Reprinted from the Archives of Neurology
January 1987, Volume 44

Relationship Between Lesion Extent in 'Wernicke's Area' on Computed Tomographic Scan and Predicting Recovery of Comprehension in Wernicke's Aphasia

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• This study investigated the relationship between severity of auditory comprehension in Wernicke's aphasia and amount of temporal lobe damage within Wernicke's area (posterior two thirds of superior temporal gyrus region) as well as the total temporoparietal lesion size. There was a highly significant correlation between comprehension and the amount of temporal lobe lesion in Wernicke's area. There was no significant correlation between comprehension and the total temporoparietal lesion size. Patients with damage in only half or less than half of Wernicke's area had good comprehension at six months after the onset of stroke. Patients with damage in more than half of Wernicke's area had poor comprehension even one year after the onset of stroke. Additional anterior-inferior temporal lobe lesion extension into the middle temporal gyrus area was associated with particularly poor recovery.

(*Arch Neurol* 1987;44:73-82)

Accepted for publication Aug 25, 1986.

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Since the time of Wernicke,[1] a lesion in the left superior temporal gyrus region has been associated with impaired auditory language comprehension. This brain/behavior relationship has been confirmed in vivo with the use of radionuclide scans[2,3] and computed tomographic (CT) scans.[4-9] Previously published studies that have focused on lesion localization and subtypes within Wernicke's aphasia have stressed relative preservation of, or recovery within, specific language modalities. Among those cited are the following: preserved reading,[10-12] preserved writing,[13,14] preserved written naming over oral naming,[10,15] and recovered spontaneous speech from excessive paraphasias.[9] The purpose of the present study was to examine the relationship between the severity of the auditory language comprehension deficit in Wernicke's aphasia and the extent of damage in specific auditory pathway areas including the so-called Wernicke's area on CT scan. Total temporoparietal lesion size was also examined.

The term *Wernicke's aphasia* is used in this study as defined by Goodglass and Kaplan[16] and Benson.[17] This includes patients with well-articulated, rapid, fluent, paraphasic verbal output that, despite the use of many words, does not convey the intended ideas. In addition, auditory language comprehension is poor, and there is impairment in sentence repetition, naming, reading, and writing.

PATIENTS AND METHODS

Patients Studied

In this retrospective study, CT scans and language comprehension scores were examined for ten male Wernicke's aphasia patients classified after six months post onset (MPO) as mild (n = 5) or moderate-severe (n = 5). Each patient was right-handed and had suffered single-episode left hemisphere occlusive-vascular stroke between the ages of 47 to 71 years ($\overline{X}$, = 58.4, SD, 6.9), with no significant group differences. The mean, in years, of education was 11.8 (SD 4.5) for the mild group and 15.8 (SD 3.03) for the moderate-severe group ($t = -2.92$, $P < .02$). Hence, although the patients in the moderate-severe group actually had undergone more years of education, their language comprehension deficits remained more severe at one to three years after onset. Each case was clinically evaluated by neurologists and speech pathologists at either the Boston or the Palo Alto (Calif) Veterans Administration medical centers. As is common with cases of Wernicke's aphasia, the neurological examination had revealed only right sensory loss and/or a right visual field defect in some cases, but this was not consistently found in either the mild group or the moderate-severe group. Duration vs intensity of speech therapy was not controlled across all subjects, and one severely ill patient had refused treatment (case 10). The CT scans used for lesion localization were performed between 3 to 36 MPO. All CT scans were performed at 15° to 20° to the canthomeatal line.

The CT scan hemispheric asymmetries were measured and quantified.[18,19] A potential relationship between reversed occipital asymmetry and anomalous dominance has been suggested.[20] In the present study, two cases were observed to have reversed (increased right) occipital asymmetry, one in the mild group (case 5) and one in the moderate-severe group (case 8) (Table 1). This small number did not allow testing of the relationship beween occipital asymmetry and recovery of comprehension in Wernicke's aphasia.

Language Testing

The language comprehension test scores were examined from two time periods. Time 1 (T1) scores were obtained at 1 to 2 MPO. Time 2 (T2) scores were obtained after 6 MPO. Patients could not be differentiated on a case-by-case basis using the early T1 test scores (Table 1). The T1 scores were used, however, as a baseline to examine recovery.

The second test (to determine T2 scores) was administered at 6 to 13 MPO for the mild group and at 12 to 38 MPO for the moderate-severe group ($P < .05$). (The T2 scores for the moderate-severe group were taken as long after onset as possible to extend the potential recovery period.) Patients were differentiated on the basis of T2 scores as follows: (1) mild cases scored above the 50th percentile on the Boston Diagnostic Aphasia Examination (BDAE) auditory comprehension Z-score[16] and above 70% on the Token Test[21]; and (2) moderate-severe cases scored below the 50th percentile on the BDAE auditory comprehension Z-score and below 70% on the Token Test (Table 1). Additional scores for each case, including paraphasia rating in spontaneous speech, repetition, naming, reading, and writing, also are included in Table 1. Statistical comparisons on language data between the two groups at T1 and T2 are presented in Table 2.

CT SCAN ANALYSIS

The CT scans were analyzed with the following two methods: (1) a computer analysis that quantified percent left hemisphere tissue loss, and (2) a visual inspection analysis that quantified extent of lesion in specific neuroanatomical sites.

ANALYSIS OF PERCENT LESION SIZE

The percent lesion size at each language-related CT scan slice (B, B/W, W, SM, and SM+1) (Fig 1) was computed for each case using the Automated Slice Information I program.[22,23] This program provides information on the lesion size at each CT scan slice in terms of *percent* left hemisphere tissue loss. This program does not localize, however, in terms of specific neuroanatomical sites where tissue loss has taken place. The percent lesion size at each CT scan slice and total temporoparietal lesion size in percent for the mild and moderate-severe groups are presented in Table 3.

Statistical Analysis of Lesion Size Between the Two Groups

The percent lesion size at each separate CT scan slice and the total percent lesion size were compared between the two groups using t tests. The moderate-severe group had significantly larger lesion size than the mild group only on CT scan slices B and B/W ($P < .05$) (containing, in part, the temporal lobe). There was no significant difference between the two groups on CT scan slice W (containing, in part, the most posterior, superior portion of temporal lobe) or slices SM or SM+1 (containing, in part, the parietal lobe) (Fig 1). There was no significant difference between the two groups in total percent left temporoparietal lesion size. Hence, results from the lesion *size* analysis indicate a significant difference in lesion size between the two groups only in the temporal lobe portion of the temporoparietal lesion. Analysis of which neuroanatomical structures within the temporal lobe had additional lesion present in moderate-severe cases is presented in the section "Analysis of Extent of Lesion in Specific Lesion Sites" later in this article.

Correlations Between Percent Lesion Size and Language Scores

Pearson's product-moment correlation coefficients were computed between percent lesion size and T2 language comprehension and naming scores. Because multiple correlations were performed, only those cases with a significance level of $P < .01$ are discussed. There was a significant correlation between the lesion size at slice B and Word Discrimination ($r = -.79$, $P < .01$) and Body Part Identification scores ($r = -.83$, $P < .01$). Only four of the ten Wernicke's aphasia cases had this extra anterior-inferior temporal lobe lesion extension present on slice B, and all were moderate-severe cases (cases 6, 8, 9, and 10). There also was a significant correlation between lesion size at slice B/W and Body Part Identification scores ($r = -.79$, $P < .01$). There were no other significant correlations between any of the T2 language comprehension test scores and total percent lesion size or percent lesion size at any of the five separate CT scan slices.

Significant correlations were observed, however, between T2 naming scores and total left temporoparietal lesion size ($r = -.88$, $P < .001$). Thus, results from the correlations between percent lesion size and language behavior indicate that naming performance appears to be associated with total temporoparietal lesion size, whereas comprehension does not.

Table 1.—Token Test, Boston

Age at onset, y
Education, y
Time 1/Time 2 testing, MPO
Token Test (100%)
BDAE
Auditory Comprehension Z-Score (+1)
Word Discrimination (72)
Body Part Identification (20)
Commands (15)
Complex Ideational Material (12)
Paraphasia Rating (7)
Word Repetition (10)
High-Probability Phrase Repetition (8)
Low-Probability Phrase Repetition (8)
Visual Confrontation Naming (105)
Word Reading (30)
Reading Sentences (10)
Narrative Writing (4)
CT scan‡
Wernicke's area (anterior half) extent of lesion—slice B/W
Wernicke's area (posterior half) extent of lesion—slice W
Anterior temporal isthmus—slice B/W
Temporal lobe at slice B (anterior/middle temporal gyrus region)
Total X lesion size, %
Occipital length asymmetry

ANALYSIS OF EXTENT OF LESION IN SPECIFIC LESION SITES

Specific neuroanatomic sites frequently damaged in Wernicke's aphasia cases were visually assessed by two of the authors (M.A.N. and S.A.) for extent of lesion involvement. A 0- to 5-point scale was used where a value of 0 indicated no lesion, a value of 5 indicated total solid lesion, and a value of 3 indicated that half of the area had lesion. (See bottom of Table 1 for complete description of the scale used to visually assess amount of damage in specific neuroanatomical sites.) The lesion extent values for these sites were determined by two of the authors (M.A.N. and S.A.) without prior knowledge of the recovery categories to which the cases belonged. The specific sites that were visually assessed for extent of lesion involvement using the 0-to 5-point scale included the following: Wernicke's

Diagnostic Aphasia Examination (BDAE) and Computed Tomographic (CT) Scan Data for Mild, Moderate, and Severe Wernicke's Aphasia Cases*

Mild Cases†					Moderate Cases†		Severe Cases†		
1	2	3	4	5	6	7	8	9	10
...	2	...	...	3	...	4	...	...	5
63	60	71	64	53	61	56	47	51	58
12	12	12	11	12	18	11	16	12	12
1/13	1/7	1/6	1/7	2/6	1/13	1/12	2/38	1/27	1.5/14
.../76	31/77	84/88	50/76	87/71	68/62	48/67	36/42	52/50	44/35
−0.4/+0.4	−0.8/+0.9	−0.5/+0.8	−1.0/+0.6	0/+0.5	−1.0/−0.3	−0.7/−0.2	−1.5/−0.4	−1.3/−0.4	−1.5/−0.9
51/64	44/69	65/72	37/68	62/70	49/70	47/60	23/48	33/54	34.5/42
14/17	16/19.5	10/19	8/18.5	16.5/18	6/14	6/12	5/8.5	3/8	4/10
8/13	5/14	4/14	3/14	8/9	6/9	7/10	4/10	3/12	3/2
3/7	0/12	6/9	3/8	5/9	0/3	5/4	0/8	6/5	2/2
2.5/...	.../1.5	3/4	2.5/5.5	.../...	3/...	1/3	2/...	1/1	1/2
7/9	1/5	8/9	6/10	9/10	4/7	4/7	8/7	0/3	0/2
0/2	0/0	3/5	0/5	6/4	0/0	0/0	2/1	0/0	0/0
0/0	0/0	2/3	0/2	1/1	0/0	0/0	0/0	0/0	0/0
89/104	.../81	95/105	55/105	102/105	65/97	44/66	65/90	0/36	45/70
30/30	.../...	24/29	7/30	29/30	30/30	5/24	28/30	3/11	8/26
9/9	.../...	6/7	6/8	8/7	7/8	4/8	7/7	6/7	7/8
1/1	.../3	1.5/2	0/3	2/...	1/...	0/...	2/...	0/1	1/1
0	0	1	2	4	3.5	3.5	4	4.5	5
4.5	4.5	2.5	4	2	3.5	4	3.5	5	5
2	3.5	0	1	2	4	3.5	3.5	5	5
0	0	0	0	0	2	0	4.5	4.5	4.5
9.9	11.2	6.7	7.9	3.1	9.5	10.3	10.2	19.7	13.5
Left	Left	Left	Left	Right	Left	Left	Right	Left	Equal

*Two cases (Nos. 1 and 4) were considered atypical Wernicke's aphasia in terms of speech output with lack of press of speech; numbers in parentheses are highest possible score for each item; MPO indicates months past onset.

†Top number in column headings indicates case number; bottom number, the figure in which CT scan (if any) is shown.

‡Extent of lesion-rating scale is as follows: 0 indicates no lesion; 1, equivocal or minimal lesion; 2, small, patchy, or partial lesion; 2.5, patchy, less than half of area has lesion; 3, half of area has lesion; 3.5, patchy, greater than half of area has lesion; 4, greater than half of area has solid lesion, and 5, total area has solid lesion involvement.

area, anterior temporal isthmus, temporal lobe at slice B, auditory contralateral pathways, supramarginal gyrus, and angular gyrus areas. The exact locations of these sites on CT scan are described later in this article. Lesions outside these areas also were considered. Only four patients had small lesions extending into the sensory cortex area or white matter deep to it.

Since the time of Wernicke, there have been multiple interpretations regarding the exact location and limits of the so-called Wernicke's area.[24] For the purposes of this CT scan research study, *Wernicke's area* was defined as the posterior two thirds of the left superior temporal gyrus region. The middle third of the superior temporal gyrus area (anterior half, Wernicke's area) was represented on the CT scan slice at the level of the maximum width of the third ventricle (slice B/W, Fig 1). The posterior third of the superior temporal gyrus area (posterior half, Wernicke's area) was represented on the CT scan slice at the level of the pineal body (slice W, Fig

Table 2.—Statistical Comparisons for Test Scores for Mild Wernicke's Aphasia Group vs Moderate-Severe Wernicke's Aphasia Group at Time 1 and Time 2 Testing*

Test	Mild Group (n = 5) X	Mild Group (n = 5) SD	Moderate-Severe Group (n = 5) X	Moderate-Severe Group (n = 5) SD	*t* Value	*P* Value
Time 1	1-2 MPO		1-2 MPO			
Token Test	63%	27.14	49.6%	11.87	1.00	NS
BDAE *Z*-Score	−0.54	0.38	−1.2	0.35	2.85	<.05
Word Discrimination	51.8	11.82	37.3	10.74	2.03	NS
Body Part Identification	12.9	3.75	4.8	1.30	4.56	<.01
Complex Ideational Material	3.4	2.30	2.6	2.79	0.49	NS
Visual Confrontation Naming	85.25	20.85	43.8	26.55	2.54	<.05
High-Probability Phrase Repetition	1.8	2.68	0.4	0.89	1.10	NS
Time 2	6-13 MPO		12-38 MPO			
Token Test	77.6%	6.27	51.2%	13.37	4.00	<.01
BDAE *Z*-Score	+0.64	0.21	−0.44	0.27	7.09	<.001
Word Discrimination	68.6	2.97	54.8	10.83	2.75	<.05
Body Part Identification	18.4	0.96	10.5	2.50	6.60	<.001
Complex Ideational Material	9	1.87	4.4	2.30	3.47	<.02
Visual Confrontation Naming	100	10.63	71.8	23.90	2.41	<.05
High-Probability Phrase Repetition	+3.2	2.17	0.2	0.45	3.03	<.02

*MPO indicates months post onset; NS, not significant; BDAE, Boston Diagnostic Aphasia Examination.

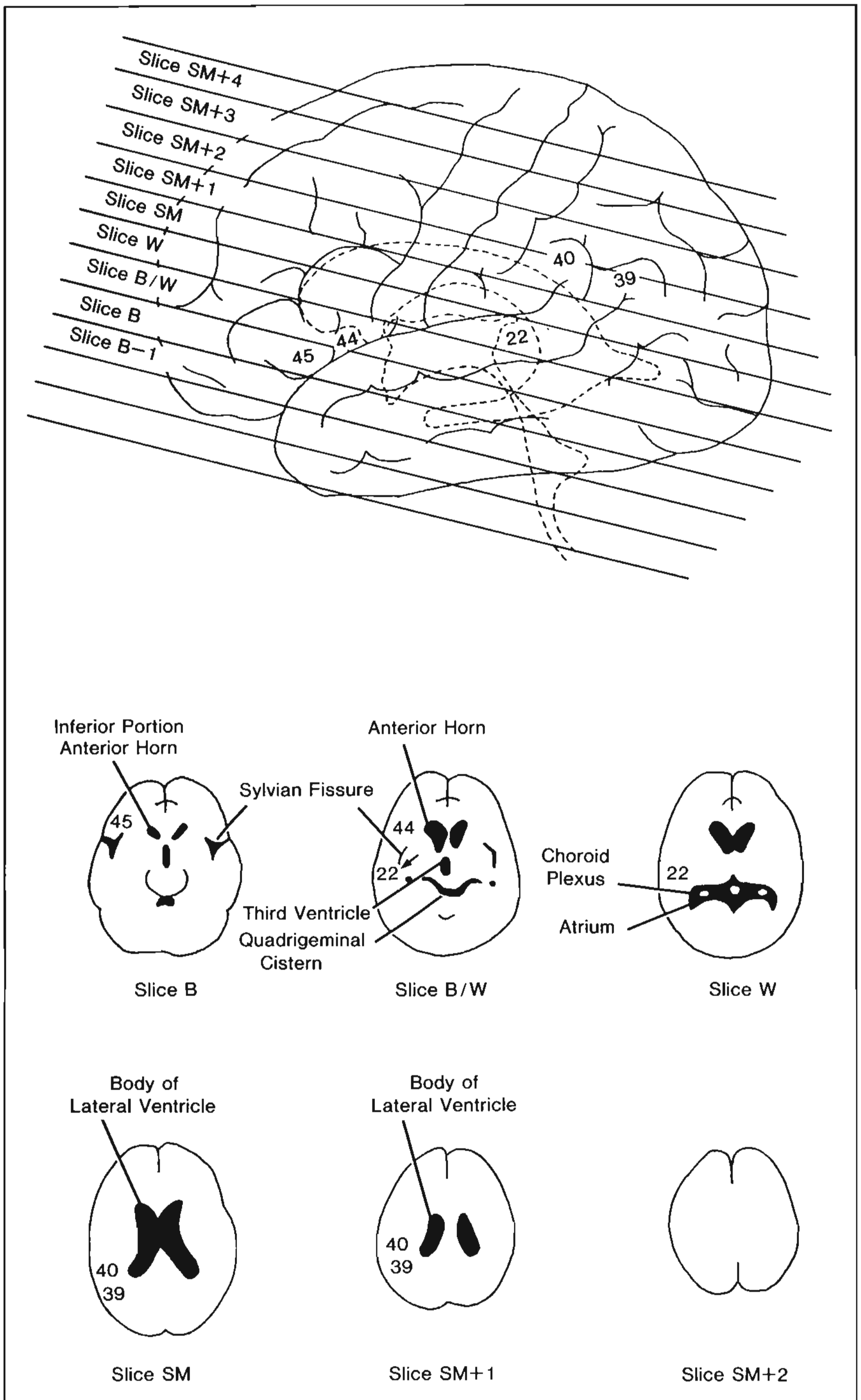


Fig 1.—Relationship of cortical language areas to ventricular system landmarks on lateral view (above) and cross-sectional view (below). "Wernicke's area," which was examined for extent of lesion in this study, is labeled area No. 22 on slice B/W at slice level of maximum width of third ventricle and slice W at slice level of pineal body. Anterior temporal isthmus area is marked with arrow at slice B/W. Numbers refer to Brodmann's areas as follows: 45, pars triangularis (Broca's area); 44, pars opercularis (Broca's area); 22, posterior two thirds, superior temporal gyrus (Wernicke's area); 40, supramarginal gyrus; and 39, angular gyrus.

1). (See areas marked "22" on slices B/W and W, Fig 1[4,25-27].) The primary auditory reception areas were included within "Wernicke's area, No. 22" at slice B/W because it is impossible to determine exactly where areas Nos. 41 and 42 merge into the middle superior temporal gyrus/planum temporale area with current CT scan resolution. The medial border (depth) of Wernicke's area was arbitrarily set as a line that was drawn from the lower portion of the sylvian fissure to the temporal horn on slice B/W and from the lower portion of the sylvian fissure to the lateral-border of the atrium on slice W.

The *anterior temporal isthmus area* containing ascending ipsilateral auditory fibers from the medial geniculate to Heschl's gyrus was defined as the anterior half of the temporal isthmus. The temporal isthmus extended from the inferior portion of the sylvian fissure to the temporal horn.[28-30] (See arrow on slice B/W in Fig 1.) The *temporal lobe at slice B area* was considered that part of the temporal lobe present on slice B (primarily anterior superior temporal gyrus area and some middle temporal gyrus area) (Fig 1). The *auditory contralateral pathways area* containing, in part, auditory fibers from the right temporal lobe that have crossed the corpus callosum was defined as that periventricular area that was lateral to the most posterior portion of the body of the lateral ventricle (slices SM and SM+1) and lateral to the occipital horn and temporal horn (slices W and B/W).[31]

The *supramarginal gyrus area* (area No. 40) was defined as that area lateral to the posterior half of the body of the lateral ventricle, surface and deep (slices SM and SM+1)[4,25-27] (Fig 1). This area also was examined separately as anterior portion, supramarginal gyrus area (parietal operculum) and posterior portion, supramarginal gyrus area. The *angular gyrus area* (area No. 39) was defined as that area immediately posterior to the supramarginal gyrus area (slices SM and SM+1) surface and deep[4,25-27] (Fig 1). The medial border (depth) of the supramarginal and angular gyrus areas was arbitrarily set as half the distance to the lateral border of the body of the lateral ventricle (slices SM and SM+1).

The extent of lesion values for each neuroanatomical area were summed across the CT scan slices where that area was represented as follows: (1) Wernicke's area (slices B/W plus W); (2) anterior temporal isthmus (B/W only); (3) auditory contralateral (B/W, W, and SM+1), etc. In addition, composite lesion extent totals were computed by combining extent of lesion values across several neuroanatomical areas. This included the following composite lesion extent totals: (1) sum of the three auditory areas (AA) mentioned above (AA, 1-3); (2) sum of the three auditory areas mentioned above (AA, 1-3) plus temporal lobe at slice B; (3) combined temporal lobe lesion only (temporal lobe at slice B plus Wernicke's area at slices B/W and W); and (4) Wernicke's area plus supramarginal gyrus area.

Statistical Analysis of Extent of Lesion Within Specific Lesion Sites Between the Two Groups

The visually assessed extent of lesion values within each neuroanatomical area and the combined areas for the two groups were compared using *t* tests (Table 4). Lesion extent values within Wernicke's area were significantly different between the two groups ($P < .01$). Examination of the visually assessed lesion extent values within Wernicke's area on a case-by-case basis showed that every Wernicke's aphasia case in the mild group had damage in only half or less than half of Wernicke's area (slices B/W plus W). These mild cases had lesion extent values in Wernicke's area of 2.5 (patchy but less than half) to 4.5 (almost total solid lesion) only on *either* slice B/W or slice W, but not both slices (Table 1, Figs 2 and 3). Wernicke's aphasia cases in the moderate-severe group had damage in greater than half of Wernicke's area (slices B/W plus W). These moderate-severe cases had lesion extent values in Wernicke's area of 3.5 (patchy and greater than half) to 5 (complete, solid lesion) on *both* slice B/W and slice W (Table 1, Figs 4 and 5).

There also were significant differences ($P < .01$) in amount of damage between the two groups for the other separate auditory areas and combined auditory area totals. The moderate-severe group had greater extent of lesion values in each of these areas and combination areas than did the mild group. Wernicke's area, however, was the only neuroanatomical area examined where there was *no overlap* in lesion extent values between cases in the two groups (Table 1). There was no significant difference between the two groups, however, for combined lesion extent in Wernicke's area plus the supramarginal gyrus area (Table 4).

Correlations Between Extent of Lesion Within Specific Lesion Sites and Language Scores

Pearson's product-moment correlation coefficients were computed between the extent of lesion values for the specific neuroanatomical areas (and combined areas) and T2 test scores (Table 5). Because multiple correlations were performed, only those with a significant level of $P < .01$ are discussed. Highly significant correlations were observed between extent of lesion values within Wernicke's area and the BDAE auditory comprehension *Z*-score ($r = -.91$, $P < .001$), the Token Test ($r = -.90$, $P < .001$), Body Part Identification ($r = -.88$, $P < .001$), and Word Discrimination ($r = -.80$, $P < .01$) (Fig 6). Significant correlations also existed between extent of lesion values in the anterior temporal isthmus and the BDAE auditory comprehension *Z*-score ($r = -.79$, $P < .01$), the Token Test ($r = -.81$, $P < .01$), and Body Part Identification ($r = -.77$, $P < .01$). There were no significant correlations between extent of lesion values in the auditory contralateral pathways area and test scores. The significant correlations between extent of lesion values in the combined auditory areas and language comprehension scores were similar to those significant correlations found between extent of lesion values in Wernicke's area and language comprehension scores (Table 5). Language comprehension scores did not correlate significantly with the extent of lesion values within Wernicke's area plus the supramarginal gyrus area combined (Table 5).

Table 3.—Statistical Comparisons for Automated Slice Information Program Percent Left Hemisphere Tissue Loss (Lesion Size) on CT Scan for Mild Wernicke's Aphasia Group vs Moderate-Severe Wernicke's Aphasia Group*

	Percent Left Hemisphere Tissue Loss					
	Mild Group (n = 5)		Moderate-Severe Group (n = 5)			
CT Scan Slices	X, %	SD	X, %	SD	*t* Value	*P* Value
	Primary Temporal Lobe Lesion					
Slice B	2.6	1.37	8.1	3.82	2.72	<.05
Slice B/W	5.2	1.17	10.9	4.34	2.55	<.05
Slice W	9.0	4.20	14.2	4.95	1.60	NS
	Primary Parietal Lobe Lesion					
Slice SM	11.5	4.78	15.1	4.43	1.1	NS
Slice SM + 1	10.0	5.84	15.0	2.70	1.49	NS
X, all slices	7.8	2.80	12.6	3.79	2.06	NS

*CT indicates computed tomography; NS, not significant.

Table 4.—Statistical Comparisons for Extent of Lesion Within Specific CT Scan Lesion Sites for Mild Wernicke's Aphasia Group vs Moderate-Severe Wernicke's Aphasia Group*

	Extent of Lesion in CT Scan Lesion Sites					
	Mild Group (n = 5)		Moderate-Severe Group (n = 5)			
CT Scan Lesion Site	X	SD	X	SD	*t* Value	*P* Value
Wernicke's area (slice B/W plus slice W)	4.9	0.97	8.3	1.21	4.39	<.01
Anterior temporal isthmus (slice B/W)	1.7	1.17	4.2	0.68	3.70	<.01
Sum of auditory areas (Wernicke's, temporal isthmus, auditory contralateral)	15.1	3.31	24.6	4.16	3.57	<.01
Sum of auditory areas plus temporal lobe lesion at slice B	17	2.77	27.7	5.16	3.65	<.01
Combined temporal lobe lesion only (temporal lobe at slice B plus Wernicke's area at slices B/W and W)	4.9	1.08	11.4	3.07	4.46	<.01
Wernicke's area plus supramarginal gyrus area	17.5	6.44	24.1	1.52	2.23	NS

*CT indicates computed tomography; NS, not significant.

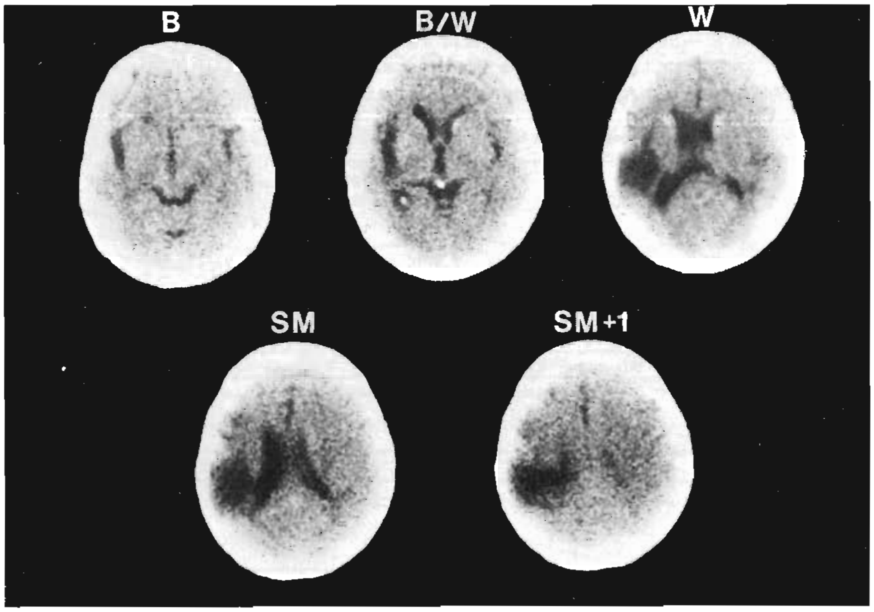
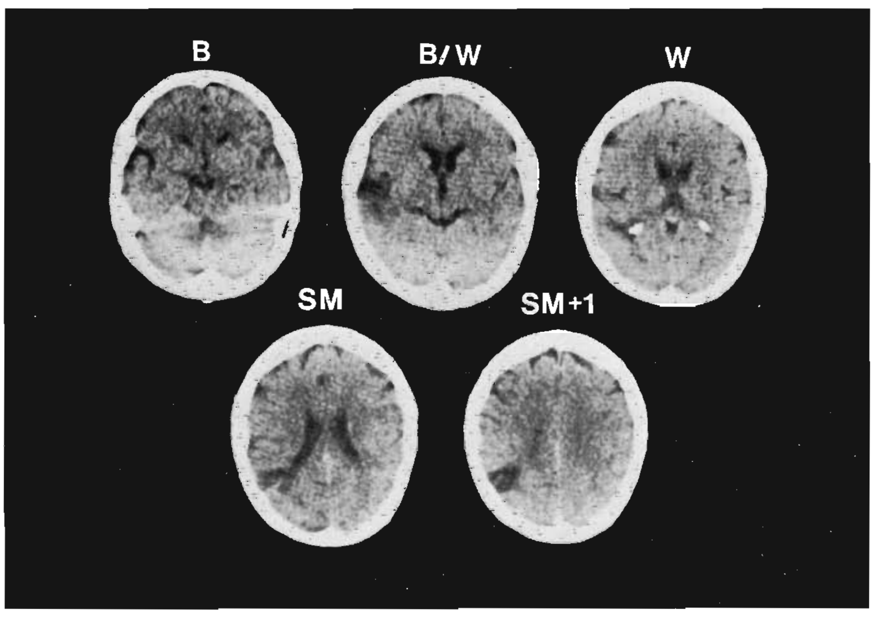


Fig 2.—Computed tomographic scan performed 24 months after onset in this mild case (No. 2) showed large lesion (extent value, 4.5) in posterior half of Wernicke's area only (slice W). There was additional superior lesion extension into both anterior and posterior supramarginal gyrus areas, surface and deep. Patchy lesion was present in auditory contralateral pathways area (slices W, SM, and SM + 1).

Fig 3.—Computed tomographic scan performed 36 months after onset in this mild case (No. 5) showed large lesion (extent value, 4) only in anterior half of Wernicke's area (slice B/W), and small lesion (extent value, 2) in posterior half (slice W). Large lesion (extent value, 5) was also present in posterior supramarginal gyrus area, surface and deep (slices SM and SM + 1). There was equivocal lesion (extent value, 1) in angular gyrus (slice SM + 1).



The highest correlation ($r = -.96$, $P < .001$) occurred between the Token Test and combined lesion extent values within the temporal lobe only (temporal lobe lesion at slice B plus Wernicke's area lesion at slices B/W and W). As was mentioned above in the percent lesion size analysis, none of the mild cases had temporal lobe lesion at slice B, but four of five of the moderate-severe cases had additional anterior-inferior temporal lobe lesion extension at this slice.

There was no significant correlation between extent of lesion values within the angular gyrus area alone, and Visual Confrontation Naming. The total percent temporoparietal lesion size, however, did correlate significantly with naming, as mentioned earlier in this article.

Additional Pearson's product-moment correlation coefficients were determined with High-Probability Phrase Repetition data at T2. There was no significant correlation between High-Probability Phrase Repetition and lesion extent values within Wernicke's area alone or total percent lesion size. There was, however, a significant correlation between High-Probability Phrase Repetition and lesion extent values within the following: (1) the anterior portion of the supramarginal gyrus area ($r = -.78$, $P < .01$) and (2) Wernicke's area plus the anterior portion of the supramarginal gyrus area ($r = -.93$, $P < .001$). There was no correlation, however, between the BDAE auditory comprehension *Z*-score, Token Test, or Visual Confrontation Naming and lesion extent within (1) the anterior portion of the supramarginal gyrus area or (2) Wernicke's area plus the anterior supramarginal gyrus area.

Recovery

To investigate the relative amount of change for the mild cases and the moderate-severe cases over time, the differences between the T1 and T2 scores on available subtests were computed for each case in each group (Table 6). There were no significant differences in the *amount* of recovery between the T1 and T2 scores for the two groups on any of the language measures examined, including auditory comprehension, naming, repetition, and reading sentences. The cases in the mild group and the cases in the moderate-severe group improved by remarkably similar amounts between the T1 and T2 testing times on single-word-level tasks—ie, Word Discrimination (approximately 17 points), Body Part Identification (approximately 5 points), and Single-Word Repetition (approximately 2 points). The moderate-severe group actually improved more in Visual Confrontation Naming (27 points) than the mild group (19.5 points), although the difference was not significant. The mild group started at a higher level, of course, and two cases reached the maximum score (105 points) with improvement of only 3 and 10 points, respectively.

The moderate-severe group showed the least recovery on the sentence-level language tasks—ie, BDAE Complex Ideational Material (scores of 1.8 vs 5.6 for the mild group) and the Token Test (scores of 2.5 vs 15 for the mild group). Because of large variations in scores, however, these differences were not significant. Thus, it appears most of the improvement for the cases in the moderate-severe group was at the single-word level rather than at the sentence level.

The T2 data for the moderate-severe cases were obtained at dates longer post onset (12 to 38 MPO) than those for the mild cases (6 to 13 MPO). Complete data were not available for moderate-severe cases for the same time period as for the mild cases (6 to 13 MPO). Data were available, however, at 3 to 9 MPO for the moderate-severe cases. Interestingly, the BDAE auditory comprehension *Z*-score profile at 3 to 9 MPO for these moderate-severe cases were remarkably similar to what they were at 13 to 38 MPO, as follows: patient 6 scored −0.3 at 3 MPO and −0.3 at 13 MPO; patient 7 scored −0.4 at 4 MPO and −0.2 at 12 MPO; patient 8 scored −0.5 at 5 MPO and −0.4 at 38 MPO; patient 9 scored −0.4 at 9 MPO and −0.4 at 27 MPO; patient 10 scored −0.7 at 7 MPO and −0.9 at 14 MPO. Thus, there was stability in the moderate-severe group between the BDAE *Z*-scores observed here at 3 to 9 MPO and at 12 to 38 MPO, with most of the recovery taking place between the T1 period (1 to 2 MPO) and the 3 to 9 MPO period.

COMMENT

Percent Lesion Size

Previous studies that have examined the relationship between percent left hemisphere total lesion size and auditory language comprehension have examined this correlation in patients with multiple aphasia types (including Wernicke's aphasics) as one group.[6,23,32-34] These studies have generally concluded that total lesion size (except when either very large or very small) cannot be used as a reliable predictor for recovery of comprehension.

Only Mazzocchi and Vignolo[8] isolated the Wernicke's aphasia group for separate analysis. Their findings suggested that there may be a relationship between total lesion size and severity of Wernicke's aphasia. It is difficult, however, to compare the results of their study with the results presented here because they examined five cases less than 2 MPO and five different cases greater than 2 MPO, whereas we followed the same ten cases at progressive time intervals.

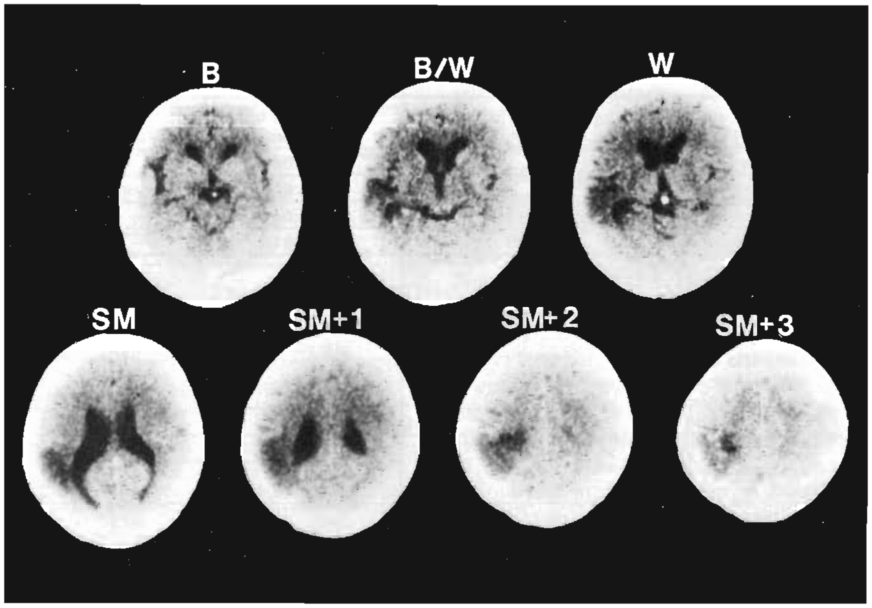


Fig 4.—Computed tomographic scan performed 24 months after onset in this moderate case (No. 7) showed large lesion in Wernicke's area at slices B/W (extent value, 3.5) and W (extent value, 4). There was large superior lesion extension into anterior and posterior supramarginal gyrus areas, surface and deep. Some lesion was also present in auditory contralateral pathways area (slices B/W, W, SM, and SM + 1). There was some patchy lesion in angular gyrus at slice SM + 1, with superior extension into parietal lobe at slices SM + 2 and SM + 3.

Fig 5.—Computed tomographic scan performed seven months after onset in this severe case (No. 10) showed large total lesion in Wernicke's area (extent value, 5) at both slices B/W and W. Large temporal lobe lesion was also present on slice B (extent value, 4.5), anterior and inferior to Wernicke's area. Large lesion (extent value, 5) was also present in anterior temporal isthmus at slice B/W (arrow). There was large superior lesion extension into anterior and posterior supramarginal gyrus areas, surface and deep (extent values, 4 to 5). There was large lesion (extent values, 3.5 to 5) in auditory contralateral pathways area (slices B/W, W, and SM). There was some lesion in angular gyrus at slices SM and SM + 1.

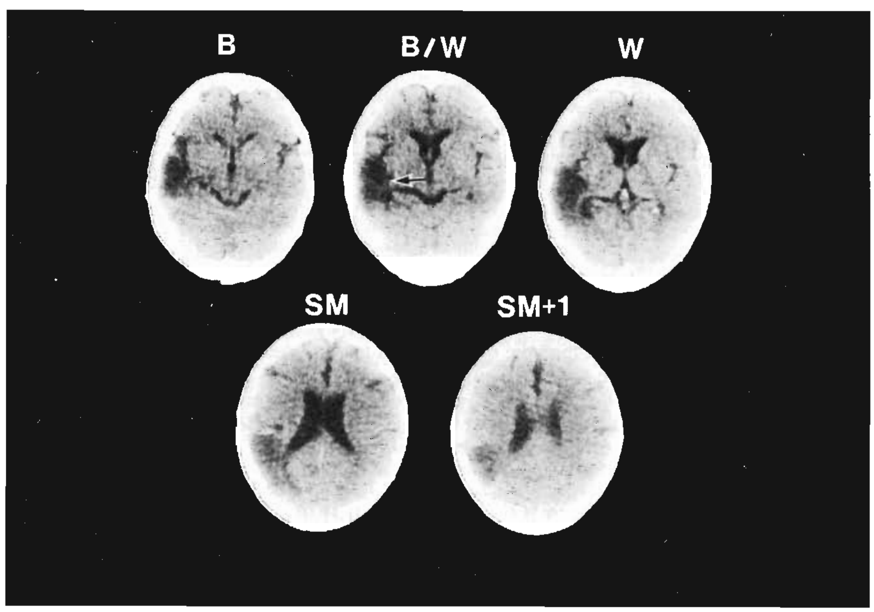


Table 5.—Correlations Between Extent of Lesion Within Specific CT Scan Lesion Sites and Total Lesion Size vs Language Comprehension Test Scores and Naming at Time 2*

CT Scan Lesion Sites	Token Test, *r*	BDAE *Z* Score, *r*	Word Discrimination, *r*	Body Part Identification, *r*	Complex Ideational Material, *r*	Visual Confrontation Naming, *r*
Wernicke's area	−.90†	−.91†	−.80‡	−.88†	−.75§	−.73§
Anterior temporal isthmus	−.81‡	−.79‡	−.67†	−.77‡	−.60, NS	−.77‡
Auditory contralateral	−.57, NS	−.55, NS	−.64†	−.62, NS	−.44, NS	−.51, NS
Sum of auditory areas	−.53, NS	−.82‡	−.81‡	−.85‡	−.67§	−.73§
Sum of auditory areas plus temporal lobe lesion at slice B	−.50, NS	−.87†	−.91§	−.90†	−.80‡	−.87‡
Combined temporal lobe lesion only (temporal lobe at slice B plus Wernicke's area at slices B/W and W)	−.96†	−.92†	−.86‡	−.93†	−.66§	−.69§
Wernicke's area plus supramarginal gyrus area	−.55, NS	−.55, NS	−.49, NS	−.62, NS	−.34, NS	−.59, NS
Total lesion size from computer program (mean percent left hemisphere tissue loss across all slices)	−.57, NS	−.56, NS	−.60, NS	−.69§	−.42, NS	−.88†

*CT indicates computed tomography; NS, not significant; BDAE, Boston Diagnostic Aphasia Examination.
†$P < .001$.
‡$P < .01$.
§$P < .05$.

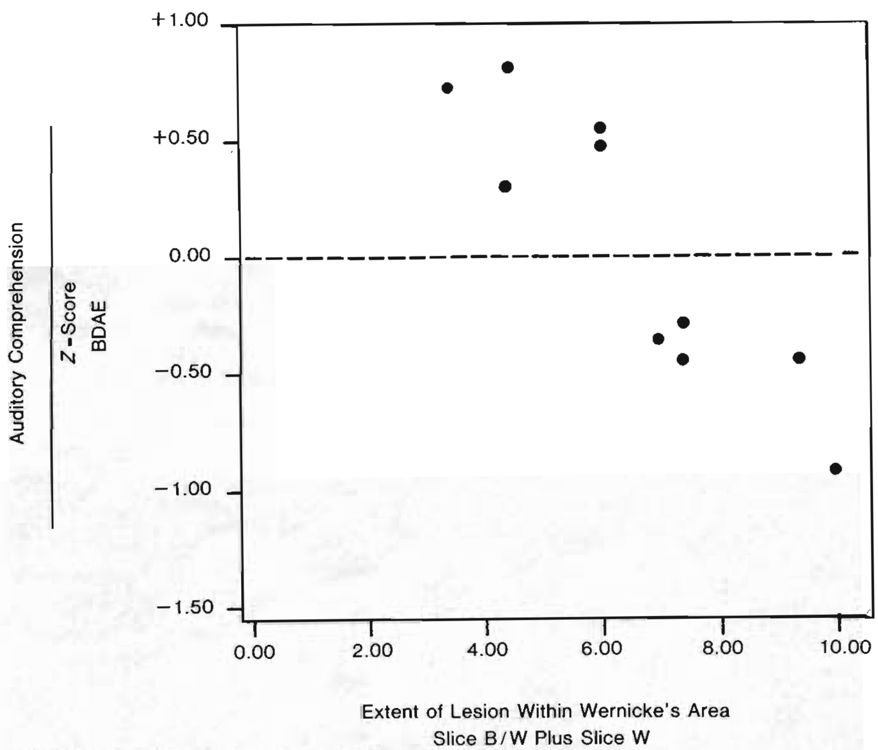


Fig 6.—Relationship between extent of lesion in Wernicke's area and recovery of auditory language comprehension in Boston Diagnostic Aphasia Examination (BDAE). Lesion extent values reported here represent the sum of two values for two slices where Wernicke's area is represented (slice B/W, slice level at third ventricle, plus slice W, slice level at pineal body). Total lesion extent value of 6, when divided by 2, reflects a mean lesion extent value of 3, ie, lesion in half of Wernicke's area (see legend to Table 1). All mild cases (above dotted line) had total lesion extent values of 6 and mean lesion extent values of 3 or less (lesion in half or less than half of Wernicke's area). Total lesion extent value of 10 (summed across two slices), when divided by 2, reflects mean lesion extent value of 5 (total area has solid lesion involvement). All moderate-severe cases (below dotted line) had total lesion extent values that ranged between greater than 6 to 10 and mean values between greater than 3 to 5 (lesion in more than half, to completely solid lesion in Wernicke's area). Correlation between extent of lesion in Wernicke's area (posterior two thirds, superior temporal gyrus area) and comprehension scores after six months post onset was $r = -.91$ ($P < .001$).

The results from the present study with only Wernicke's aphasics suggest that total percent temporoparietal lesion size does not appear to be a significant factor in recovery of comprehension in Wernicke's aphasia. Total percent temporoparietal lesion size, however, was observed to correlate significantly with naming. This latter finding (naming) is in general agreement with Kertesz,[7] who found that the highest degree of correlation between total lesion size and severity of aphasia existed for anomic aphasic patients.

Extent of Lesion in Specific Lesion Sites

This is the first study, to our knowledge, to examine the relationship between extent of lesion within Wernicke's area (posterior two thirds of the superior temporal gyrus region) and severity of the auditory language comprehension deficit in patients with Wernicke's aphasia. The results from this investigation showed that Wernicke's aphasics whose lesion included only half, or less than half, of Wernicke's area had good auditory comprehension at 6 to 13 MPO. Those whose lesion included more than half of Wernicke's area had poor auditory comprehension, even at one to three years after onset. Four of five cases in the moderate-severe group had a lesion that included not only more than half of Wernicke's area, but also had extra anterior-inferior temporal lobe lesion extension into the middle temporal gyrus area at slice B. None of the cases in the mild group had this

Table 6.—Statistical Comparisons for Mean Change (Recovery) Between Time 1 and Time 2 Test Scores for Mild Wernicke's Aphasia Group vs Moderate-Severe Wernicke's Aphasia Group*

	Time 1/Time 2 Change					
	Mild Group (n = 5)		Moderate-Severe Group (n = 5)			
	X	SD	X	SD	*t* Value	*P* Value
Single-Word-Level Tests						
Word Discrimination	16.80	9.56	17.50	6.34	−0.12	NS
Body Part Identification	5.50	3.56	5.70	1.47	−0.10	NS
Visual Confrontation Naming	19.50	18.12	27.00	5.34	0.88	NS
Word Repetition	2.40	1.40	2.00	1.60	0.39	NS
Word Reading	7.25	9.28	11.75	7.08	0.33	NS
Sentence-Level Tests						
Token Test	15.00	23.40	2.50	11.10	1.01	NS
Commands	7.20	3.71	4.00	3.35	1.28	NS
Complex Ideational Material	5.60	3.26	1.80	3.43	1.61	NS
High-Probability Phrase Repetition	1.40	2.33	−0.20	0.40	1.35	NS
Low-Probability Phrase Repetition	0.60	0.80	0.00	0.00	1.50	NS
Reading Sentences	0.50	1.12	1.50	1.50	0.942	NS
BDAE *Z*-Score	1.18	0.46	0.70	0.14	1.98	NS

*NS indicates not significant; BDAE, Boston Diagnostic Aphasia Examination.

extra anterior-inferior lesion extension.

These findings appear, in part, to be in agreement with the suggestions of Marie,[35,36] Marie and Foix,[37] and others[38,39] that the so-called Wernicke's area includes the middle temporal gyrus area as well as the superior temporal gyrus area. Marie[36] suggested further, however, that the supramarginal and angular gyrus areas also were part of Wernicke's area. This was not supported by our findings, which suggest that it is the *temporal* portion, *not* the *parietal* portion, of the temporoparietal lesion in Wernicke's aphasia that contributes most directly to the severity of the auditory language comprehension deficit.

It was not the purpose of the present study to demarcate the exact location and limits of the so-called Wernicke's area. The results seem to indicate, however, that the severity of the auditory language comprehension deficit in Wernicke's aphasia is directly and significantly associated with the extent of lesion within the posterior two thirds of the superior temporal gyrus region. Additional anterior-inferior temporal lobe lesion into the middle temporal gyrus area may also adversely affect auditory comprehension. Additional posterior-superior extension of the lesion into the supramarginal gyrus area of the parietal lobe and the total temporoparietal lesion size, however, appear not to affect the auditory comprehension.

The results showed that in terms of change between T1 and T2 scores there was no significant difference in amount of recovery between the mild and moderate-severe groups. The mean amount of improvement at the single-word level for comprehension repetition and naming was about the same for the mild group as for the moderate-severe group. The mean amount of improvement on the sentence level, however, was much less for the moderate-severe group than the mild group. For example, there was only a mean improvement of 1.8 in BDAE Complex Ideational Material scores for the moderate-severe group and 5.6 for the mild group. Thus, although the amount of change was not significant between the two groups, the mean improvement for sentence-level material was greater for the mild group. It appears that the greatest potential for improvement in moderate-severe cases of Wernicke's aphasia may be primarily at the single-word level. Studies of patients with split-brain syndrome indicate that the right hemisphere is capable of processing language at the single-word level.[40,41] It may be that the recovery observed at the single-word level here, especially in severe Wernicke's aphasia, is mediated to some degree by the right hemisphere.

The mechanisms underlying the auditory language comprehension deficit and recovery in Wernicke's aphasia are poorly understood. One possible explanation for the better comprehension skills of patients with less than half of Wernicke's area damaged is that the remaining half of Wernicke's area may contribute directly to comprehension. Neuroanatomical studies that have examined the cytoarchitectonics of the left temporoparietal region may provide some insight to this notion.[42-45] These studies have shown that the Tpt cells in this area in the human brain are unique in number (usually more on the left) and location (primarily superior temporal plane and parietal operculum).[42,43,45] It may be that when more than half of this Tpt cytoarchitectonic area is damaged, auditory language comprehension is permanently compromised, especially at the sentence level. Whether this relationship will hold for other aphasia syndromes with superior temporal gyrus lesions plus frontal and/or deep subcortical lesions remains to be explored.

This research was supported in part by the Medical Research Service of the Veterans Administration and in part by US Public Health Service grant NS06209.

The authors thank Carole Palumbo for assistance with the computed tomographic scans, Leigh Peake and Hiram Brownell, PhD, for statistical work; Pat Fitzpatrick, MA, Barbara Barresi, MA, and Mike Walsh, MA, for assistance in obtaining aphasia data; and Roger Ray for typing the manuscript.

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Printed and Published in the United States of America