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Late Recovery of Auditory Comprehension in Global Aphasia

Improved Recovery Observed With Subcortical Temporal Isthmus Lesion vs Wernicke's Cortical Area Lesion

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• **This study examined the relationship between recovery of auditory comprehension in global aphasia patients after 1 year post onset, and temporal lobe lesion in Wernicke's cortical area vs temporal lobe lesion in the subcortical temporal isthmus area. Computed tomographic scans and language behavior were examined in 14 right-handed globally aphasic stroke patients with lesion in the left hemisphere. Nine patients had large cortical/subcortical frontal, parietal, and temporal lobe lesion that included more than half of Wernicke's cortical area (FPT cases). Five patients had large cortical/subcortical frontal and parietal lobe lesion, but only subcortical temporal lobe lesion, including the temporal isthmus (FPTi cases). All patients were tested acutely at 1 to 4 months post onset and again at 1 to 2 years post onset. There was a significantly greater increase in the amount of recovery that had taken place after 1 to 2 years post onset for the FPTi group vs the FPT group in the overall Boston Diagnostic Aphasia Examination (BDAE) Auditory Comprehension *Z* score. In four of the five FPTi cases, the late BDAE Auditory Comprehension *Z* scores were above −0.5 (mild-to-moderate comprehension deficits). Most recovery was in single-word comprehension. In eight of the nine FPT cases, the late BDAE Auditory Comprehension *Z*-scores were *below* −0.5 (moderate-to-severe comprehension deficits). There was no significant difference between the two groups in recovery of spontaneous speech, repetition, or naming, where severe deficits remained in most cases. Careful examination of the type of temporal lobe lesion (cortical vs subcortical) appears relevant for predicting potential for recovery of some auditory language comprehension (especially single-word comprehension) in some global aphasia patients after 1 year post onset.**

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Long-term aphasia recovery studies have observed that recovery of auditory language comprehension is superior to (and not related to) recovery of speech output.[1-6] Some studies have focused on specific time periods post onset when recovery occurs. Sarno and Levita[7,8] have reported, for example, that a subset of global aphasia patients demonstrated recovery in comprehension *after* the first 6 months following stroke onset. A review on auditory comprehension in aphasia has been published by Riedel.[9]

Recent studies that have focused on computed tomographic (CT) scan lesion sites and language comprehension have observed comprehension deficits to be particularly associated with lesion in either cortical or subcortical temporal lobe structures. This includes Wernicke's cortical area, eg, the posterosuperior temporal gyrus area[6,10-14] and the subcortical temporal isthmus area.[15-17]

The purpose of the present study was to examine the relationship between recovery of auditory language comprehension in global aphasia patients after 1 year post onset and presence of temporal lobe lesion in Wernicke's cortical area vs presence of temporal lobe lesion only in the subcortical temporal isthmus area.

SUBJECTS AND METHODS

Subjects and CT Scan Analysis

In this retrospective study, CT scans and language behavior were examined in 14 right-handed stroke patients (12 men and two women; age, 50 to 66 years) who had unilateral left hemisphere ischemic infarcts. All patients had been tested a minimum of twice with the Boston Diagnostic Aphasia Examination (BDAE).[18] Time 1 (T1) testing ranged from 1 to 4 months post stroke onset (MPO). All patients had been classified as globally aphasic at T1 on the basis of the BDAE. All patients had BDAE Auditory Comprehension *Z* scores at T1 that were below −1.0, ie, severe auditory comprehension deficits. Time 2 (T2) testing was approximately 1 to 2 years post stroke onset.

All patients had CT scans that were obtained after 2 MPO (range, 2 to 110 MPO). The CT scans were performed at either the Boston (Mass) Veterans Administration Medical Center, using an Ohio Nuclear Delta 2060 CT scanner, or at the Palo Alto (Calif) Veterans Administration Medical Center, using a Syntex Systems 60 CT scanner. The CT scans were visually assessed for extent of lesion in the cortical and subcortical areas, as shown in Fig 1. This included major frontal, parietal, and temporal lobe areas as well as subcortical structures.

Wernicke's cortical area (including immediately subjacent white matter) was defined as the posterior two thirds of the superior temporal gyrus area.[10,14] This area was assessed for extent of lesion on two CT scan slices, slices B/W and W. The *anterior half* of Wernicke's area was located lateral to the maximum width of the third ventricle on slice B/W. This portion was likely to contain portions of Heschl's gyrus, because it is not possible to separate the primary auditory cortex area from the auditory association cortex area on CT scans. The *posterior half* of Wernicke's area was located anterior and lateral to the atrium portion of the occipital horn on slice W (Fig 1, slices B/W and W).

The *subcortical temporal isthmus area*, containing afferent pathways from the medial geniculate body to Heschl's gyrus, was defined as the white matter that is inferior to the sylvian fissure/insular area and superior to the temporal horn[15,16] (Fig 2). Nielsen[15] has described the following measurements of the small subcortical temporal isthmus white matter area: "It measures from 10 to 15 mm across and is in height nearly equal to that of the thalamus. . . . The artery of supply of the isthmus is the anterior choroidal." In the present study, only the anterior half of the temporal isthmus was evaluated for extent of lesion in auditory pathways; the posterior

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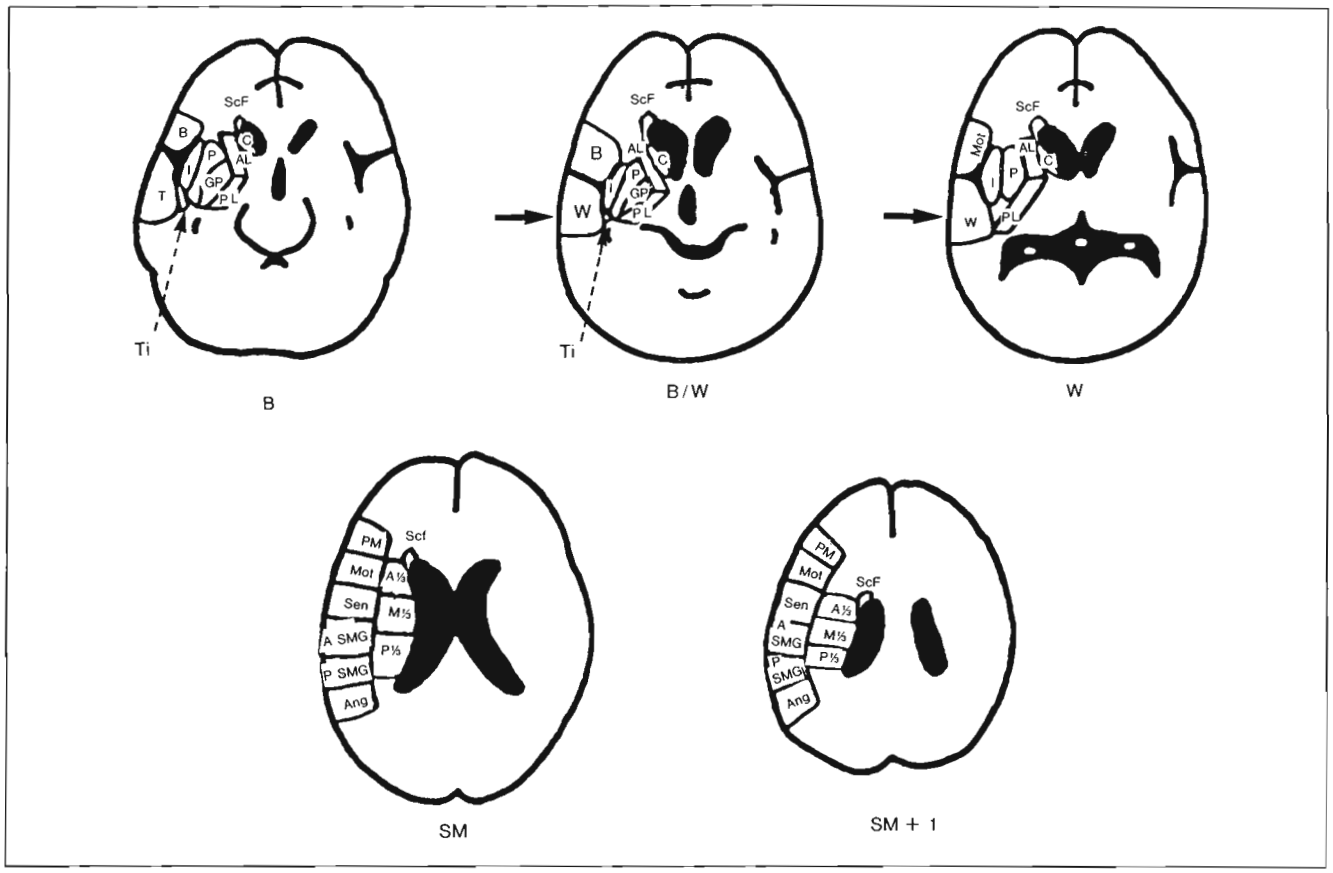


Fig 1.—Location of specific neuroanatomic areas on computed tomographic scan slices B, B/W, W, SM, and SM + 1.[14] B indicates Broca's area (Brodmann's area No. 45 on slice B, No. 44 on slice B/W); T, temporal lobe anterior-inferior to Wernicke's area on slice B; Ti, temporal isthmus; I, insular structures including insula, extreme capsule, claustrum, and external capsule; P, putamen; GP, globus pallidus; AL, anterior limb, internal capsule; PL, posterior limb, internal capsule; ScF, subcallosal fasciculus; C, caudate; W, Wernicke's area (Brodmann's area No. 22); Mot, motor cortex; PM, pre-motor cortex; Sen, sensory cortex; A SMG, anterior supramarginal gyrus; P SMG, posterior supramarginal gyrus; Ang, angular gyrus; A ⅓, anterior one third periventricular white matter; M ⅓, middle one third periventricular white matter; and P ⅓, posterior one third periventricular white matter.

half of the temporal isthmus contains visual pathways. The anterior half was assessed for extent of lesion on two CT scan slices, slices B and B/W.

The extent of lesion within each area was visually assessed using the following scale: 0, no lesion; 1, equivocal lesion; 2, small, patchy, partial lesion; 2.5, patchy lesion in less than half of the area; 3, lesion in half of the area; 3.5, patchy lesion in more than half of the area; 4, solid lesion in more than half of the area; and 5, solid lesion in the total area. A similar scale has been used in our previous studies where a reliability coefficient of .93 was obtained.[19] When a structure was present on more than one CT scan slice, a mean extent of lesion for that structure across slices was computed.

On the basis of the CT scan analysis, the subjects were classified into two groups. Group 1 cases had cortical/subcortical lesion in the frontal, parietal, and temporal lobes including Wernicke's cortical area. Each case in group 1 (n = 9) had lesion in at least half of Wernicke's cortical area (Table 1). Group 1 cases are labeled FPT cases to reflect cortical lesion in the *f*rontal, *p*arietal, and *t*emporal lobes.

Group 2 cases (n = 5) had cortical/subcortical lesion in the frontal and parietal lobes, but only subcortical lesion in the temporal lobe including the subcortical temporal isthmus area. Group 2 cases are labeled FPTi cases to reflect cortical lesion in the frontal and parietal lobes, but only subcortical temporal lobe lesion including the temporal isthmus (Ti). Three of the FPTi cases had small, patchy white matter lesion deep to Wernicke's cortical area. These small white matter lesions were a lateral extension of the white matter lesion within the Ti. None of these cases had lesion that extended into the cortex of Wernicke's area or the immediately subjacent white matter.

Unpaired *t* tests were used to compare the mean extent of lesion between the two groups in the major cortical and subcortical areas. The $P < .01$ level was used as the minimum level for statistical significance. There were no significant differences between the two groups in mean extent of lesion for any of the frontal, parietal, or subcortical areas shown in Fig 1.

There was no overlap between the two groups in mean extent of lesion in Wernicke's cortical area. The FPT group had mean lesion extent values in Wernicke's area that ranged from 3.1 to 5, ie, lesion in greater than half of, to complete solid lesion in, Wernicke's area. The FPTi group had mean lesion extent values in Wernicke's area that ranged from 0 to 2, ie, no lesion, or only small, patchy, partial lesion, in Wernicke's area; none of the FPTi cases had lesion in the cortex of Wernicke's area. All FPT cases had lesion in greater than half of Wernicke's cortical area as well as lesion in greater than half of the Ti (mean range, 3.8 to 5). All FPTi cases had lesion in almost half of the Ti, to almost total solid lesion in the Ti (mean range, 2.75 to 4.95). There was no significant difference between the two groups in mean extent of lesion in the subcortical temporal isthmus area (FPT cases: mean, 4.8; SD = 0.4) (FPTi cases: mean, 4.1; SD = 0.9).

In summary, both groups had similar mean lesion extent values in frontal and parietal and subcortical areas, including the subcortical Ti area. All cases in the FPT group had lesion in more than half of Wernicke's cortical area; none of the cases in the FPTi group had cortical lesion in Wernicke's area.

There was no significant difference in age at stroke onset between the two groups

(FPT group: mean, 58.2 years; SD = 4.2) (FPTi group: mean, 57.8 years; SD = 5.0). Each group had one woman. There were no significant differences between the two groups in terms of MPO when T1 or T2 testing was performed (Table 1).

The CT scan hemispheric asymmetries were measured in each group in order to assess the possible increased potential for recovery of single-word comprehension, repetition, and naming in cases with reversed, right occipital asymmetry.[20] There were only three cases in group 1, and only one case in group 2, with reversed, right occipital asymmetry. Thus, the possible effect of reversed occipital asymmetries could not be studied.

RESULTS

There was a significantly greater increase ($P < .01$) in the amount of recovery that had taken place from T1 to T2 for the FPTi group vs the FPT group in overall BDAE Auditory Comprehension Z score. The mean change from T1 to T2 for the FPTi group was +1.58. The mean change from T1 to T2 for the FPT group was only +0.65 (Table 1). In four of the five FPTi cases, the T2 BDAE Auditory Comprehension Z scores were *above* −0.5. In eight of the nine FPT cases, the T2 BDAE Auditory Comprehension Z scores were *below* −0.5. In only one of the nine FPT cases was the T2 BDAE Auditory Comprehension Z score above −0.5 (Fig 3). Thus, most global aphasia cases with

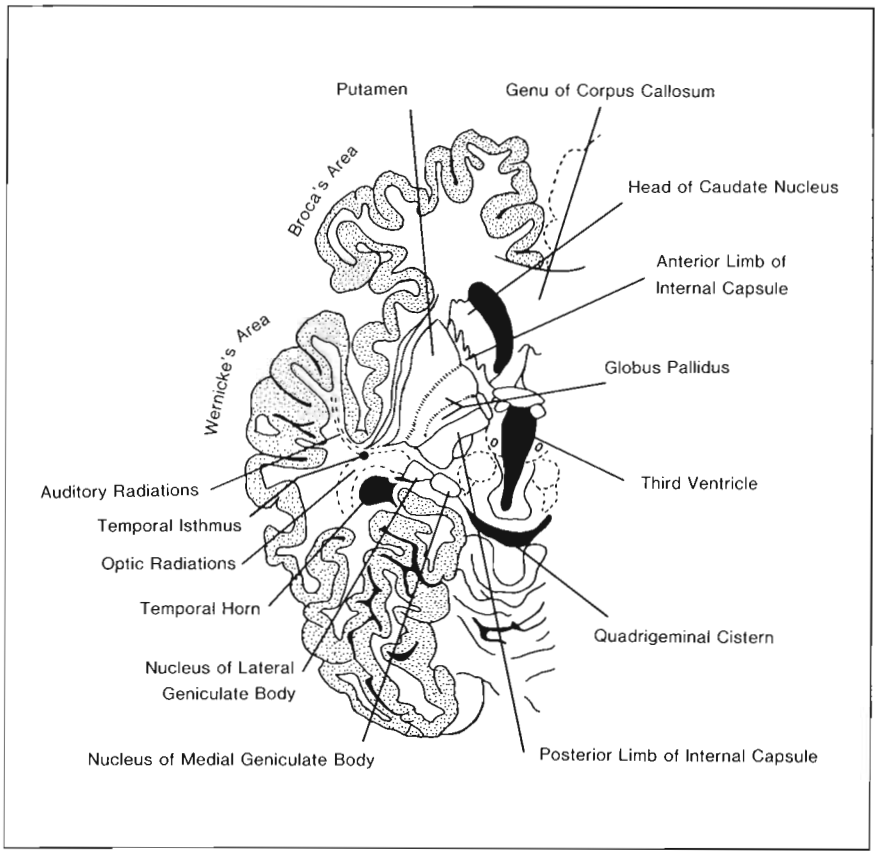


Fig 2.—Schematic drawing of computed tomographic scan slice B/W (left hemisphere) showing location of the auditory radiations within the anterior half of the temporal isthmus (Ti). The Ti is located in the white matter inferior to the sylvian fissure and superior to the temporal horn.

Table 1.—Time 1 (T1) and Time 2 (T2) BDAE Language Scores and t Test Results for Each Group*

Patient No.	Mean Lesion Extent (Wernicke's Area)	Months Post Onset			Auditory Comprehension Z Score			No. Words per Phrase Length (7)			Word Repetition (10)			Naming (105)		
		T1	T2	Change, T2 − T1	T1	T2	Change, T2 − T1	T1	T2	Change, T2 − T1	T1	T2	Change, T2 − T1	T1	T2	Change T2 − T1
Group 1.—Frontal, Parietal, Plus Cortical Wernicke's Area Lesion (FPT Cases)																
1	4.38	1	25	...	−1.6	+0.09	...	0	1	...	0	3	...	0	18	...
2	3.13	2	15	...	−1.7	−0.32	...	1	1	...	0	2	...	0	0	...
3	3.2	3	16	...	−1.7	−0.7	...	0	4	...	8	10	...	0	26	...
4	4.63	2	42	...	−2.1	−0.86	...	0	0	...	0	4	...	0	0	...
5	5	4	15	...	−1.3	−0.9	...	1	1	...	...	...	...	2	4	...
6	4.63	1	27	...	−1.8	−0.98	...	1	3	...	5	7	...	7	17	...
7	5	3	17	...	−2.0	−1.3	...	0	0	...	0	0	...	0	0	...
8	5	4	27	...	−1.6	−1.6	...	1	1	...	6	5	...	0	0	...
9	5	1	13	...	−1.8	−1.8	...	1	1	...	2	4	...	0	15	
Mean	4.4	2.3	21.9	19.6	−1.65	−1.0	+0.65	0.6	1.3	+0.7	2.6	4.4	+1.75	1.0	8.9	+7.9
SD	0.8	1.2	9.3	9.6	0.3	0.6	0.6	0.5	1.3	1.3	3.2	3.1	1.6	2.3	10.1	9.8
(Temporal Isthmus Area)		**Group 2.—Frontal, Parietal, Plus Subcortical Temporal Isthmus Lesion (FPTi Cases)**														
10	4.5	2	26	...	−2.2	+0.20	...	0	1	...	0	8	...	0	27	..
11	2.75	1	14	...	−1.9	−0.24	...	0	0	...	0	0	...	0	0	...
12	4.5	4	19	...	−1.9	−0.28	...	3	2	...	8	9	...	5	33	...
13	4.95	1	12	...	−2.1	−0.44	...	0	2	...	0	6	...	0	14	...
14	3.87	4	100	...	−1.6	−0.89	...	1	1	...	0	5	...	0	4	...
Mean	4.1	2.4	34.2	31.8	−1.91	−0.33	+1.58	0.8	1.2	+0.4	1.6	5.6	+4.0	1	15.6	+14.6
SD	0.9	1.5	37.2	36.2	0.2	0.3	0.6	1.3	0.84	+1.0	3.6	3.5	3.4	2.2	14.3	12.8
Unpaired t Test Levels, Group 1 vs Group 2																
		NS	NS	NS	NS	NS	.01	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Numbers in parentheses indicate maximum possible score. BDAE indicates Boston Diagnostic Aphasia Examination; NS, not significant.

temporal lobe lesion that included at least half of Wernicke's cortical area had poor recovery of auditory comprehension at 1 to 2 years post stroke onset, whereas most global aphasia cases with only subcortical temporal lobe lesion including the temporal isthmus had better recovery of auditory comprehension at 1 to 2 years post stroke onset.

There were no significant differences between the two groups in the amount of recovery that had taken place from T1 to T2 in the number of words per phrase length in spontaneous speech, single-word repetition, or naming. Most subjects in each group remained severely impaired in these three areas at T2 (Table 1).

The overall BDAE Auditory Comprehension *Z* score is made up of the following four subtests: (1) Word Discrimination, which includes single-word comprehension for pictures of objects, actions, letters, colors, forms, and numbers; (2) Body-Part Identification, which includes single-word comprehension for body parts; (3) Commands, which includes comprehension of single- and multiple-stage commands, some with actual objects; and (4) Complex Ideational Material, which tests sentence- and paragraph-level comprehension where there are no visual clues, and the subject must answer questions with a "yes" or a "no" regarding the content.

Table 2 shows that the FPTi cases had a significantly greater ($P < .01$) amount of recovery from T1 to T2 vs the FPT cases at the single-word level of comprehension (Word Discrimination and Body-Part Identification subtests). Patients in the FPTi group actually had significantly higher ($P < .01$) Body-Part Identification raw scores at T2 than did patients in the FPT group (Table 2 and Fig 4). The FPTi group also had a significant increase ($P < .003$) in Commands scores (sentence-level comprehension task) at T2 vs T1; however, this increase was not significantly greater than the increase in Commands scores for the FPT group at T2 vs T1 (Table 2).

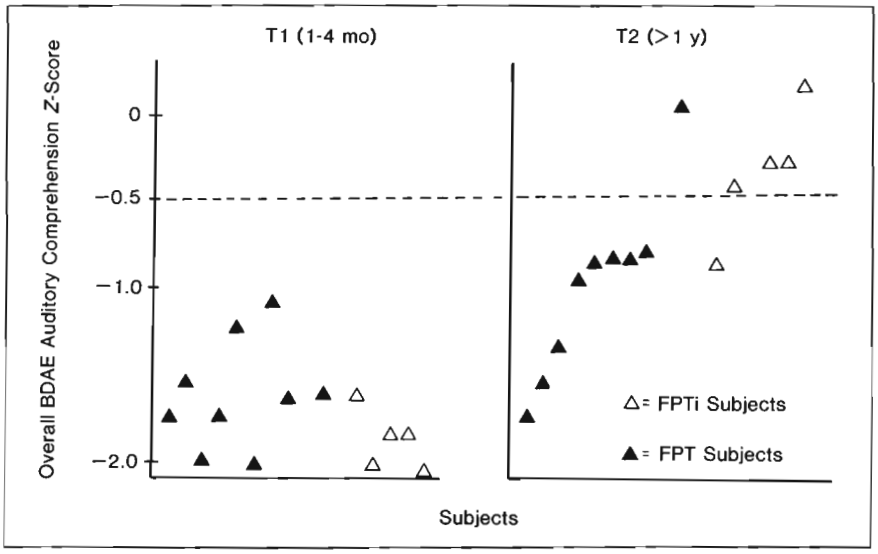


Fig 3.—Graph of overall Boston Diagnostic Aphasia Examination (BDAE) Auditory Comprehension *Z* scores for all cases at time 1 (T1) testing and time 2 (T2) testing. Note that at T1 testing, not one FPT (cortical/subcortical lesion in the *f*rontal, *p*arietal, and *t*emporal lobe including Wernicke's cortical area) or FPTi (cortical/subcortical lesion in the *f*rontal and *p*arietal lobes, but only subcortical temporal lobe lesion including the *t*emporal *i*sthmus) case achieved a *Z* score that was better than −1.0. At T2 testing, four of five FPTi cases achieved *Z* scores better than −0.5. At T2 testing, only one of nine FPT cases achieved a *Z* score better than −0.5.

REPORT OF CASES

Case 9.—FPT Case.—Figure 5 shows the CT scan (8 MPO) and BDAE Auditory Comprehension *Z* scores at 1, 8, 13, 63, and 96 MPO for an FPT case, case 9. This patient had extensive cortical/subcortical lesion in

Table 2.—Time 1 (T1) and Time 2 (T2) BDAE Auditory Comprehension Subtest Scores and *t* Test Results for Each Group*

		Group 1 Only, FPT Cases				Group 2 Only, FPTi Cases				Group 1 vs Group 2 Unpaired *t*-test *P* Values		
Subtest		T1	T2	Changes T2 − T1	Paired *t* Test *P* Values	T1	T2	Change, T2 − T1	Paired *t* Test *P* Values	T1	T2	Change, T2 − T1
Word Discrimination (72)	Mean	23.7	45.0	+21.3	.004	8.7	53.8	+45.1	.002	NS	NS	.02
	SD	13.2	12.3	16.1		7.2	11.7	14.1				
	Min/Max	0/42	23/59.5	−1.5/+45.5		1/20	35/67	+25/+59				
Body Part Identification (20)	Mean	2.4	5.7	+3.3	NS	1.8	14.3	+12.5	.01	NS	.01	.004
	SD	2.6	4.5	3.8		2.6	3.6	6.0				
	Min/Max	0/6.5	0/15	−2/+13		0/6	8.5/18	+2.5/+18				
Commands (15)	Mean	3.1	5.7	+2.6	NS	2	9.2	+7.2	.003	NS	NS	NS
	SD	1.6	2.9	3.8		1.6	2.7	2.6				
	Min/Max	0/5	2/10	−3/+7		0/4	5/12	+4/+11				
Complex Ideational Material (12)	Mean	1.1	2.7	+1.6	NS	0.8	2.4	+1.6	NS	NS	NS	NS
	SD	1.3	2.1	2.2		0.8	2.7	3.2				
	Min/Max	0/4	0/7	−2/+5		0/2	0/7	−1/+7				
Auditory Comprehension *Z* Score (+1.0)	Mean	−1.65	−1.0	+0.65	.01	−1.91	−0.33	+1.58	.004	NS	NS	.01
	SD	0.3	0.6	0.6		0.2	0.3	0.6				

*Numbers in parentheses indicate maximum possible score. FPT refers to patients with cortical/subcortical frontal, parietal, and temporal lobe lesion including Wernicke's cortical area; FPTi refers to patients with cortical/subcortical frontal and parietal lobe lesion, but only subcortical temporal lobe lesion in the temporal isthmus. Max indicates maximum; min, minimum.

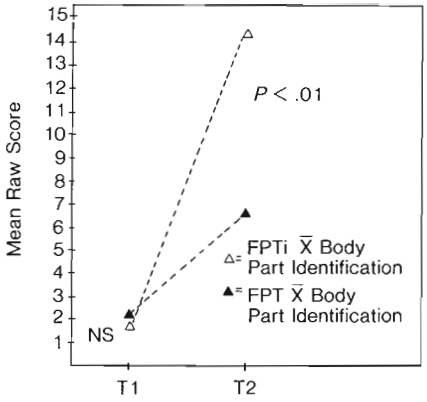
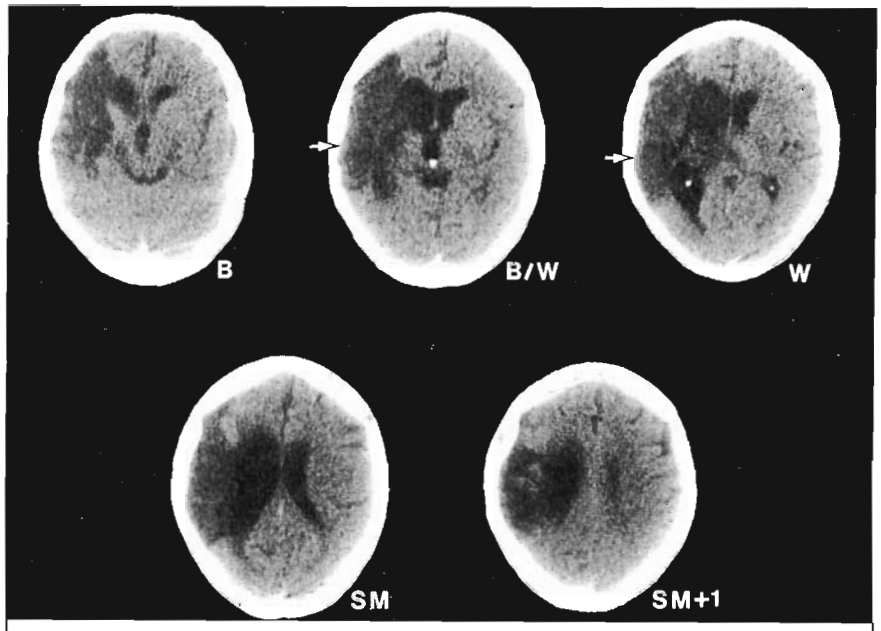


Fig 4.—Graph of mean raw scores on the Body-Part Identification subtest of the Boston Diagnostic Aphasia Examination. At time 1 (T1) testing, there was no significant difference in the scores between the two groups. At time 2 (T2) testing, there was a significant difference in the scores between the two groups ($P < .01$), where the FPTi (cortical/subcortical lesion in the *f*rontal and *p*arietal lobes, but only subcortical temporal *l*obe lesion including the *t*emporal *i*sthmus) group had the greatest amount of recovery. FPT indicates cortical/subcortical lesion in the *f*rontal, *p*arietal, and *t*emporal lobes including Wernicke's cortical area.



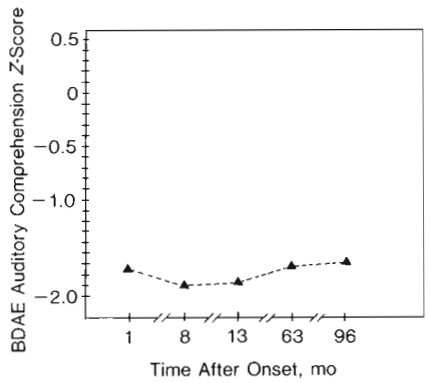


Fig 5.—Top, Computed tomographic scan at 8 months post onset of an FPT case, case 9 (age, 61 years), showing extensive cortical/subcortical lesion in the *f*rontal, *p*arietal, and *t*emporal lobes, including Wernicke's cortical area, compatible with global aphasia. There was complete lesion in Wernicke's cortical area, including the immediately subjacent white matter on slices B/W and W (arrows). Bottom, Graph showing this patient's Boston Diagnostic Aphasia Examination (BDAE) Auditory Comprehension *Z* scores over a period of several months post onset. A severe auditory comprehension deficit was still present at 12 years post onset (*Z* score = −1.7).

the frontal, parietal, and subcortical areas, as well as complete lesion in Wernicke's cortical area; there was poor recovery of auditory comprehension, even at 12 years post onset (−1.7, BDAE *Z* score). There was also poor recovery of spontaneous speech output at 12 years post onset (one-word phrase length). Single-word repetition recovered to 7 and 8 of 10 words at 63 and 96 MPO, respectively. There was poor recovery of naming at 12 years post onset (6/105) (Table 1, case 9).

CASE 11.—**FPTi Case.**—Figure 6 shows the CT scan (33 MPO) and BDAE Auditory Comprehension *Z* scores at 1, 2, 4, 14, 33, and 54 MPO for an FPTi case, case 11. This patient had extensive cortical/subcortical lesion in the frontal, parietal, and subcortical areas, but only a subcortical temporal lobe lesion in the temporal isthmus; there was good recovery of auditory comprehension with scores of −0.24, −0.33, and −0.18 at 14, 33, and 54 MPO, respectively. There was poor recovery of spontaneous speech output, word repetition, and naming; however, with all of these scores remaining at 0, except at 54 MPO, he was able to repeat two words, "what" and "purple." This patient had better recovery of auditory comprehension at 14 MPO than did the FPT patient, above, even at 12 years post stroke. The FPT patient, however, had better recovery of word repetition at 63 MPO. Both cases remained severely aphasic in spontaneous speech output and naming.

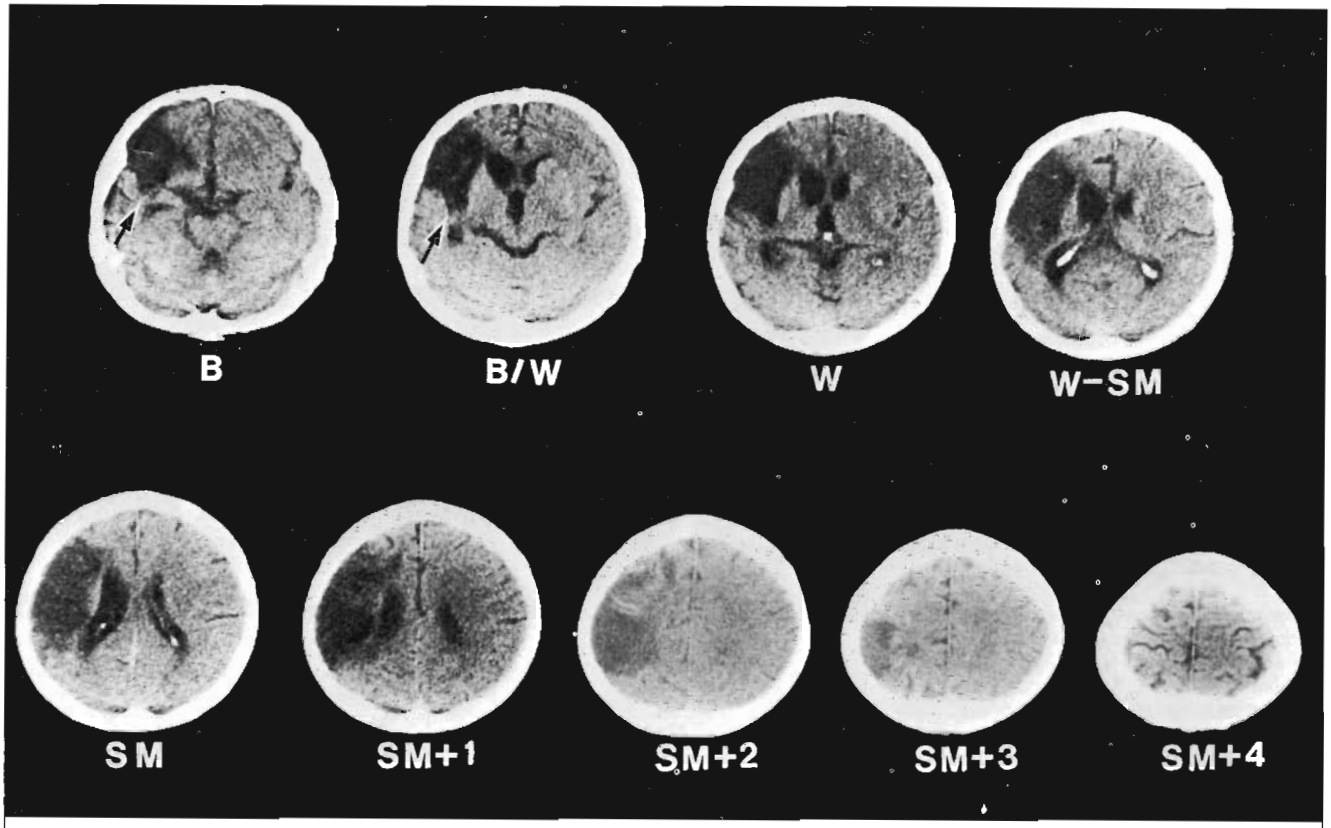
COMMENT

The results from this study suggest that careful examination of cortical-vs-subcortical lesion in the temporal lobe on CT scan provides information regarding potential for recovery of some auditory language comprehension (especially single-word comprehension) after 1 year post onset in a subset of global aphasia patients. A majority of the patients (approximately 80%) with only subcortical temporal isthmus lesion in the temporal lobe (vs Wernicke's cortical area lesion in the temporal lobe) had increased recovery of single-word comprehension, as well as some sentence-level comprehension, after 1 year post onset.

Although there was increased recovery of some auditory comprehension in the patients of the FPTi group, these patients had minimal recovery of spontaneous speech. There were no significant differences between the FPTi group and the FPT group in spontaneous speech, word repetition, or naming at T1 or T2, or in recovery from T1 to T2. Performance at T2 on word repetition and naming was actually variable within each of the two groups (Table 1). Thus, in this study no relationship was observed between recovery of auditory comprehension and recovery of spontaneous speech. These results are in agreement with previous studies where a dissociation between recovery of auditory comprehension and spontaneous speech has been observed.[1-6]

The majority of the FPTi cases in this study achieved some Auditory Comprehension scores on the BDAE after 1 year post onset that were close to, but not within, the normal range. The cut-off score for normal subjects on Word Discrimination is 67 of 72.[21] In four of five FPTi cases there was improvement in Word Discrimination with scores of at least 53 of 72 at 12 to 26 MPO; only three of the nine FPT cases reached scores of this level at 15 to 25 MPO. One FPTi case reached the normal cut-off score of 67 of 72 on Word Discrimination at 26 MPO.

The cut-off score for normal subjects on Body-Part Identification is 18 of



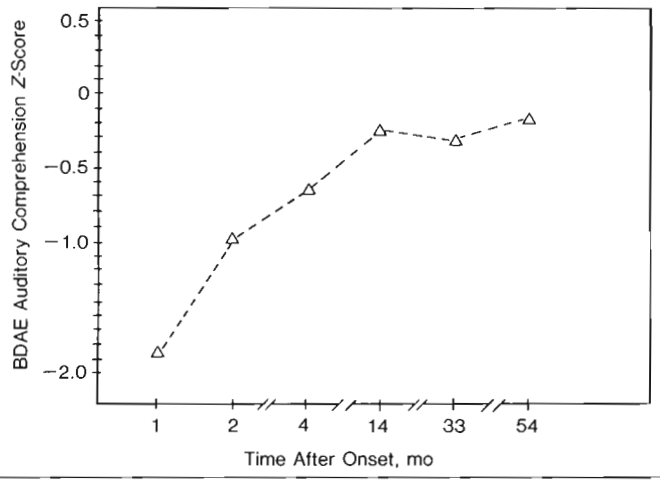


Fig 6.—Top, Computed tomographic scan at 33 months post onset (MPO) of an FPTi case, case 11 (age, 61 years), showing extensive cortical/subcortical lesion in the *f*rontal and *p*arietal lobes, but only subcortical temporal lobe lesion in the *t*emporal *i*sthmus at slices B and B/W (arrows). Note complete sparing of Wernicke's cortical area on slices B/W and W. Bottom, Graph showing this patient's Boston Diagnostic Aphasia Examination (BDAE) Auditory Comprehension *Z* scores over a period of several months post onset. Note good recovery of auditory comprehension beginning at 2 to 4 MPO. His BDAE Auditory Comprehension *Z* scores were −0.24, −0.33, and −0.18 at 14, 33, and 54 MPO, respectively.

20.[21] In four of five FPTi cases there was improvement in Body Part Identification with scores of at least 14 of 20 at 12 to 26 MPO; only one of the nine FPT cases reached a score of this level at 25 MPO. One FPTi case reached the normal cut-off score of 18 of 20 on Body Part Identification, at 12 MPO.

The normal cut-off score on Commands is 13 of 15.[21] In four of the five FPTi cases there was improvement in Commands with scores of 9 of 15 at 14 to 26 MPO (and one case at 100 MPO); only two of the nine FPT cases improved to scores of this level at 25 to 42 MPO. No FPTi cases reached the normal cut-off score on Commands.

In summary, 80% (4/5) of the FPTi cases had total BDAE Auditory Comprehension *Z* scores that were in the mild-to-moderate range (*above* −0.5) at 1 to 2 years post onset. In contrast, 89% (8/9) of the FPT cases had BDAE Auditory Comprehension *Z* scores that were in the moderate-to-severe range (*below* −0.5) after 1 to 2 years post onset.

These results are, in general, compatible with results from another CT scan study that examined recovery of single-word comprehension.[13] That study defined Wernicke's area in a different manner, however, from the present one. In that study, the inferior border of the posterior superior temporal (PST) region (Wernicke's area) was at the level of the pineal gland, and the superior border was at the level of the roof of the right thalamus.[12] In the present study, the inferior border of Wernicke's area was at the level of the maximum width of the third ventricle, slice B/W in Fig 1 (the pineal gland was not always present at this slice level); and the superior border was at the level of the roof of the third ventricle, slice W (Fig 1).

It appears that the present study included a larger regional area in the definition of what was considered to be "Wernicke's area" in the temporal lobe

(posterior two thirds, superior temporal gyrus area), than did the study by Selnes et al.[13] The present study included the middle third (slice B/W), as well as the posterior third (slice W), of the superior temporal gyrus area as part of Wernicke's area. (In the present study, it is possible that portions of Heschl's gyrus area were included as part of Wernicke's area on slice B/W, because it is not possible to separate the primary auditory cortex area from the auditory association cortex area on CT scans.) It appears that the study by Selnes et al[13] placed more emphasis on the posterior third of the superior temporal gyrus area and the infrasylvian supramarginal gyrus area. The study by Selnes et al reported that six of seven cases with limited recovery of comprehension had lesion in Wernicke's area, but two cases with complete destruction of Wernicke's area (aphasia type not specified) had good recovery of single word comprehension at 6 MPO.[13]

It is possible that due to a difference in the definition of the inferior border of Wernicke's area between the two studies that the two patients with good recovery of single-word comprehension in the study by Selnes et al,[13] despite the total destruction of Wernicke's area as defined by Selnes et al,[12] did not have total destruction of Wernicke's area as defined in the present study. No FPT cases in the present study with complete destruction of Wernicke's area as defined in the present study had what would be considered good recovery of single-word comprehension (a score of at least 67/72). The four FPT cases with complete destruction of Wernicke's area on slices B/W and W in the present study recovered to achieve Word Discrimination scores of only 55.5, 47, 28.5, and 23 of 72, at 15, 17, 27, and 13 MPO, respectively. Thus, it is difficult to make comparisons between the study by Selnes et al[13] and the present one, because the definitions of Wernicke's area are not the same. In general, the results, however, appear to be compatible, with the exception of the two patients with complete destruction of "Wernicke's area" who had good recovery of single-word comprehension in the study by Selnes et al.[13]

The results from the present study of global aphasia patients are in agreement with our recently published study with Wernicke's aphasia patients.[14] In that study, Wernicke's aphasia patients with lesion in more than half of Wernicke's cortical area (defined exactly as in the present study) had poor recovery of auditory comprehension at 1 to 2 years post stroke onset (BDAE Auditory Comprehension *Z* scores ranged from −0.2 to −0.9). Wernicke's aphasia patients with lesion in only half, or less than half, of Wernicke's cortical area had good recovery of auditory comprehension at 6 months to 1 year post stroke onset (BDAE Auditory Comprehension *Z* scores ranged from +0.4 to +0.8). It did not matter whether the lesion spared the middle third or the posterior third of the superior temporal gyrus area. As long as half of Wernicke's cortical area was spared (including immediately subjacent white matter), there was good recovery at 6 months to 1 year post onset. There was no significant correlation between total temporoparietal lesion size and BDAE Auditory Comprehension *Z* scores or any of the auditory subtests. The severity and recovery of comprehension was significantly correlated with only the extent of lesion in Wernicke's area and the temporal lobe, not the total lesion size, including extent of lesion into the parietal lobe.

Thus, our results with global aphasia patients are similar to those with Wernicke's aphasia patients in that most global aphasia patients with lesion in greater than half of Wernicke's cortical area (ie, FPT cases) had poor recovery of auditory comprehension 1 to 2 years post stroke onset, as did the moderate and severe Wernicke's aphasia patients. In contrast, most global aphasia patients with only subcortical temporal isthmus lesion (ie, FPTi cases) had better recovery of auditory comprehension, as did the mild Wernicke's aphasia patients with lesion in only half, or less than half, of Wernicke's cortical area. The range of scores on the BDAE Auditory Comprehension *Z* score was higher for the mildly recovered Wernicke's aphasia patients (range, +0.4 to +0.9, at 6 months to 1 year post onset), however, than it was for the four of five FPTi patients who had some recovery of auditory comprehension (range, −0.4 to +0.2, at 1 to 2 years post onset). The additional frontal lobe lesion that was present in the recovered FPTi cases (but not, obviously, in the recovered Wernicke's aphasia cases) probably precluded further recovery and contributed to a relatively more severe comprehension deficit in the FPTi patients. The relative contribution of a frontal lobe lesion to the severity of a comprehension deficit in aphasia patients who also have a temporal isthmus lesion (or a Wernicke's cortical area lesion) remains to be investigated.

The results from the present study help to underscore the unique importance of Wernicke's cortical area in auditory syntactic comprehension, as was suggested in a previous study from our laboratory.[22] In that study, auditory syntactic comprehension was tested across multiple aphasia types where CT scan lesion sites were known. The patients with lesions that included at least half of Wernicke's cortical area (Wernicke's and/or global aphasia patients) consistently performed the worst in auditory syntactic comprehension, whereas other aphasia patients with perisylvian lesions that spared most of Wernicke's cortical area performed the best (conduction, transcortical motor, Broca's, subcortical capsular/putamenal with anterosuperior periventricular white matter lesion, recovered Wernicke's, and mixed nonfluent patients). All patients exhibited the same overall rank order of difficulty with various syntactic comprehension pairs. The patients who made the greatest number of errors, however, had extensive lesion in Wernicke's cortical area (Wernicke's and global aphasia patients).

Similar results have been observed by Parisi and Pizzamiglio[23] in a study of aphasics in Italy. In that study, the Wernicke's and mixed/global aphasics performed more poorly on a syntactic comprehension task than did the Broca's or anomic aphasics. All groups had a similar rank order of difficulty on the syntactic comprehension task, but the former two groups made the most errors. In fact, the study by Naeser et al[22] of the English-speaking aphasics in the United States observed a rank order of difficulty for syntactic pairs that was similar to that observed with the Italian-speaking aphasics.[23] A CT scan study conducted by Selnes et al[12] with the Token Test had made the same general observation regarding the relationship between sentence level comprehension and presence of lesion in the area they described as "Wernicke's area" (posterosuperior temporal gyrus and infrasylvian supramarginal gyrus regions), although variability across individual aphasia cases was, of course, also sometimes observed.

Some aphasia recovery studies have suggested that the right hemisphere may play a role in recovery from aphasia. These studies have included cerebral blood flow studies[24] and dichotic listening studies,[25-27] as well as cortical evoked potential studies.[28] Hemispherectomy studies by Zaidel[29-31] have suggested that the right hemisphere is capable of some single-word comprehension and some limited syntactic

comprehension.

Results from the present study reveal the area of greatest recovery to be at the single-word level of comprehension with the FPTi cases. This area of recovery may be, in part, compatible with some contribution by the right hemisphere to recovery in the FPTi cases, but less so in the FPT cases. Thus, the global aphasia patients with temporal lobe lesions that were limited to the subcortical temporal isthmus area (vs Wernicke's cortical area) may, through mechanisms not yet fully understood, have better recovery, in part, through the right hemisphere, or through absence of cortical lesion in the left superior temporal gyrus area, or both.

There are multiple temporofrontal connections in the brains of primates and humans.[32] In the rhesus monkey, for example, there are connections from the superior temporal gyrus to the frontal lobe via the extreme capsule, the arcuate fasciculus, and the superior longitudinal fasciculus,[33] as well as connections from the superior temporal gyrus through the anterior commissure and corpus callosum to the contralateral hemisphere.[34] With only CT scan imaging, it is unknown which, if any, of these intrahemispheric and interhemispheric connections were better preserved in the FPTi cases. It is possible that the FPTi cases, without lesion in the superior temporal gyrus area, preserved more of these intrahemispheric and interhemispheric connections than did the FPT cases (despite large frontal and parietal lobe lesions present in both groups). In addition, none of the FPTi cases had complete destruction of the anterior temporal isthmus area; thus, some temporal lobe pathways through the temporal isthmus are likely to have been preserved. Some of these preserved intrahemispheric and interhemispheric connections in the FPTi cases may have facilitated better recovery of auditory comprehension at the single-word level (Word Discrimination and Body Part Identification), and to some extent at the sentence level (Commands).

The results from this study support the notion of Sarno and Levita[7,8] that global aphasia patients are not a homogeneous group. Indeed, results from this study suggest that careful examination of cortical-vs-subcortical lesion in the temporal lobe can result in information that may be useful in predicting a subset of global aphasia patients (ie, those with subcortical temporal isthmus lesion, not Wernicke's cortical area lesion) who have potential for increased recovery of auditory comprehension (primarily at the single-word level) after 1 or 2 years post stroke onset. The CT scans used for this predictive information should be obtained at 2 or 3 MPO, as the borders of an infarct are not well visualized on CT scans performed earlier.

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