loadings of these two errant tasks and the word readings tasks suggests that they may tap different underlying constructs that could not be statistically reconciled with any of the other factors. The final three factors represent intact visuospatial and auditory processing. Factor 5, *Right Attentional Processing*, is composed of the right-sided complement of subtests that were primarily subsumed under Factor 1 (mean residual = 0.09). Factor 6, *Right Auditory Processing*, simply suggests that auditory processing should be independent of the other cognitive measures when it is not influenced or hampered by attentional deficiencies (mean residual = 0.06). This is supported by Factor 7, *Left Unilateral Sensory Processing*, where it is clear that contralesional detection of auditory and visual sensory stimuli can be dissociated from attentional dysfunction when such stimuli are presented singularly (mean residual = 0.11).

The fact that the factor analysis extracted three factors that are clearly related to left hemispatial neglect (*Left Attentional Processing*, *Line Bisection*, and *Word Reading*) suggests that these tasks may reflect different underlying cognitive constructs.[2] To further examine the existence of dissociations in individual subjects, we calculated the number of subjects who were impaired on only one of these factors. Impairment on any one factor was defined as impairment on at least one of the tasks loading on that factor. This calculation was based on the full data set of 120 patients, although individual comparisons may be less due to incomplete data. Interestingly, of the 21 patients who were impaired in *Word Reading*, each had a concomitant impairment in at least one of the other two factors (2 were impaired in *Line Bisection*, 4 were impaired in *Left Attentional Processing*, and 15 were impaired in both). This finding suggests that although word reading represented a separate construct in our battery, there were no individual cases of dissociable neglect dyslexia.

A similar analysis was performed to examine dissociations in individual subjects between *Left Attentional Processing* and *Line Bisection*. To this end, Factor 1 was broken out into its component tasks. As shown in Table 3, a large number of patients did show impairment in tasks included

[1] The factor analysis was repeated using the mean performance across the three line lengths of the line bisection task and the identical factor structure was obtained. This suggests that the *Line Bisection* factor was not attributable simply to the high correlation between the three line lengths, but rather the distinct contribution of this task, regardless of length, to the overall test battery.

[2] Note that although there was a separate factor for *Visual Construction*, the left hemispace performance of the patients for both figure copy and hidden figure copy was better accounted for by the *Left Attentional Processing* factor.

Table 3. Number of cases whose performance was either impaired or normal in *Left Attentional Processing* (broken out into subtests) and *Line Bisection* (collapsed across line length) (n = 120). Shaded areas indicate the number of cases in which the two factors were dissociated

	FACTOR 2: Line Bisection	
	Impaired	Normal
FACTOR 1: Attentional Processing		
Impaired		
Letter Search	69	14
Line Erase	18	2
Line Trace	46	9
Symbol Search	62	12
Figure Copy	33	9
Hidden Copy	34	20
Visual double simultaneous stimulation	27	5
Auditory double simultaneous stimulation	58	8
Normal		
Letter Search	29	8
Line Erase	80	20
Line Trace	52	13
Symbol Search	36	10
Figure Copy	65	13
Hidden Copy	64	12
Visual Extinction	71	17
Auditory Extinction	40	14

in both factors. Errors on letter search, line trace, symbol search, and auditory double simultaneous stimulation occurred in approximately half of the cases in conjunction with abnormal line bisection performance. Overall, however, it appears that patients were more likely to display left-sided errors in the line bisection task than in left attentional processing tasks. This raises the possibility that the two tasks may be differentially sensitive to the presence of neglect. This is not likely the case, however, because if line bisection were simply a more sensitive measure of visuospatial neglect, isolated deficits in *Left Attentional Processing* should not occur. Yet, we observed a number of cases with deficits in *Left Attentional Processing* in the absence of deficits in *Line Bisection* (see Table 3). In addition, significant positive correlations should be present between the two types of tasks, but this was not the case. Because the magnitude of the deviation in line bisection performance can be a function of length, the correlations were computed for each line length separately. Impairment on the *Left Attentional Processing* tasks were not correlated with performance on the 14-cm lines (left copy, r = .07; left erase, r = −.09; left hidden, r = .13; left letter search, r = .13; left line trace, r = .16; left figure recall, r = .11). Similarly, impairment on *Left Attentional Processing* tasks were not correlated with performance on the 19-cm lines (left copy, r = .03; left erase, r = −.15; left hidden, r = .15; left letter search, r = .15; left figure recall, r = .18), with the exception of left line tracing (r = .22, $p < .05$). Similar relationships were found for performance correlations with the 25-cm lines, where again only left line tracing was significant (r = .24, $p <$ .05; left copy, r = −.09; left erase, r = −.16; left hidden, r = .16; left letter search, r = .14; left figure recall, r = .15). These data suggest that the line bisection task is not simply more sensitive to neglect severity.

Neuroanatomical Factor Structure

The anatomical ratings for the 83 individuals for whom CT or MRI scans were available were similarly entered into a factor analysis with varimax rotation using a listwise deletion of variables. Varimax converged in six iterations and extracted six factors that accounted for 80% of the overall variance. Specific regions and structures that loaded on each factor are presented in Table 4 and depicted in Figure 1. The six factors correspond to general regions of the brain served by specific blood supply sources. Factor 1, *Lateral Temporal/Parietal*, is comprised of temporal and parietal cortices fed by the central branch of the middle cerebral artery (MCA) (mean residual = 0.12). Factor 2, *Capsular-Striatal*, consists of deep subcortical structures fed by the medial branch of the MCA (mean residual = 0.07). Factor 3, *Dorsolateral Frontal*, comprises frontal areas fed by the frontal branch of the MCA (mean residual = 0.11). Factor 4, *Polar*

Table 4. Factors extracted from neuroanatomical ratings and their factor loadings

Factor 1: Lateral Temporal/Parietal	
Angular gyrus	.88483
Inferior parietal cortex	.86517
Superior temporal cortex	.84183
Superior parietal cortex	.75266
Sensory cortex	.70311
Lateral temporal cortex	.70163
Posterior periventricular white matter	.55250
Factor 2: Capsular-Striatal	
Anterior limb internal capsule	.90645
Putamen	.88364
Caudate	.86485
Anterior periventricular white matter	.69591
Factor 3: Dorsolateral Frontal	
Frontal operculum	.89015
Dorsolateral frontal cortex	.87212
Motor cortex	.67301
Factor 4: Polar Medial Frontal	
Lateral frontal cortex	.96876
Medial frontal cortex	.90712
Orbital frontal cortex	.83144
Factor 5: Medial Temporal/Occipital	
Medial occipital cortex	.88847
Lateral occipital cortex	.80788
Medial temporal cortex	.75900
Factor 6: Thalamus	
Thalamus	.84364

Medial Frontal, comprises medially located areas serviced by the anterior cerebral artery (mean residual = 0.01). Factor 5, *Medial Temporal/Occipital*, is comprised of the posterior regions fed by the posterior cerebral artery (mean residual = 0.001). Lastly, Factor 6, *Thalamus*, is fed by the thalamic artery (mean residual = 0.02). We assume that these factors are a reasonable and consolidated representation of the distribution of lesions in our patients and thus use these data as a means with which to classify patients' brain damage.

Relationship between Behavior and Neuroanatomy

The pattern of behavioral impairment was examined as a function of lesion site (see Table 5). We used the six anatomical regions identified by the factor structure as an organizational tool, but a patient was not included as a case in any one particular area unless the neurologist's rating was a 2 or 3, indicating that the damage to the structure/area was greater than 25%. This excluded ambiguous cases where intact areas could not be distinguished from mildly damaged areas. It is clear from Table 5 that for any given lesion site, the incidence of impairment in *Left Attentional Processing* and *Line Bisection* were nearly identical. In contrast, *Word Reading* deficits were much less common than impairments in the other two factors following damage to the *Temporal/Parietal, Capsular-Striatal,* and *Dorsolateral Frontal* regions. These observations were confirmed in a series of nonparametric tests that indicated that for each of these three brain regions, there was a significant difference across the three behavioral factors (chi-square, p values $<.001$) that was due only to significantly fewer cases of *Word Reading* impairment than *Left Attentional Processing* ($p < .001$) and *Line Bisection* ($p < .001$). Chi-square comparisons were not significant for *Polar Medial* cortex, *Medial Temporal/Occipital* cortex, or *Thalamus* (p values $>.05$). While the number of cases of dissociated impairment in *Left Attentional Processing* and *Line Bisection* did not permit formal statistical analysis, it appears that impairment in either factor alone was equally likely, regardless of lesion site.

A series of logistic regressions were performed using *Left Attentional Processing, Line Bisection*, and *Word Reading* as dichotomous dependent measures and each lesion location as a predictor variable. For example, whether or not there was damage to the *Temporal/Parietal* cortex was used to predict whether or not there was impairment in *Left Attentional Processing*. None of these analyses were found to be significant (p values $>.10$), suggesting that whether or not an individual will be impaired on any particular factor could not be predicted on the basis of lesion location. Of note, this analysis was also not significant even when *Temporal/Parietal, Capsular-Striatal*, and *Dorsolateral Frontal* areas were included together as predictors.

Table 5. Percentage of cases with impairment in *Left Attentional Processing, Line Bisection,* and *Word Reading* as a function of lesion location (lesions >25%). Shaded areas represent cases of behavioral dissociation

Lesion location	Left Attentional Processing	Line Bisection	Word Reading	Left Attentional Processing only	Line Bisection only
Temporal/Parietal Cortex (n = 43)	86	88	23	12	14
Capsular-Striatal (n = 36)	86	86	19	14	14
Dorsolateral Frontal Cortex (n = 23)	87	91	26	9	13
Polar Medial Frontal Cortex (n = 4)	100	75	50	25	0
Medial Temporal/Occipital (n = 13)	85	62	23	38	15
Thalamus (n = 6)	83	67	0	33	17

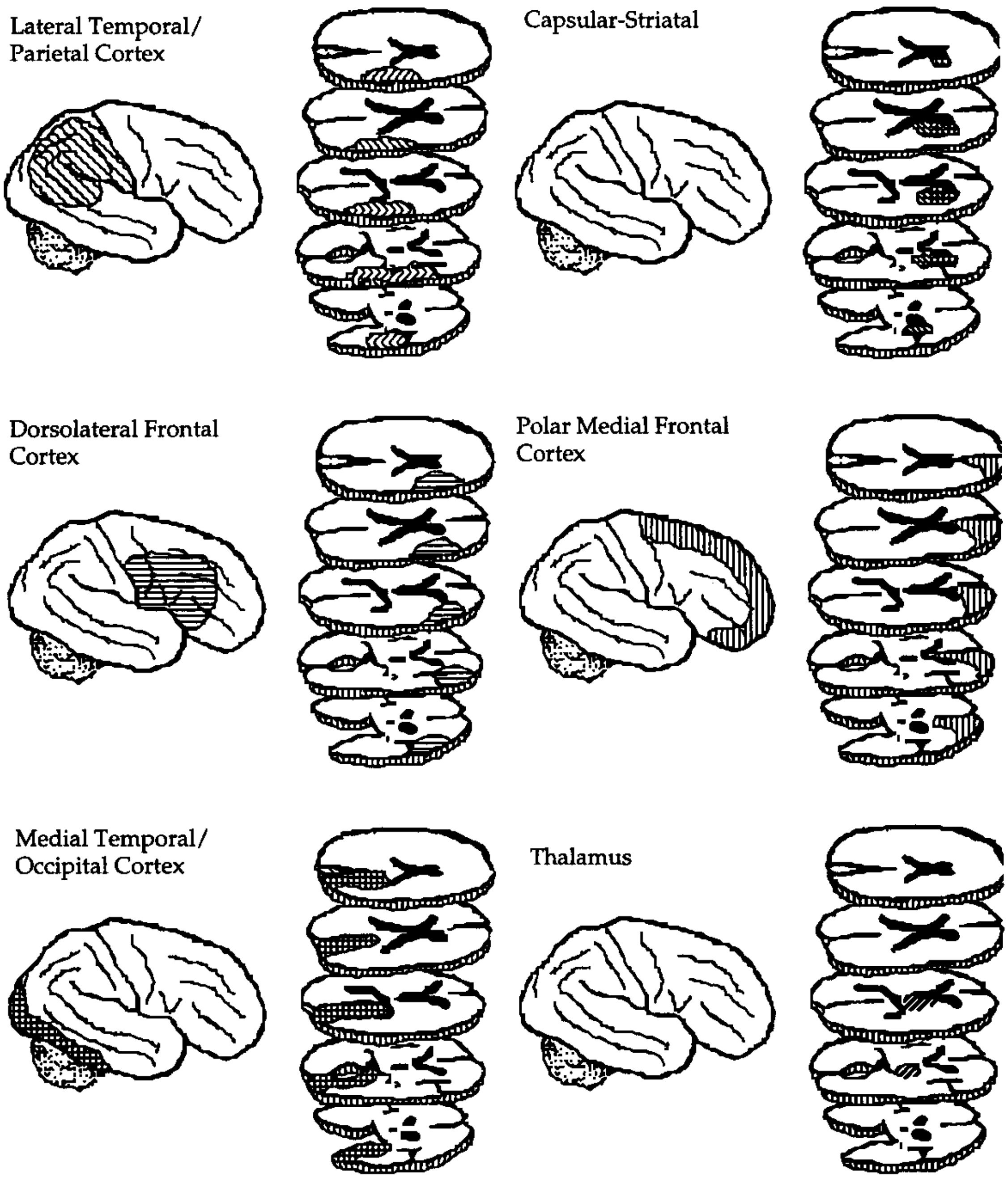

Fig. 1. Right hemisphere templates displaying regions of damage identified by factor analysis.

Next, we classified patients based on their pattern of behavioral impairment and determined the distribution of cases that had damage in the six brain regions. As shown in Table 6, the distribution of lesion localization for each type of behavioral impairment is strikingly similar. In particular, most cases for each type of impairment cluster around *Temporal/Parietal*, *Capsular Striatal*, and, to a lesser extent, the *Dorsolateral Frontal* areas. The remaining three brain regions account for a minority of cases and are distributed similarly for each behavioral factor. An analogous set of nonparametric tests were performed to determine if the frequency of occurrence was different for each behavioral factor separately across the six neuroanatomical factors. A significant difference was found for each of the behavioral factors (chi-square, p values $<.001$). For *Left Attentional Processing*, cases of *Temporal/Parietal* and *Capsular Striatal* damage were more common than *Dorsolateral Frontal* damage ($p < .01$). The latter, in turn, were more

Table 6. Percentage of patients with lesions (>25%) in the six neuroanatomical regions as a function of behavioral impairment. Shaded areas represent cases of behavioral dissociation

Behavioral factor	Temporal/ Parietal Cortex	Capsular-Striatal	Dorsolateral Frontal Cortex	Polar Medial Frontal Cortex	Medial Temporal/ Occipital	Thalamus
Left Attentional Processing (n = 96)	39	32	21	4	11	5
Line Bisection (n = 98)	39	32	21	3	8	4
Word Reading (n = 21)	48	33	29	10	14	0
Left Attentional Processing only (n = 18)	28	28	11	6	28	11
Line Bisection only (n = 13)	46	38	23	0	15	8

common than *Medial Temporal/Occipital* damage ($p < .01$). The pattern of significant differences was identical in cases of impaired performance in *Line Bisection*. Impairment in *Word Reading* was equally likely following damage to *Temporal/Parietal*, *Capsular-Striatal*, and *Dorsolateral Frontal* areas ($p < .05$). Cases of dissociated impairment in *Left Attentional Processing* were associated equally often with damage to *Temporal/Parietal*, *Capsular-Striatal*, and *Medial Temporal/Occipital* areas, and were significantly more frequent than following damage in *Polar Medial Frontal* area ($p < .05$). Lastly, cases of dissociated *Line Bisection* impairment were more frequent following damage to the *Temporal/Parietal* and the *Capsular Striatal* region compared to the *Medial Temporal/Occipital* region ($p < .05$).

A second series of logistic regressions were performed to determine whether or not the region of brain damage could be predicted on the basis of each of the three behavioral factors. For example, *Left Attentional Processing* was coded as the dichotomous dependent variable and each of the six anatomical factors were entered as predictor variables. In each case, the regression was not significant (p values $>.1$).

DISCUSSION

A systematic analysis of a battery of commonly used tests to detect the presence of unilateral visuospatial neglect revealed three underlying cognitive constructs that were specifically associated with processing information in the left hemispace. They were labeled *Left Attentional Processing*, *Line Bisection*, and *Word Reading*. Although impairments in these three factors were commonly associated, *Word Reading* deficits were significantly less common than impairments in the other two factors. One possible explanation for this finding lies in the differential demands these tasks make on local *versus.* global attention. Marshall and Halligan (1994), for instance, have suggested that the left hemisphere may be specialized for focal attention, whereas the right hemisphere is involved primarily in global attention. According to this view, right hemisphere lesions may interfere more with performance on tasks that require attention to be broadly distributed across space (such as visual search and detection of double simultaneous stimulation) than with tasks that require a relatively narrow focus of attention (such as word reading). Alternatively, the attentional requirements in *Word Reading* may be quite different from those in nonverbal tasks, because reading allows for the interaction between perceptual input and preexisting knowledge representations. That is, even partial information about letters in a word may be sufficient to activate lexical and semantic information, which, in turn, may facilitate reading performance (Siéroff, 1990).

While we did uncover evidence suggesting that the mechanisms involved in word reading are independent of those in other tests of visuospatial neglect, it was somewhat surprising that there were no dissociated cases of neglect dyslexia. Each of the 21 cases for whom a reading impairment was observed had additional deficits in *Left Attentional Processing* and/or *Line Bisection*. This finding was unexpected in light of the dissociations reported by Costello and Warrington (1987) and Cubelli et al. (1991) in which left neglect dyslexia was seen in cases of right visuospatial neglect. Note, however, that these cases both had left hemisphere lesions. In our study of right hemisphere patients, neglect dyslexia always occurred in the context of a more general visuospatial neglect. A similar finding was obtained by Black et al. (1990). This raises the possibility that the few reported cases of isolated neglect dyslexia following right hemisphere lesions (e.g., Baxter & Warrington, 1983; Siéroff, 1990) are due to less stringent testing of attentional processing in the visuospatial compared to the verbal domain.

Dissociations between different components of visuospatial neglect, however, were not uncommonly observed. There were 18 cases of impaired performance on *Left Attentional Processing* with normal performance on *Line Bisection*, whereas 20 followed the opposite pattern. These findings replicate those of other investigators who have demonstrated a dissociation between similar measures. However, because our index of *Left Attentional Processing* was composed of several different types of tasks (i.e., search, construction, extinction), our findings extend those of previous investigators by suggesting that understanding this dissociation may have more to do with the nature of *Line Bisection* than in differences between it and exactly which *Left Atten-*

tional Processing task is chosen in any given study. Our findings indicate that search tasks, construction tasks, and the detection of double simultaneous stimuli can *all* dissociate from *Line Bisection*. Accordingly, it is difficult to imagine how concepts such as distributed versus focused attention (Paquet, 1992) and object versus viewer centered representational frames (Chatterjee, 1994) can account for the data, because one would expect that such opponent processes would dissociate tasks within the *Left Attentional Processing* factor (i.e., search *vs.* construction). Rather, it is more likely that the processing involved in the line bisection task is sensitive to psychophysical properties (Chatterjee et al., 1994; Marshall & Halligan, 1989) that are not present in any of the *Left Attentional Processing* tasks. Particularly relevant may be the fact that line bisection requires the computation of a midpoint that is not physically present in the stimulus array (Marshall & Halligan, 1995).

Despite the behavioral dissociations discussed above, we were unable to associate a pattern of performance deficit with damage to any one particular region of the brain. This finding is in opposition to previous reports and suggests that the lack of coherence between Binder et al. (who found impaired line bisection following posterior damage and impaired visual search following cortical or subcortical frontal damage) and Marshall and Halligan (who found the opposite pattern) may be attributable to the wide distribution of lesions that can give rise to equivalent patterns of neglect. Note, however, that individual cases consistent with such dissociative behavioral and neuroanatomical impairment could be drawn from our larger dataset. That is, there were cases of temporal/parietal damage that produced only an impairment in *Left Attentional Processing*, and there were cases of temporal/parietal damage that produced only an impairment in *Line Bisection*.

Just as the precise pattern of performance deficit could not be predicted on the basis of lesion site, neither could lesion site be predicted based solely on the performance deficit, except to say that the damage was likely in *Temporal/Parietal, Capsular Striatal*, or *Dorsolateral Frontal* regions (and, perhaps to a lesser extent, the *Medial Temporal/Occipital* region). This is perhaps not entirely surprising, as many of the *Left Attentional Processing* measures as well as *Line Bisection* had both an attentional and a response-related (intentional) component. It is possible that the pattern of behavioral impairment would have been more directly linked to lesion site had these components been examined in isolation (e.g., Daffner et al., 1990; Tegner et al., 1991; Watson et al., 1978). Nonetheless, the lack of convergence between the behavioral and neuroanatomical factors is important, in that it suggests that the mechanisms that give rise to impaired performance on standard clinical tests of visuospatial neglect are widely distributed in the right hemisphere.

In summary, hemispatial neglect is clearly a complex phenomenon. Even when assessment was restricted to visuospatial processing of near space, three independent processing functions were uncovered. These functions appear to be widely distributed within the right hemisphere, as deficits in any one of these functions could not be linked to lesions in any one particular area. This study, representing the largest sample of patients who have undergone such a systematic evaluation, underscores the need for caution in generalizing from small group and single case studies. To fully gain an understanding of the neuroanatomical underpinnings of this disorder, theoretically derived and experimentally proven assessment techniques are necessary.

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