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Grammatical Comprehension, Aphasic Syndromes and Neuroimaging

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ABSTRACT

This paper presents grammatical comprehension, computerized tomography (CT) and positron emission tomography (PET) data from a group of 43 aphasic patients. Comparison of comprehension performance with structural lesion (CT) revealed a correlation between comprehension of syntax and one inferior frontal lobe region (Broca's area) and one temporal lobe region (Wernicke's area). In contrast, comparison between comprehension performance and metabolic data demonstrated strong correlations between morphology and syntax comprehension and regional measures throughout the temporal, parietal and occipital lobes. The second aspect of the study looked at performance differences between diagnostic groups of aphasic patients. Very few behavioral differences were observed between aphasic groups (Broca's, Anomic, Conduction and Wernicke's), other than differences in severity. On all measures, Broca's and Wernicke's patients performed similarly. Overall, the findings support a model of brain–behavior relations in which language comprehension is represented by more widespread regions of the left hemisphere than is traditionally thought, and the aphasic syndromes differ from each other less than is traditionally believed.

INTRODUCTION

Throughout the history of aphasiology a central focus of research has been to utilize the clinical symptomatology of the aphasias to better understand the relationship between the brain and language. However, until the advent of computerized tomography (CT), attempts to map behavioral patterns onto the brain could be approached only through post-mortem examination. Since that time, there have been remarkable advances in the technology of neuroimaging, making possible for the first time the study of the neurology of language and language impairments in the living brain.

Over the past nine years, our group has reported on number of studies of cerebral glucose metabolism in aphasia (Kempler *et al.* 1988, 1990; Metter *et al.* 1981, 1983, 1984, 1985, 1986, 1987a, 1989). The early studies considered approximately 15 subjects imaged on a positron emission tomography (PET) scanner with $1.6 \times 1.6 \times 1.0$ cm resolution. Over the past five years, the subjects were drawn from a group of 50 aphasic patients who had a history of a single cerebrovascular event, and underwent neuroimaging (CT and PET) studies and behavioral evaluations more than one month post onset. They were studied on a PET scanner with improved resolution of $1.1 \times 1.1 \times 1.0$ cm.

Several general comments can be made about glucose metabolism and brain damage and about its relationship to aphasia in particular. Firstly, and most generally, it has become apparent that the areas of metabolic abnormality (hypometabolism) following either cerebral infarction or haemorrhage, as measured by PET, are much larger than the areas of structural damage measured by CT. This finding is expected immediately post onset due to local inflammation and residual ischaemia. The more surprising finding is that large metabolic changes are observed (1) many months post onset, suggesting that it is not entirely due to an acute effect of regional inflammation; and (2) in regions very distant from the site of injury, suggesting that it is not a regional effect at all. For instance, we have demonstrated that subcortical lesions have a direct effect on metabolic function of specific cortical regions (Metter *et al.* 1988), and a number of investigators have found a metabolic deficit in cerebellar regions contralateral to the structural lesion (Metter *et al.* 1987a). These findings have been interpreted as a reflection of disrupted systems which are represented in widespread but specific regions throughout the brain. In addition to the basic finding that metabolic lesions are larger than structural lesions, we have found that those cases where this does not hold (i.e. structural lesions in which the metabolic abnormality was limited to the region of structural damage) were not associated with clinical symptomatology (Metter *et al.* 1987b; Metter 1987). This suggests that it is the interaction of structural damage and its functional consequences elsewhere in the brain that are critical in determining behavioral sequelae of cerebral lesions. In summary, it appears that the metabolic effects of local damage give us information about how the structurally damaged regions interact (or fail to interact) with other, crucial, but sometimes quite distant, regions.

With regard to aphasia, we have analyzed PET data from Broca's, Wernicke's and Conduction aphasic patients in order to investigate the relationship between the major

syndromes and glucose metabolism (Metter *et al.* 1989). P
tural damage and classic aphasic syndromes (e.g. Kertesz 1
behavioral syndromes can be associated with structural dan
the left hemisphere. For example, Broca's aphasia (non-flu
preserved comprehension) is associated with posterior fron
subcortical left hemisphere lesions while Wernicke's aphasi
comprehension) is typically associated with posterior temp
lesions. While evaluation of the structural damage asso
syndromes has contributed greatly to a specific model of ce
1979; Kertesz 1979), the glucose metabolic data give u
picture of the regional deficits which distinguish these behav
Specifically, we have found that all aphasic patients that
abnormalities in the temporoparietal regions. The most c
was the angular gyrus which had abnormal glucose metabol
(Metter *et al.* in press)[1]. A second important observation i
including prefrontal areas, is metabolically abnormal in abo
In examining the glucose metabolic activity of the left fro
the supplementary motor area responds in a manner di
prefrontal, Broca's area and primary motor cortex to structu
(Metter *et al.* 1990). Therefore, the emerging picture of ap
glucose metabolism emphasizes both similarities and dif
groups. Although temporal lobe metabolism appears unif
these aphasic patients, the behavioral syndromes can b
another by the degree of hypofunction in other regions.
cortex distinguished the Conduction from Wernicke's and
(relatively preserved in Conduction aphasia), while frontal
Broca's from Wernicke's aphasia (significantly more impa
argued that common features in these groups of aphasic pat
the metabolic changes in the temporal lobe, while unique fea
frontal and parietal changes (Metter *et al.* 1989).

In summary, the relationship between aphasia and brai
from that observed for aphasia and structural brain damage
metabolic lesions are much larger than structural lesions,
systems throughout the brain. In addition, we have obs
aphasic syndromes can be distinguished from one another
disturbance, it is not in the same way that aphasic syn
guished with structural lesion data. That is, all aphasic
temporal lobe hypofunction, regardless of syndrome or
appear to differ from one another in degree of metabolic
undamaged prefrontal and parietal cortex.

These provocative findings from the use of PET have been accompanied by a growing interest in aphasia by linguists and significant advances in linguistic theory. For instance these developments in the field of linguistics have produced grammatical characterizations of aphasia which differ in content from classical clinical diagnostic typology. Clinical diagnoses have relied largely on characteristics of speech such as fluency, incidence of paraphasias, and relative performance across task modalities, such as comprehension, production, repetition, writing and reading. In contrast, linguistic analyses of aphasic symptoms have tried to characterize aphasic impairments in terms of the grammatical system. Such theory-based analyses have already made important contributions to our understanding of aphasia, offering unified grammatical explanations for aspects of aphasic performance which had previously appeared to be unrelated (e.g. Caplan *et al.* 1985; Caplan and Futter 1986; Grodzinsky 1984, Kean 1977, 1985; Linebarger *et al.* 1983).

Linguistic analyses of aphasic symptoms, however, have to date not been related to results from currently available imaging techniques. The goal of this paper is to extend the enterprise of relating behavioral and neurological data by examining the relationships between aphasic syndromes, neuroimaging, and specific linguistic impairments. The specific questions we address in this paper are: (1) what is the relationship between CT findings and aspects of the comprehension of morphology and syntax? (2) what is the relationship between PET findings and comprehension performance? and (3) what is the relationship between clinically diagnosed aphasic syndrome and linguistic performance?

METHODS

Subjects

The patients were 43 right-handed, monolingual speakers of Standard American English with radiological evidence of a single (left hemisphere) infarct or haemorrhage and aphasia. All patients were studied more than one month post onset of the stroke. None was receiving therapy with anticonvulsants, antidepressants, or sedatives. Each subject was administered the Western Aphasia Battery (Kertesz 1982), which was used to classify the type of aphasia. Of the 43 patients sampled, 11 (26%) had Broca's aphasia, six (14%) had Wernicke's aphasia, eight (19%) had Conduction aphasia, and 18 (42%) had Anomic aphasia. See Table 1 for additional subject information. Each patient also received additional tests of auditory comprehension, and 38 of the patients also received a non-contrast CT scan and a resting state (F18)-fluorodeoxyglucose PET scan. Control subjects for the PET were 22 healthy volunteers with no known neurological disorder.

TABLE 1
Subject Information

ID number	Sex	Age	Mon… o…
Anomic aphasia			
151	Male	66	
144	Male	57	
138*	Male	56	
129	Male	63	
135	Male	62	
125	Female	72	
110	Male	61	
109	Male	55	
112	Male	57	
111	Male	63	
103	Male	71	
108	Male	63	
104	Male	60	
116*	Male	60	
119	Male	73	
124	Male	58	
118*	Female	49	
122	Male	67	
Anomic means:		61.833	29
(n = 18) SD:		6.219	28
Broca's aphasia			
114	Male	59	
115*	Male	65	
142	Male	43	
136	Male	64	
128*	Male	57	
133	Male	62	
131	Male	59	
106	Male	62	
105	Male	64	
152	Male	56	
130	Male	63	
Broca's means:		59.455	20
(n = 11) SD:		6.219	16

TABLE 1—continued

ID number	Sex	Age	Months post onset	Aphasia quotient
Wernicke's aphasia				
121	Male	69	1	45.5
148	Male	74	32	57.0
132	Male	73	1	45.1
117	Male	63	5	30.3
154	Male	65	1	16.4
143	Male	63	2	38.0
Wernicke's means:		67.833	7	38.717
(n = 6) SD:		4.916	12.345	14.074
Conduction aphasia				
101	Male	60	6	74.1
102	Male	66	10	88.4
126	Male	55	35	84.5
123	Female	37	79	76.1
127	Female	67	10	80.7
147	Male	70	2	65.5
146	Male	58	3	76.7
139	Male	62	2	62.2
Conduction means:		59.375	18.375	76.025
(n = 8) SD means:		10.309	26.774	8.887
Total means:		61.605	22.093	67.393
(n = 43) SD:		7.32	24.245	24.522

* CT and PET data are not available for these patients.

PET—Functional Imaging

Each subject underwent a resting state PET scan using (F18)-2-fluoro-2-deoxy-D-glucose (NeuroECAT, CTI, Knoxville, TN). Subjects lay on the scanner bed in a darkened room, listening to ambient room noise (eyes and ears unoccluded), and had (F18)-2-fluoro-2-deoxy-D-glucose injected intravenously, and serial arterialized venous blood samples were drawn over time. Scanning was begun 40 min later, with the head positioned using the techniques described by Mazziotta *et al.* (1985), and the distance from the auditory meatus to the vertex was measured and used as a reference to determine plane localization. Values of local cerebral metabolic rates for glucose (LCMRGlc) were calculated as previously described (Phelps *et al.* 1979). Fifteen cerebral regions from each hemisphere (Fig. 1) were outlined on a video monitor using an interactive

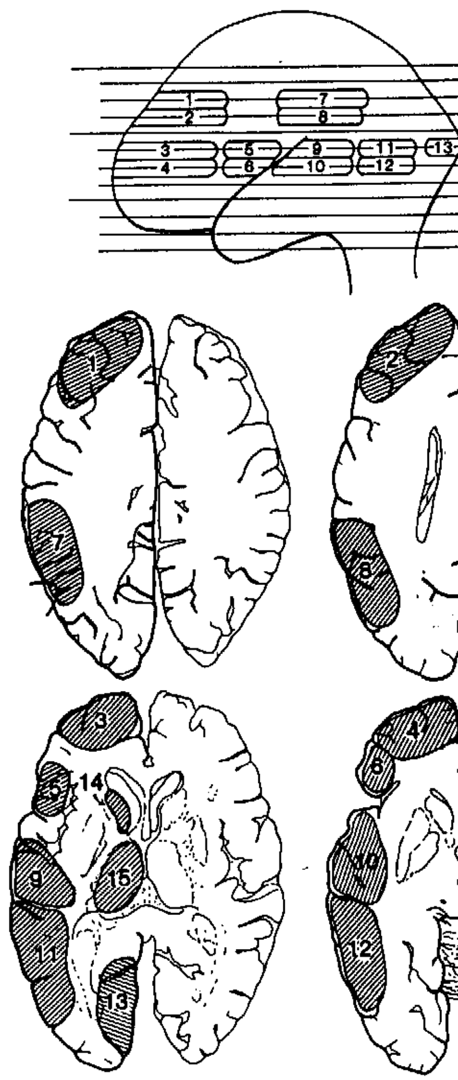

Figure 1. **Schematic Illustration of Cerebral Region Damage and Glucose Metabolic Rates. R Frontal; 3 and 4 are Low Frontal; 5 and 6, 9 and 10, Wernicke's; 11 and 12, Temporal; and 15, Thalamus. (Reprinted from Kempl *Cerebral Metabolism, Archives of Neurol* 1988, American Medical Association.)**

program, and regional LCMRGlc values were derived in milligrams of glucose per 100 g of tissue per min. Region of localization was based on the data of Matsui and Hirano (1978). The LCMRGlc values of aphasic patients' right hemispheres differ little from those of healthy controls but may show interindividual variation; therefore, left–right ratios for homologous regions were calculated and used in the analyses.

CT—Structural Imaging

Each subject had a computed tomographic scan (1200SX [Picker, Cleveland, OH] or 8800 Scanner [General Electric, Schenectady, NY]) at approximately the same time and in the same scanning plane as PET. The same regions as measured for glucose metabolism were rated. In addition, the anterior internal capsule, posterior internal capsule, insula and lenticular nuclei were rated. The regions of interest were rated using a five-point scale (0, normal; 1, atrophy; 2, structural damage with no tissue loss; 3, structural damage with partial tissue loss; 4, structural damage with complete tissue loss) by a neuroradiologist who was naïve to the project and by one of the authors (EJM). Regional scores showed a 90% agreement between raters, and the two ratings were averaged to obtain an estimate of the degree of structural damage.

Grammatical Comprehension

The linguistic comprehension measures were comprised of a set of 45 comprehension items, assessing 15 syntactic and morphological structures (three items assessed understanding of each structure). All items followed a picture-matching format in which the subject selected one (of two, three or four) pictures which best matched an auditorily presented sentence. The distractor pictures (wrong answers) represented different permutations of the grammatical relations involved in the test sentence. Therefore, it was not possible for a subject to consistently select the correct answer by virtue of lexical knowledge alone. The subtests were divided into those which assessed syntax vs those which assessed morphology, and all items were drawn from the *CYCLE-R* (*Curtiss–Yamada Comprehensive Language Evaluation—Receptive Measures*) (Curtiss and Yamada 1987). The morphology items assessed two distinct types of morphology—items which express grammatical inflection (e.g. marking of number, person, tense) by a change in the word form; and items which express grammatical relationships by the use of an individual word from "closed classes" such as prepositions (e.g. "with") or modals (e.g. "will"). Syntactic structures (sentences) are also assessed in two distinct type of sentences, those which involve only one clause (simple structures) and those which involve two or more clauses (complex structures which involve embedding, such as relative clauses).

A list of structures tested, with examples, is presented in the Appendix, and a

sample item is presented in Fig. 2. Scoring procedures va
CT and PET analyses, the total number of subtests passed
understood) in each component was the measure of comp
that component. For the linguistic analyses, the total perce
component (e.g. closed class morphology or simple synta
for the comparisons.

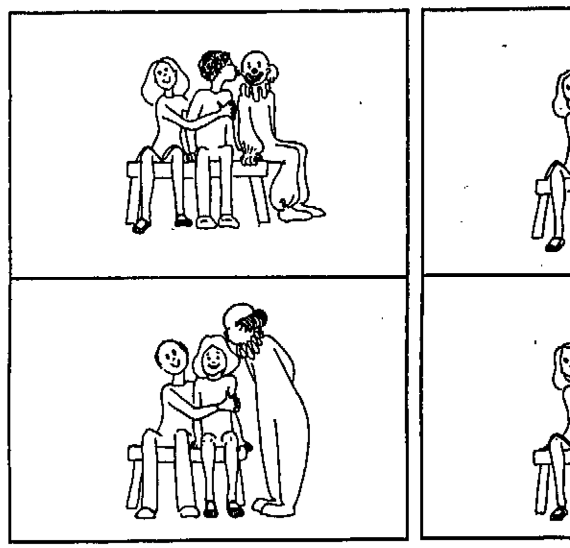

Figure 2. Sample Picture Response Array for Syntac
"The Girl is Hugging the Boy that the Cl

RESULTS

To assess the first question, *What is the relationship*
aspects of the comprehension of morphology and synt
coefficients were calculated between CT region ratings and
morphology and syntax subtests. There were no significa
of structural damage and comprehension of morphol
correlations between comprehension of complex syntax
damage which were a single temporal lobe measure (Wern
$p = 0.0191$) and one of the Broca's measures ($r = 0.33$
relations do not change significantly if the two morphology
summed into two scores, one representing morphology (s

region) and one representing syntax (which remains significant for only the Wernicke region). These results are presented in Table 2 and Fig. 3.

TABLE 2
Correlations Between Grammatical Comprehension and Areas of Structural Damage

Region	Morphology: Inflectional	Morphology: Closed Class	Syntax: Simple	Syntax: Complex
Frontal 4	0.13258	0.17396	0.13001	0.17184
Frontal 3	0.13429	0.09260	−0.00437	−0.02843
Frontal 2	0.16253	0.23612	−0.01750	−0.05676
Frontal 1	0.11041	0.09016	0.02878	−0.02018
Broca's 2	0.04916	−0.07377	−0.22932	−0.26261
Broca's 1	0.07721	−0.16985	−0.22207	−0.33331*
High parietal	0.13957	−0.24723	−0.17918	−0.01002
Parietal	−0.00758	−0.22977	−0.15700	−0.20939
Wernicke's 2	−0.06162	−0.01690	−0.18236	−0.26723
Wernicke's 1	−0.31034	−0.21056	−0.29063	−0.37844*
Temporal 2	−0.06796	−0.23157	−0.14757	−0.28108
Temporal 1	−0.21539	−0.23200	−0.18830	−0.13536
Occipital	−0.10477	−0.16082	−0.15247	−0.13932
Caudate	−0.11597	−0.21291	−0.04250	−0.12640
Thalamus	0.36587	0.03987	−0.26442	−0.09843
Cerebellum	−0.05958	−0.06909	−0.11664	0.03958
Ant. int. cap.	0.10978	0.11903	0.07533	0.07289
Post. int. cap.	0.07683	0.11746	−0.10390	0.10243
Lenticular nuc.	0.15070	0.17987	0.09327	0.18513
Insula	0.04404	0.21771	−0.05146	0.07064

*$p < 0.05$.

These CT results contrast with the significant correlations found between regions of hypometabolism (PET) and (poor) performance on linguistic measures. Firstly, occipital lobe metabolism correlated with all linguistic measures, possibly reflecting the proximity of temporal lobe language zones to the occipital lobe, and the visual processing component of these language tasks. Secondly, posterior temporal lobe (not Wernicke's area) correlated significantly with comprehension of both syntax measures and closed class morphology. Thirdly, the parietal lobe measure correlated

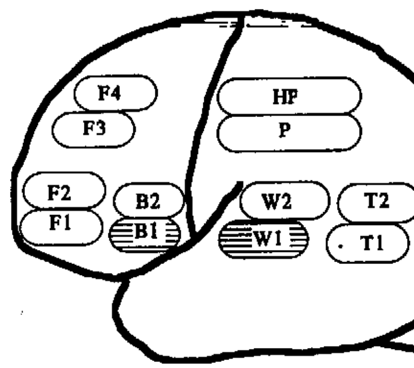

Figure 3. Regions of Structural Brain Damage Whicl matical Comprehension Deficits.

with both simple and complex syntax comprehension. If summed to yield a single morphology score and a single sy regions remain essentially the same, with the exception t significantly correlate with total syntax comprehension ($r =$ it did not correlate with either simple or complex syntax

Notwithstanding the possibility that this many comparis meaningless yet statistically significant correlations with b conservative view of these findings is consistent with o suggests that metabolic damage as reflected in PET corres behavioral symptomatology of aphasia than structural dam is borne out in the greater number of significant correlation and PET and the higher level of significance reached in compared with CT. That is, for example, although only a w between structural damage in Wernicke's area and compreh ($p < 0.05$), the relationship was more strongly represented of glucose metabolism in the posterior temporal lobe (p reinforce the important point that any model of brain-beh consider the interplay of structural damage and the res throughout the brain.

To address the third question of the study, *What is the rel syndrome and linguistic performance?*, we conducted two s looked at performance of each diagnostic category (Broca's Anomic) on morphology and syntax subtests. A two-factor r revealed a significant effect of group [$F(3,39) = 7.848$,

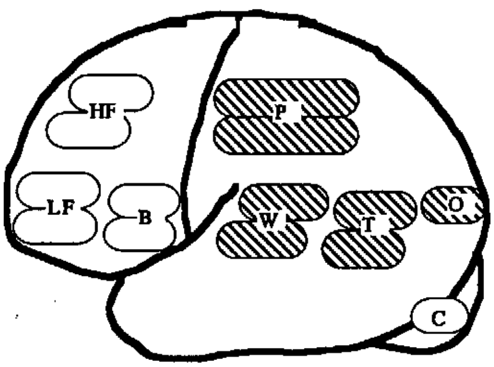

Figure 4. Regions of Glucose Hypometabolism which Correlate with Grammatical Comprehension Deficits.

sentence type [$F(1,39) = 20.846$, $p = 0.0001$], and a group-by-sentence type interaction [$F(1,3) = 3.861$, $p = 0.0164$]. Examining the data in more detail, we find that the effect of group reflects the different levels of severity of each diagnostic group with Anomics being least impaired and Wernicke's being most impaired. The effect of sentence type is shown in Fig. 5 by the consistently superior performance of all four groups on morphology compared with syntax. The group-by-sentence type interaction stems from the fact that the two less impaired groups (Anomic and Conduction) perform similarly on both morphology and syntax items, while the two more severely impaired patient groups (Broca's and Wernicke's) both perform significantly worse on syntax items ($t = 3.653$, $p = 0.0044$ and $t = 5.825$, $p = 0.0021$ respectively).

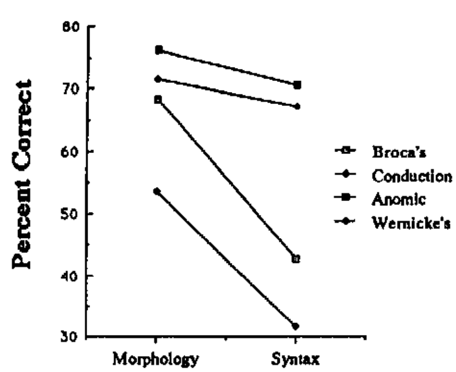

Figure 5. Comprehension of Morphology and Syntax for Four Groups of Aphasic Patients.

We also analyzed the data looking at the morpholog (bound vs closed class morphology; simple vs complex sy syndrome. Comparison of the four aphasic groups and fou (two factor ANOVA with repeated measures) revealed a [$F(3,39) = 5.632$, $p = 0.0026$] and a significant effect o $p = 0.0001$], but only a trend toward a group × task 1.958, $p = 0.0503$]. Figure 6 shows that the significant

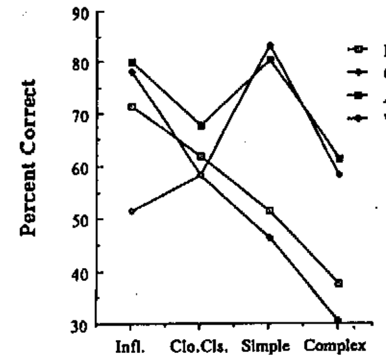

Figure 6. Comprehension of Four Aspects of Gra phology, Closed Class Morphology, Simple for Four Groups of Aphasic Patients.

TABLE 3

Correlations Between Grammatical Comprehe Cerebral Metabolism

	Morphology	
Region	Inflectional	Closed class
High frontal	0.10266	−0.03453
Low frontal	0.03590	0.08604
Broca's	0.0089	0.00827
Parietal	0.11496	0.26147
Wernicke's	0.21304	0.08727
Temporal	0.30933	0.34974*
Occipital	0.36549*	0.39183*
Caudate	0.00313	−0.05520
Thalamus	0.03120	−0.10246

*$p < 0.05$.
†$p < 0.001$.
‡$p < 0.01$.

the fact that the anomics and conduction aphasics were generally less impaired (particularly on syntax items) than the Broca's and Wernicke's patients. *Post-hoc* Scheffe *F*-tests again revealed significant differences between the mildly impaired patients (Anomic and Conduction) and the severely impaired patients (Broca's and Wernicke's) on comprehension of simple syntax, and a significant difference between Wernicke's and all other groups on comprehension of inflectional morphology. There were no significant differences between the aphasic groups on comprehension of closed class morphology or complex syntax.

SUMMARY AND DISCUSSION

This investigation of comprehension, brain structure and brain metabolism in a population of aphasic patients has confirmed and perhaps expanded what we know about the relationship between the brain and behavior. Firstly, our comparison of comprehension performance with ratings of structural lesions demonstrated that relatively small and well-localized structural lesions in the frontal and temporal lobe cause significant syntactic comprehension deficits. This, of course, is not surprising, and is consistent with findings from the time of Wernicke to the present. Perhaps more interesting, none of the morphological comprehension scores reached significance with any particular region of structural damage, suggesting that these two aspects of language (morphology and syntax) may be differentially disrupted by structural lesions in the left hemisphere. This could be seen as a confirmation of linguistically motivated distinctions between the structural properties of morphological and syntactic components of the grammar. Our subsequent comparison of comprehension performance with metabolic lesions revealed a much less familiar picture of brain-behavior relations. Specifically, poor comprehension of both syntax and morphology seem to correlate significantly with metabolic lesions in the posterior temporal, parietal and occipital lobes, yielding an impression of a much wider focus of comprehension within the left hemisphere than was given by the CT data. While it is probable that some of this correlation may reflect perhaps extraneous aspects of the task (e.g. using visual response arrays will involve the functions of the occipital lobe which are not necessarily part of language performance), it would be imprudent to disregard all of these findings as artifactual. It is interesting to observe that the correlations between comprehension and metabolic abnormalities not only cover a wider region of the left hemisphere than structural correlations, but are in fact higher correlations and include both syntax and morphology. It is likely that what we are observing in these results is the fact that Broca's and Wernicke's areas, while structurally important for auditory comprehension, do not operate in isolation, but rather in tight integration with surrounding temporal, parietal and occipital regions. Taken together, the CT and PET data confirm what we already knew from previous studies: small structural lesions

create large metabolic lesions. This investigation has go
behavioral data into the larger picture. Brain–behavior
grammatical comprehension, appear to indicate stronger t
impairment and the larger metabolic lesions than between
and the smaller structural lesions. These findings suggest
our hard-won maps of localization of function within th
somewhat less localized to small regions. Minimally, t
choice of methodology (e.g. CT vs PET) will create a
degree to which cortical function is focally represented.

The data on diagnostic groups and grammatical compre
at similarities and differences between the aphasic syndro
relevant to auditory comprehension. Our findings were
Firstly, contrary to recent reports indicating that morp
ticularly vulnerable to brain injury in aphasia (e.g. Bate
morphological comprehension appeared to be better pre
prehension. In fact, all of our aphasic groups performed
morphology than on syntax (although the performance dif
for the more severely impaired Broca's and Wernicke's
these findings are relevant to the centuries-old debate r
comprehension impairment with aphasic syndromes. It is
been a general consensus on the status of comprehensi
the one hand, the standard lore in aphasiology was fo
(Wernicke's) aphasics suffer from specific auditory comp
in other aphasic syndromes (e.g. Goodglass and Kaplan
recent investigations with Broca's aphasics have empha
comprehension and production (Caramazza and Zurif 19
Wulfeck 1988). Our findings do not clearly support eith
ficant differences in overall severity, we did not find c
the grammatical comprehension performance of Broca's
Although it is unquestionable that Broca's and Wernicke'
teristic symptoms (e.g. fluency), our data suggest that
model of aphasia may not map neatly or meaningfully on
sion. Rather, grammatical comprehension appears quite
syndromes.

The picture of aphasic impairments that we are building
to a small degree to traditional views established by analys
and performance on standardized aphasia batteries. In kee
we find that aphasic patients have language comprehensi
to temporal lobe lesions. However, the details of both the
findings are somewhat different than the traditional model

We find that the locus of damage which contributes most to the comprehension deficit is not focal, but rather involves the entire posterior peri-sylvian region, including widespread temporal, parietal and occipital areas. Secondly, we find little to distinguish traditional aphasic syndromes in terms of grammatical comprehension as measured by the CYCLE. In general, we believe this suggests a more unified view of aphasia and a more complex view of the mapping of language onto the brain. Under this view, some aphasic symptoms reflect a neurological commonality among aphasic patients, and therefore serve to de-emphasize syndrome-specific differences. Our findings may be interpreted to suggest, therefore, that language function, as an example of cognitive functions more generally, may not be as focally represented in the brain as suggested on the basis of structural data alone.

NOTES

1. It should be noted that we have not studied transcortical aphasics with damage in the supplementary motor area. These more purely frontal lobe aphasias may behave differently than the more posteriorally based aphasias.

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Appendix

Examples of Grammatical Comprehension Stimuli

MORPHOLOGY

Inflectional morphology

Possessive 's
    Point the the baby's bear.
Verb singular
    The sheep stands.
Noun plurals
    Point to the picture of the boxes.
Tense/aspect -ed
    The mother dressed the baby.

Closed Class morphology

Tense/aspect "will"
    The girl will open the present.
Case marking preposition "with"
    The boy is carrying the suitcase with the man.

SYNTAX

Simple sentences

Active voice
    The dog is chasing the cat.
Passive voice
    The boy is being pushed by the girl.
Wh- Object questions
    Who is the girl pushing?

Complex sentences

Subject relatives
    The boy who is smiling is pulling the girl.
Object relatives
    The boy is pushing the girl who is happy.
Subject relatives ending in noun-verb
    The girl who is pulling the boy is smiling.
Object relatives with relativized object
    The boy is kissing the girl that the clown is hugging.
Double embedding
    The girl that is chasing the clown that is big is little
Double function relatives
    The boy that the girl is pulling is pulling the clown.