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William P. Gordon

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Neuropsychologic Assessment of Aphasia

. . . Fournie has written, "Speech is the only window through which the physiologist can view the cerebral life." Certainly, language presents in a most striking form the integrative functions that are characteristic of the cerebral cortex and that reach their highest development in human thought processes (Lashley, 1960, p. 507).

In the past few years, the study of the neural mechanisms subserving language has undergone a major revolution. The principal fields contributing to this extraordinary new development are neuroradiology, neuroanatomy, neurology, and neuropsychology. Each of these fields is itself undergoing an explosive growth at present. Inferences about the organization of language within the living brain depend largely upon accurate testing of cognitive disorders and accurate localization of pathology. The historical attempts to localize aphasia-producing lesions have been reviewed by Benson (1979), and methodologic problems of localization in aphasiology have been elucidated by Kertesz (1983).

The study of acquired disorders of language is highly complex. De-

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fects include neural substrates of language, linguistic processes, and cognitive disorders that coexist with aphasia. In order to establish the constellation of cognitive impairments in aphasic patients, there are several forms of examinations that may be administered. These examinations depend on clinical or research objectives. Clinical neuropsychology has as a major focus assessment of diagnosis, prognosis, remediation, and recovery. Experimental neuropsychology, by contrast, places a major emphasis upon brain–behavior relations, i.e., what pathology is likely to produce distinct aphasic syndromes, what defects usually follow certain lesions, and what cerebral events underlie recovery.

The clinical neuropsychologist may establish presence or absence of aphasia by a screening examination. By contrast, a specialized aphasia examination delineates the severity, syndrome, and specific dimensions of language impairment. If the objective is to establish disorders that coexist with aphasia, a general battery may be administered such as the Halstead-Reitan Battery (Reitan & Davison, 1974), the Luria-Nebraska Neuropsychological Battery (Golden, Hammeke, & Purisch, 1978), and the Montreal Neurological Institute Battery (Kolb & Whishaw, 1980). These batteries are briefly described as is the use of intelligence testing and mental status exams.

NEUROPSYCHOLOGIC ASSESSMENT

Mental Status Examination

Many aphasic patients cannot be reliably tested on neuropsychologic instruments, particularly in the first few weeks postonset of symptoms. Confusion, inattention, mutism, and other factors, which can be separate from the language disturbance itself, may make bedside testing uninterpretable. Many investigators will not attempt to obtain research-related assessments of language prior to 2 months postonset. In order to sample mental status and thereby facilitate determination of the testability of the patient, one might wish to begin by administration of a mental status examination.

Strub and Black (1977) published a mental status examination for neurology. This brief examination includes (1) level of consciousness; (2) attention; (3) appearance and emotional status; (4) language; (5) memory; (6) constructional ability; (7) higher cognitive functions; and (8) related cortical functions (including tests of apraxia, left–right disorientation, finger agnosia, Gerstmann syndrome, visual agnosia, and geographic orientation).

The language section has information regarding handedness, spontaneous speech, simple assessment of comprehension by study of patient's

response to pointing commands, repetition, naming and word finding for colors, body parts, clothing and room objects, and parts of objects, reading, writing and spelling. Assessment requires about 15–20 minutes. Although these scales have few items and are not as yet standardized, they can provide a direction for further assessment.

The Mini-Mental State exam (Folstein, Folstein, & McHugh, 1975), designed for clinical psychology or neuropsychology, contains indices sensitive to general cognitive processes. The subtests assess orientation, registration, digits forward, digits backward, calculations, recall, knowledge, language, and construction. A composite score can be computed to calculate total impairment. The scales are standardized and norms are available for various patient populations, including dementing disorders.

The Neurobehavioral Mental Status examination (Kiernan, 1983) is applicable to neuropsychology and neurology. Standardized norms are provided for level of consciousness, orientation, attention, language, repetition, naming, constructional ability, memory, calculations, and reasoning. The exam may be administered in about 15 minutes.

Intelligence

Most neuropsychology services test intelligence. The most commonly utilized measure of intelligence in adults is the Weschler Adult Intelligence Scale (WAIS). Although the WAIS was not designed to assess neurologic deficits, it is often used to provide supporting evidence of neural dysfunction (Benton, 1974). Selective impairment of verbal intelligence quotient (IQ) (i.e., information, comprehension, arithmetic, similiarities, digit span, and Vocabulary), is regarded as most sensitive to left hemisphere pathology. By contrast, reduced performance IQ (i.e., digit symbol, picture completion, block design, picture arrangement, and object assembly) is most often sensitive to right hemisphere damage. These inferences may be drawn from dominant and nondominant hemispherectomy (Smith, 1972). Caution must be exercised when interpreting the complex neural events occurring when any of these tasks is being performed. For example, although one normally assumes that block design performance is most sensitive to the integrity of the right hemisphere, it has been possible to individually test each cerebral hemisphere in the commissurectomized patient. Distinct forms of errors are produced depending on whether the left or right hemisphere is being tested (see Geschwind, 1979). Further, in commissurectomized subjects both hemispheres are reportedly relatively equal in matching block designs to a sample (Gazzaniga & LeDoux, 1978); the right hemisphere is superior when engaging in the manipulospatial components of block design.

When IQ scores are especially low in the performance scale, and these scores are markedly lower than verbal IQ (i.e., by 30 points), some

investigators will propose pathology of the right hemisphere. There are many instances where this generalization is invalid (see Boll, 1978). Aggregate IQ is often insensitive to brain damage and can mask significant impairment on individual subtests. However, norms for each subtest may provide hypotheses for additional assessment. One cannot reliably assess verbal IQ in aphasic patients. Some performance scales may be tested in aphasic patients when disturbances of movement, apraxia, attention, or sensation do not impair testing.

Neuropsychologic Batteries

This review emphasizes batteries rather than individual instruments. There are, however, a multitude of individualized tests for assessment of language functioning (Benton, Hamsher, Varney, & Spreen, 1983; Golden, 1978; Lezak, 1976; Smith, 1975; Strub & Black, 1977; see also the *8th Mental Measurements Yearbook*, Buros, 1978). Many investigators prefer to use different tests for different patients (a divergent approach) rather than the same test for all patients (a covergent approach). Whether the divergent or convergent testing approach or a combination of the two yields the most clinically or experimentally useful information is open to question.

Halstead-Reitan Neuropsychological Battery

An attempt to develop a biologically valid instrument of human intelligence was undertaken by Halstead (1947). The first studies were performed with patients who had circumscribed anterior frontal resections. Indices particularly sensitive to far frontal pathology were regarded as measuring what Halstead termed *biological intelligence*. Refinement and expansion of Halstead's measures were carried out by Reitan, a student of Halstead, who was responsible for the development of the Halstead-Reitan Neuropsychological Battery. This was the first battery developed for neuropsychologic screening. Attempts were also made to establish which indices might help to localize particular lesions based on patterns of deficits. At present, the role of localization from a neuropsychologic battery is secondary; neuroradiologic techniques, for example, provide this information far more effectively. There are three Halstead-Reitan Neuropsychological batteries, one for children, another for adolescents. The version presented in the following text is designed for adults.

These tests include The Category Test, in which the patient attempts to establish the principle underlying series of items varying in one or more dimensions. In the Tactual Performance Test, the patient is blindfolded and attempts to place blocks of different shapes and sizes into specified holes as rapidly as possible). The Rhythm Test assesses ability

to determine whether two rhythms are the same or different. The Speech–Sounds Perception Test includes presentation of nonsense words on tape; the patient attempts to identify, from four written words, the one that had been presented. Note that this test, in its usual form, cannot be given to the aphasic patient with alexia, but might be of interest to study word-deaf patients. The Finger Oscillation Test assesses speed of finger oscillation of each hand. Allied procedures are included to increase the sensitivity of the battery to various defects. More than 4 hours may be required to administer the instrument to a patient, and the equipment utilized makes it awkward to test a client at bedside.

A separate aphasia screening test is administered to determine presence or absence of aphasia. The screening exam has had different names: Halstead-Aphasia Test, Aphasia Screening Test (Reitan & Heimburger, 1955), and the Reitan-Indiana version (Boone, 1978). Neuropsychologic studies of specific aphasic syndromes necessitate a more specialized instrument (Boone, 1978).

If the patient has an aphasia, one may be interested in administering particular subtests of the Halstead-Reitan Battery in order to learn more about various cognitive disorders. For additional information regarding the utilization of this battery in neuropsychologic research, refer to Boll (1981).

Luria-Nebraska Neuropsychological Battery

One of the important contributions to neuropsychology of the late Soviet neuropsychologist, Alexander Luria, was his extensive studies and elaborate tests designed to measure many neuropsychologic deficits. Luria's approach, in essence was to apply a wide variety of neuropsychologic tests to his patients (Luria, 1976). The particular tests varied from patient to patient, depending on the nature of the deficit observed. Thus a standardized battery was not developed by Luria's neuropsychologic laboratory nor was this their intent. A summary of neurodiagnostic procedures developed by Luria, many of which were unknown to the Western world, was compiled by Christensen (1974), who had studied under Luria.

The Luria-Nebraska Neuropsychological Battery has little to do with Luria's divergent testing methodology. Golden and associates in Nebraska (Golden et al., 1978) pretested some of the procedures described by Christensen (1974) and thereafter developed a battery of their own. The entire battery takes about 2–3 hours to administer. There are many scales, and three particularly concern language processing, e.g., impressive speech, expressive speech, and reading and writing. The exam was not constructed to delineate aphasic syndromes, and the terminology used is distinct from that encountered in modern neurology to describe aphasias.

Impressive speech includes tests of receptive functions such as articulation of simple speech sounds (phonemic hearing) and reproduction of verbal discriminations orally or graphically. The subject names familiar and unfamiliar objects from pictures and responds to statements and questions requiring understanding of logical grammatical constructions, words, and simple sentences.

Expressive speech includes articulation of speech sounds, reflected (repetitive) speech, naming, classification, and production of narrative speech. This section includes tasks requiring articulation of simple speech sounds (such as vowels and words), familiar and unfamiliar words of varying lengths, and phrases or sentences of varied length and complexity. The subject names days of the week in reverse order and describes a test picture.

Reading and writing subtests require the subject to break words into component sounds or letters (phonetic analysis), integrate sounds or letters into words (synthesis), copy letters and words, write words from dictation, and read sounds, words, phrases, and paragraphs.

A general methodologic critique has been offered by Adams (1979, 1980a, 1980b), including standardization, scaling, and item selection. Further, Spiers (1981, 1982) raised fundamental questions involving selection of subjects, localization procedures, confounding of items, and failure to have sufficient items sensitive to specific neurologic syndromes including the many syndromes encountered in the study of aphasia. Moreover, a separate screening test for aphasia is not part of the Luria-Nebraska examination.

In a clinical setting, the Luria-Nebraska examination may be of value for detecting the presence of neural pathology but is of more limited value in diagnosing specific neurologic disorders or localizing which loci are damaged. The brevity of the exam as compared with the Halstead-Reitan Battery has been appreciated by some researchers. However, the value of this examination for delineating features of aphasia remains unproven.

Montreal Neurological Battery

Brenda Milner and associates at the Montreal Neurological Institute and McGill University (see Kolb & Whishaw, 1982) have studied patients with specific surgical resections. Tests were devised that were sensitive to deficits such as anterior temporal lobectomy, mesiotemporal amygdalectomy and hippocampectomy, and anterior frontal lobectomy. The tests were based mainly on the study of epileptic patients with surgical procedures. The development of most of the specific testing procedures were the result of individual experiments rather than an a priori conception of what ought to be defective in neurologically handicapped patients. Un-

like the Halstead-Reitan and Luria-Nebraska batteries, primarily utilized in clinical settings, the Montreal Neurological Battery is mainly used as a research instrument.

Auditory–verbal functions of potential interest to the study of language are assessed by tests of speech lateralization with a handedness questionnaire and by dichotically presented digits, object naming, the Chapman-Cook speed of reading test, spelling, phonetic discrimination, and the Token Test, an aphasia screening examination (DeRenzi & Vignolo, 1962).

Additional measures include the following: intelligence (WAIS or Wechsler-Bellevue IQ scales); visual perceptual skills (McGill picture–anomalies test, Mooney faces, Rey Complex Figures); memory, (Weschsler memory scale); spatial tests (left–right orientation and Semmes body-placing test); somatosensory tests (passive movement, point localization, 2-point discrimination, and simultaneous extinction); hippocampal function (Corsi's recurring blocks are sensitive to right hippocampal impairment and Hebb's recurrent digits are sensitive to left hippocampal dysfunction); frontal lobe function (Wisconsin Card-Sorting Test and the Chicago Word-Fluency Test); motor function (dynamometer test, the Kimura Box Test, and complex arm and facial movement copying).

Since most of these tests originated from separate published neuropsychologic studies that described particular groups of patients with focal lesions, the battery is constructed in a manner that is likely to prove valuable for experimental neuropsychology, but its clinical utility remains unknown. At present, the Montreal Neurological Battery is not marketed because it is mainly used as a research instrument. The time needed to administer the entire testing protocol requires multiple testing sessions.

The value of the three batteries in differential diagnosis of dementing and schizophrenic disorders remains to be determined and constitutes an important research area for future exploration. Overall, none of these instruments, including the aphasia screening tests of the Halstead-Reitan Battery and the Montreal Neurological Battery, provide extensive assessments of aphasia. Instead, batteries specialized for the study of aphasia are utilized.

Aphasia Batteries

Weisenburg and McBride in 1935 created the first formal examination for aphasia. Subsequent batteries included Examining for Aphasia (Eisenson, 1954), the Language Modalities Test for Aphasia (Wepman & Jones, 1961), and the Minnesota Test for Differential Diagnosis of Aphasia (Schuell, 1965). Although these aphasia exams offer valuable insights to the speech pathologist and neuropsychologist, Benton (1967) empha-

sized the failure of these and other aphasia batteries to provide publish test norms for each scale, as well as reliability and validity coefficients. general, these methodologic concerns have been remedied in more rece test including the Porch Index of Communicative Ability (Porch, 196 the Neurosensory Center Comprehensive Examination for Aphasia (Be ton, 1967; Spreen & Benton, 1969), the Boston Diagnostic Aphasia Exa ination (Goodglass & Kaplan, 1972), the Western Aphasia Battery (K tesz & Poole, 1974), and an aphasia screening examination, the Tok Test (TT) (DeRenzi & Vignolo, 1962).

Token Test

The Token Test was developed by DeRenzi and Vignolo in 1962. utilizes sequential commands of increasing complexity. This instrume requiring about 15 minutes to administer, is sensitive to very mild rece tive disorders. The patient is shown tokens of two shapes (circles a rectangles), two sizes (large and small), and five colors. The tokens a arranged in front of the patient, who is then given oral commands e pressed in progressively more complex, nonredundant sentences. The p tient attempts to perform simple manual tasks with the tokens such picking up, touching, or moving one or more of them. The instructio vary in length and number of choices from the set of tokens. Vario versions of the TT have been developed and translated into many la guages including English (Spreen & Benton, 1969).

Porch Index of Communicative Abilities

The Porch Index of Communicative Abilities (Porch, 1967) was d vised as a standardized instrument for measuring a limited sample language functions. This test, mainly utilized in clinical settings, is bas on a theoretical model that communication has three parts: (1) input information through visual, tactile, and auditory channels; (2) integr tion; and (3) output through gestural, verbal, and graphic modalities. T three output modalities are measured through a series of 18 subtes Each subtest uses 10 common objects. Classification is based on one of fi clinical categories, i.e., uncomplicated aphasia, aphasia with verbal fo mulation problems, aphasia with accompanying illiteracy, bilater brain damage, and nonaphasia.

The examination takes about 1 hour to administer and can be r peated with high test–retest reliability. This battery contains 18 te item subtests, 4 verbal, 8 gestural, and 6 graphic. The test is sensitive slight changes and aids in charting clinical improvement. The classific tion of aphasic syndromes does not correspond to clinical syndromes th have long been identified with particular clinico-anatomical correlat (Benson, 1979).

Neurosensory Center Comprehensive Examination for Aphasia

The Neurosensory Center Comprehensive Examination for Aphasia (Benton, 1967; Spreen & Benton, 1969) has 20 tests for the assessment of aspects of language comprehension, language production, retention of verbal material, reading, articulation, and writing (a patient whose writing hand is paralyzed can demonstrate "graphic" behavior by manipulating wooden letters to form words). Additional subtests are given only when the patient performs poorly on a measure of visual or tactile stimuli. These evaluate stereognosis with simple objects, visual agnosia, and form perception. Results can be plotted in a profile for the purpose of comparing the subject's performance with that of a normal standardization group and a group of aphasic patients. Correction procedures are employed for age and education. Most subtests require less than 5 minutes to administer. A variety of materials are used in the tests, including common objects, sound tapes, printed cards, a screened box for tactile recognition, and the TT. Percentiles are available for individual subtests. Each subtest can be separately rated or the language disturbance rated in its entirety.

Boston Diagnostic Aphasia Examination

The Boston Diagnostic Aphasia Examination by Goodglass and Kaplan (1972) is regarded by many researchers as the most comprehensive instrument for assessing aphasic disorders. The examination had its genesis in the neurolinguistic research of Goodglass and Kaplan and associates and the neurologic investigations of Geschwind, Benson, and many others.

This examination was designed to identify language disturbances in aphasic syndromes including fluent (Wernicke's and conduction) and nonfluent (transcortical motor, Broca's, and global) disorders and allied defects such as word-deafness. Characteristic profiles are presented for each aphasic syndrome.

There are 44 scores that assess severity rating, fluency (composed of an articulation rating, phrase length, and verbal agility), auditory comprehension (word discrimination, body part identification, commands, and complex ideational material), naming (responsive, visual confrontation, animal, and body part), reading (word reading and oral sentence reading), repetition (words, high-probability sentences, low-probability sentences), paraphasia (neologistic distortion, literal paraphasias), parietal functions (drawing to command, stick memory, total fingers, right–left orientation, arithmetic, clock setting, three-dimensional blocks), and seven clinical ratings (melodic line, phrase length, articulatory agility, grammatical form, paraphasia in running speech, word finding, and auditory comprehension).

The entire test takes about 3 hours to administer, and requires mul tiple testing sessions when the patient has a global aphasia. The exami nation has been used extensively in neurologic and neurolinguistic stud ies and has been translated into various languages. A detailed study o many of the indices of the Boston Diagnostic Aphasia Examination i provided later in the chapter.

Western Aphasia Battery

The Western Aphasia Battery developed by Kertesz and Poole (1974 is a variation of some of the methods used in the Boston Diagnosti Aphasia Examination. Subtests and scoring methods of clinical interes were preserved so that the test could be administered to an ambulan patient within an hour rather than several hours. The test examine spontaneous speech (fluency and information content), comprehensio (yes–no questions of graded complexity, pointing to items on commanc and performing sequentially ordered auditory commands), repetitio (words, numbers, and sentences), naming (visual naming, naming of ob jects in a category, sentence completion, and questions requiring single word replies). Reading, writing, spelling calculation, drawing, and bloc design are also tested. The scores, scaled for equal difficulty level, ar added to provide the aphasia quotient (AQ) (maximum score is 100). A additional feature of this standardized test is that classification of th major aphasia syndromes (global, Broca's isolation, transcortical moto Wernicke's, transcortical sensory, conduction, and anomic) is achieved b criterion scores for fluency, comprehension, repetition, and naming.

Kertesz and McCabe (1977) have used the Western Aphasia Batter to chart recovery patterns in patients with various aphasic syndrome and etiologies (i.e., vascular and traumatic). Many other instruments ar available for aphasic disorders, and this review, by necessity, is limited t only a few. For additional information regarding aphasia examinatio please refer to Lezak (1976), Benson (1979), and the *8th Mental Measur ments Yearbook* (Buros, 1978).

LOCALIZATION IN APHASIA BY MULTIPLE DISSOCIATION

Aphasia-producing lesions are most frequently the consequence occlusive vascular etiologies whereas traumatic and neoplastic lesio are less common (Benson, 1979). This clinical finding is of importance neuropsychologic assessment. Cases with single-episode vascular lesio are more likely to provide stable baselines of cognitive functioning tha those resulting from traumatic lesions. Many factors govern the loc and severity of traumatic lesions, and thus it is difficult to obtain

homogeneous sample. Neoplastic lesions can produce remote secondary effects through compression. Localization is therefore more complex and the patient's capability of being retested is likely to be compromised by the tumor. Consequently, adequate localization in aphasia research is largely dependent on studies of focal, occlusive–vascular infarcts.

The advent of computerized tomography (CT) scans has made it possible to perform cliniconeuropathologic studies within the living brain. Of the methods available for localization of aphasia-producing lesions, CT is presently the most practical and effective procedure to study vascular etiologies (Hayward, Naeser, & Zatz, 1977). This technique is noninvasive, widely utilized, and available for follow-up studies.

It is important to realize some of the limitations of CT scans and the ways these limitations may be overcome. Although subcortical lesions are most easily identified, cortical lesions of vascular etiology are more difficult to localize. Since the cerebral cortex represents only a small fraction of brain thickness, it is difficult to recognize cortical density changes with certainty. Further, most cortex is situated next to the skull and is therefore a source of artifact. Additionally, it is often difficult to follow gyral configurations on CT. Individual variation in "cut-angle" produces axial images that are substantially different from those found in a standard atlas. These problems, however, can be mitigated by identifying ventricular and other cranial landmarks that bear a relatively constant relationship to the cortical surface. For example, the CT slice that depicts calcification of the choroid plexus also represents portions of the posterior superior temporal gyrus (Hayward et al., 1977). For additional information about localization procedures including nuclear magnetic resonance (NMR) and positron emission transaxial tomography (PETT) scans, see chapter 5.

Several approaches may be undertaken in the analysis of CT scan data including the following.

Method of Multiple Overlap

The most common method utilized in localization studies involves identifying a small group of patients who have lesions that all overlap a single anatomical locus and who exhibit similar symptoms. This approach has the advantage of enhancing information regarding the single structure under investigation. A problem of interpretation, however, is that an area of complete overlap, while being correlated with a deficit, may not be primarily responsible for the impairment as there may be multiple sources of overlap. For example, the insula is the source of many infarcts of the middle cerebral artery yet is identified with a few features of aphasic disorders. It does not follow, therefore, that the insula is responsible for the defects seen in all patients with this lesion. Another

disadvantage of the method of multiple overlap is that the relative impor tance of structures adjacent to the locus under consideration are no directly evaluated.

Computer-assisted Analyses

The CT scan image is composed of density values (also referred to a CT scan numbers or absorption coefficients). The density values are con verted into an image on CT scan film of varying intensities for each pixe (picture element). Low-density (dark) values reflect cerebrospinal fluic (CSF) as well as pathologies such as infarction. Computer programs have been written to perform inferential statistical tests on tissue of a signifi cantly lower density than encountered in control sites. The region under analysis may be limited to a zone designated by the researcher, a method known as *framing,* first utilized by Gordon and Naeser (1977) to study patients with word-deafness and thereafter in various studies including aphasia (Naeser, Hayward, Laughlin, & Zatz, 1981a). The techniques provide an estimate of the lesion volume and distribution of damage producing aphasic disorders at distinct CT slices. Additionally, it is possi ble with the automated hemisphere program to estimate the volume of an entire hemisphere (Naeser, Hayward, Laughlin, Becker, Jernigan, & Zatz, 1981b). Variations in CT signal–noise ratios for different patients, the influence of artifacts such as partial voluming, and motion artifacts make it essential to perform neuropathologic studies to ascertain the accuracy of computer-assisted CT estimates of lesion size. Metter and Hansen (chap. 6) provide additional information about CT scan analyses.

Multiple Dissociation

The term *double-dissociation* refers to a methodology in which it is demonstrated that two lesions of the brain produce differing behavioral consequences by showing that one lesion produces the defective behavior while another one does not, and vice versa. When this concept includes multiple sites identified with distinct deficits it is referred to as *multiple dissociation* (Pribram, 1954, 1982).

The procedure, illustrated in several studies that follow, involves selection of a large, representative sample. The patients, varying from mild transcortical motor aphasics to severely affected global aphasics, have areas of overlap in their lesions. By contrasting negative and posi tive cases of aphasic disorders for the same and different loci, it is possible to establish the loci most likely to be related to the actual disturbance. A matrix of lesion sites is constructed by neuroradiologic assessment that is independent of behavioral testing. The patients receive a wide range of

tests designed to be sensitive to damage of markedly distinct loci. Inferential statistical tests are applied by analyzing the scores on each test of the lesioned and nonlesioned subjects at each neuroanatomical locus. In this manner it is possible to ascertain which sites are most consistently (and significantly related to neuropsychologic deficits on particular tests.

There are several limitations of multiple dissociation. Cases with vascular lesions usually involve damage to the adjacent structures supplied by the arterial system, thus adjacent sites to the critical structure may reveal statistical significance. This problem of overinclusivity is mitigated by showing that for different neuropsychologic tests in the same group of patients, dissociable patterns of lesions can be statistically identified. Other problems include the artifacts that exist in any CT scan analysis.

The three methods are neither mutually exclusive nor exhaustive. For example, it should be possible to design computer programs to isolate specific neural structures, and then perform multiple dissociation. As higher-resolution images become available, i.e., through nuclear magnetic resonance scans, this possibility becomes more practical.

The following studies demonstrate the use of multiple dissociation to establish defects of immediate memory, auditory comprehension, naming, and expression.

MATERIALS AND METHOD

Subjects

The patients all had aphasic disorders. The patients included 26 males and 2 females with single-episode occlusive vascular lesions limited to the territory of the middle cerebral artery of the left hemisphere. The patients ranged in age from 34–78 with a mean of 58 years. All were right-handed, native speakers of English, with at least a high school education. Aphasia testing and CT scans were administered at least 2 months postonset of symptomatology and within 2 weeks of each other.

Aphasia testing included assessment of immediate memory (Gordon, 1983), the TT (Spreen & Benton, 1969), and the Boston Diagnostic Aphasia Exam (Goodglass & Kaplan, 1972). At the time of testing, 7 cases were designated as transcortical motor, 3 as Broca's, 3 as Wernicke's, 5 as conduction, 7 as mixed, and 3 as global aphasics (see Naeser et al., 1981a).

Radiologic Evaluation

CT scans were obtained at the Palo Alto Veterans Medical Center or a Syntex Systems 60 CT-Scanner.* Scans were taken 20 degrees to the orbitomeatal line. Each slice defined a 1-cm thick section of brain. Ter consecutive slices were taken from the level of the base of the brain to the top of the skull. The scans used to assess the lesions and the time o aphasia testing were performed at least 2 months postonset of symptom with a mean of 30 months.

The CT scan film of each patient was evaluated by a radiologist a Stanford University (R. W. H.) for the presence of infarction in distinc neuroanatomical structures. A matrix of the lesion sites was thus con structed. This matrix, shown in Table 6-1, contains the lesion sites for 2 patients who have damage limited to the territory of the middle cerebra of the left hemisphere. This vascular territory was divided into 21 dis tinct zones:

- frontal region (anterior to the precentral gyrus and to Broca' region)
- Broca's area (Brodmann's area 44)
- head of the caudate nucleus
- lenticular nucleus
- anterior limb of the internal capsule
- genu of the internal capsule
- posterior limb of the internal capsule
- zone of the external capsule (external capsule, claustrum, an extreme capsule)
- insula
- temporal pole
- middle temporal gyrus
- Heschl's gyrus
- cortical portion of Wernicke's area (i.e., the posterior two thirds c the superior temporal gyrus)
- white matter immediately deep to Wernicke's area
- cortical portion of the supramarginal gyrus
- white matter underlying the cortex of the supramarginal gyrus
- cortical portion of the angular gyrus
- white matter deep to the angular gyrus
- precentral gyrus
- postcentral gyrus
- corona radiata.

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* Syntex Corp., Palo Alto, Calif.

Table 6-1
CT Scan Localization in Aphasia: Results from 28 Patients

	Transcortical Motor							Broca's			Wernicke's			Conduction					Mixed							Global		
Region	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Frontal zone		+		+	+	+	+																					+
Broca's area		+				+		+		+											+	+				+		+
Head of caudate nucleus	+							+		+										+	+	+	+			+		+
Lenticular nucleus	+		+					+	+	+										+	+	+	+			+		+
Anterior limb of internal capsule	+				+			+		+										+	+	+	+	+		+		+
Genu of internal capsule	+							+													+	+	+					+
Posterior limb of internal capsule	+							+							+						+	+	+	+	+	+	+	+
External capsule			+				+	+	+	+											+	+				+		+
Insula			+		+		+	+	+	+	+	+					+	+	+		+	+	+	+		+	+	+
Temporal pole			+								+	+	+	+										+		+	+	+
Middle temporal gyrus												+		+					+		+	+		+	+		+	+
Heschl's gyrus											+	+	+	+					+		+	+		+	+		+	+
Wernicke's area											+	+	+	+							+	+		+	+		+	+
Deep to Wernicke's											+	+		+	+				+		+	+		+	+		+	+
Supramarginal gyrus			+				+	+		+	+		+	+				+			+	+		+	+		+	+
Deep to supramarginal gyrus			+					+		+	+			+	+			+			+	+		+	+	+	+	+
Angular gyrus								+		+	+		+	+										+	+		+	+
Deep to angular gyrus								+		+	+		+	+										+	+	+	+	+
Precentral gyrus						+	+	+	+							+		+			+	+					+	+
Postcentral gyrus						+	+	+	+	+						+		+			+	+		+	+			+
Corona radiata						+		+	+	+										+	+	+	+	+	+	+	+	+

This table depicts 21 loci for each of 28 aphasic patients. A plus designates the presence of a lesion as demonstrated from neuroradiologic evaluation of CT scan film. Note that the aphasia classifications for the patients are listed in Table 6-2.

The particular selection of sites was based upon structures known or postulated to be related to language functioning and adjacent loci.

This matrix of lesions is fairly representative of most common aphasic syndromes of predominantly prerolandic and postrolandic etiologies and includes at least 6 examples of damage to each site. Structures presented in Table 6-1 are listed from anterior to posterior at various horizontal cross-sectional planes from ventral to dorsal.

Statistical Evaluation by Multiple Dissociation

All of the patients who had damage to a particular structure, such as the anterior limb of the internal capsule, were sorted into a single group, and those without this lesion, into a second group. It was thereby possible to establish whether patients with this lesion scored lower than the remaining patients through the use of one-tailed independent-group *t* tests. The statistical evaluation was carried out in this manner for all 21 sites for each neuropsychologic test. Some investigators, though, have used Bonferroni's criterion for multiple *t* tests. Bonferroni's criterion, however, leads to a high probability of type II (false–negative) errors. The present approach was designed to achieve optimal sensitivity. Only results with *p* less than or equal to .01 are reported. With 21 tests, the binomial probability of a result occurring by chance (alpha = .05) is 2 in 21 comparisons for a value indicated at p less than or equal to .01 and 1 in 21 comparisons for *p* less than or equal to .001. Thus in spite of the fact that multiple *t* tests are performed, the reported results are still highly significant.

Immediate Memory: Binary Digits and Binary Tones

The study of auditory immediate memory was undertaken to further examine how recall of auditory sequences might underlie the ability to understand spoken language. There are many possible reasons why an aphasic patient might fail to comprehend speech. An impairment of phoneme discrimination has been hypothesized. Blumstein, Baker, and Goodglass (1977) concluded that the comprehension deficit of the Wernicke's aphasic, for example, could not be attributed to a deficit in phoneme discrimination; these results were supported by Basso, Casati, and Vignolo (1977). A failure of phoneme discrimination is most likely to arise in word-deafness rather than in aphasia, and in these cases, interhemispheric involvement has been implicated (Geschwind, 1965). A second hypothesis for a defect of aural comprehension is that the patient fails to understand semantic features of individual words. This concept, however, may be difficult to demonstrate. For example, Zaidel (1976) demonstrated that the right hemisphere of patients with either left hemispherectomy or commissurectomy have the capability of identifying pic-

tures corresponding to spoken words at a level commensurate with the 13-year-old. A third hypothesis is that many aphasic patients have a significant impairment in their span of immediate memory for auditory sequences. While most adults can repeat approximately 7 ± 2 digits (Miller's magical number), aphasic patients are markedly limited not only in repetition of numbers but also in pointing to items in a fixed sequence (Albert, 1972). Aphasic patients appear to have a greater defect of immediate recall than patients with other disorders identified with focal lesions. For example, span of immediate recall is generally limited to about two or three items in subjects with posterior perisylvian damage.

Method. The Binary Digit Span Test (DS) (Gordon, 1983) consists of repetition of increasingly long series of binary digits composed of the numbers 1 and 2. All patients tested could correctly repeat at least 2 digits. Since oral apraxia could limit speech, melodies were also tested, consisting of increasingly long combinations of two tones. Singing is usually spared in aphasia. Thus, sequences of tones separated by the musical interval of the fourth (high and low pitched) were sung by the examiner and repeated by the patient. For example, a digital sequence might contain the items 1 1 2 1 whereas a tonal sequence would be produced as L L H L (L = low tone; H = high tone).

Results and discussion. Structures critically related to a deficit in digit span included portions of the entire superior temporal gyrus, middle temporal gyrus, and inferior parietal lobule. The lowest mean involved Wernicke's area (2.5 binary digits), whereas the highest mean was for the patients with damage to the frontal zone (4.87). The overall mean, excluding the transcortical patients, who had normal repetition, was 3.10 bits. Significant diminution of digit span p less than or equal to .01 was identified with damage to Wernicke's area, the middle temporal gyrus, Heschl's gyrus, white matter deep to Wernicke's area, the white matter underlying the supramarginal gyrus, the gray and white matter of the angular gyrus, and the corona radiata (see Table 6-2).

Tone span was equally impaired in these patients, with the lowest span following damage to the middle temporal gyrus (2.69) and Wernicke's area (2.89), whereas the highest tone span was for patients with frontal zone lesions (4.24). The overall mean, excluding transcortical motor aphasics, was 3.14 bits. Lesions related to reduction of tone span included white matter deep to Wernicke's area and the cortex of the middle temporal gyrus. Overall, these aphasic patients were capable of repeating approximately 3 ± 1 bits, whether digital or tonal. These findings are consistent with the idea that a failure to recall any form of unlearned auditory sequence is a fundamental disorder in aphasic patients.

Impairment of repetition of digits was most profoundly produced by

Table 6-2
Loci Identified with Deficits of Immediate Memory, Auditory Comprehension, Recall, and Speech Production

	IM	Comprehension			Recall					Production			
Region	DS	TT	CO	WD	BP	RN	CN	BPN	GN	AA	ML	GF	PL
Frontal zone													
Broca's Area								***	**	***	***	**	
Head of caudate nucleus										***	**	**	
Lenticular nucleus									***	***	***	***	**
Anterior limb of internal capsule		**	***	***		***	**			***	***		
Genu of internal capsule													
Posterior limb of internal capsule		**	**	**	***	**	**	**	**	**	**		**
External capsule zone												**	
Insula											**	**	
Temporal pole													**
Middle temporal gyrus	**	**	**		***	***	***	**			**	**	***
Heschl's gyrus	***	***				**	***						***
Wernicke's area	***	**				**	**						***
Deep to Wernicke's area	***					***	***						***
Supramarginal gyrus													
Deep to supramarginal gyrus	**												
Angular gyrus	**												
Deep to angular gyrus	**												
Precentral gyrus											**	**	
Postcentral gyrus													
Corona radiata	**	**	**	**	***	***	**	***	***	***	***	***	**

This table indicates the structures significantly identified with damage to distinct loci. The tests involve digit span (DS), an assessment of immediate memory (IM), aural comprehension including the Token Test (TT) and the commands (CO), word discrimination (WD), and body part (BP) subtests of the Boston Diagnostic Aphasia Exam. Also from this exam are indices of recall including responsive naming (RN), confrontation naming (CN), body part naming (BPN), and animal naming (an example of generative naming [GN]). Production of speech was assessed by rating scales of the Boston Diagnostic Aphasia Exam included articulatory agility (AA), melodic line (ML), grammatical form (GF), and phrase length (PL).

Two asterisks (**) indicate values where p is less than or equal to .01 and three asterisks (***) indicate values where p is less than or equal to .001 as based upon multiple one-tailed *t* tests.

damage to Wernicke's area, where the mean digit span was 2.5 binary digits. In support of this concept, Selnes, Knopman, and Rubens (1983) reported that damage to Wernicke's area was the best predictor of an enduring deficit of repetition.

Deficits of Auditory Comprehension

To investigate the relationship between auditory–verbal immediate recall and auditory comprehension, various standardized tests were administered including the TT and the comprehension subtests of the Boston Diagnostic Aphasia Exam (Gordon 1985a).

Method. The TT (Spreen & Benton, 1969) was administered to the same group of patients. Auditory comprehension was assessed on the Boston Diagnostic Aphasia Exam including (1) word discrimination (WD) (e.g., pointing on command to pictures of familiar objects, actions, geometric forms, numbers, or letters); (2) Commands (CO), i.e., following sequential commands (Co); and (3) body parts (BP), i.e., pointing to parts of the body named on command.

Results and discussion. The sequential commands of the TT resemble the digit span and tone span tests; increasing long strings of auditory sequential information are retained for a few seconds. Overall, the structures related to deficient performance on the TT included the anterior and the posterior limbs of the internal capsule, the middle temporal gyrus, Heschl's gyrus, Wernicke's area, and the corona radiata. Moreover digit span scores were highly correlated with TT scores (r = .650, p less than .001). By contrast, tone span scores were less associated with the TT scores (r = .460, p less than .05). These findings show that sequential processing is one aspect of auditory comprehension measured by the TT. These results are also consistent with Lesser (1976), who had found a failure of sequencing to be associated with poor performance on the TT.

Deficits on all WD stimuli (verbal and nonverbal materials) were related to damage of white matter tracts including the anterior and posterior limbs of the internal capsule and the corona radiata.

As predicted, the CO section correlated the most highly with the digit span test (r = .589, p less than .01) of the comprehension tests. Tone span was less significantly correlated (r = .481, p less than .05). Thus digit span, the TT, and CO, which all utilize sequential activities, are highly interrelated and involve similar sites within the region of the superior temporal gyrus.

On the BP comprehension test, the lowest percentile score was identified among patients with damage to the posterior limb of the internal capsule. Pyramidal tract lesions within the posterior limb (Ross, 1980) thus may confound scores on this test of "comprehension" either by slow-

ing the rate or reducing the ability of the patient to point to parts of his or her own body.

Damage to the angular gyrus was identified with a difficulty of the patient in pointing to pictures of numbers and letters (verbal items) but not to the other pictures. This finding is consistent with the concept that the angular gyrus subserves auditory–visual functions related to reading (Geschwind, 1965).

Deficits of naming

Naming disorders are ubiquitous in aphasic syndromes, yet their anatomical correlates are not well established. Identification of neural substrates of naming is complicated by the possiblity that storage, retrieval, or both depend on multiple and interdependent systems. A failure of storage may occur among patients with a deficit of WD (as assessed by identifying a visual stimulus that had been named), whereas a failure of retrieval may occur among patients who have intact WD but a deficiency of visual confrontation naming (CN) (as assessed by naming a stimulus that had been identified).

Because there may be distinct forms of naming disturbances, the following scales of the Boston Diagnostic Aphasia Exam were devised (Gordon 1985b): (1) responsive naming (naming by verbal description, e.g., what does one shave with in the morning?); (2) CN (naming by visual presentation of the stimulus object); (3) BP naming (naming parts of one's own body); and (4) controlled fluency, also known as generative naming (GN), involves producing words from a particular category (e.g., naming as many animals as possible in 60 seconds).

Results and discussion. Damage to the middle temporal gyrus and adjacent postrolandic structures had the most detrimental effect on tests of confrontation, responsive, and BP naming, whereas prerolandic lesions had a more detrimental effect on GN as evaluated by the number of animals recalled in 1 minute. Generative naming was most sensitive to damage that included the head of the caudate and the anterior limb of the internal capsule (Gordon, 1980). BP naming was also identified with caudate damage but not the anterior limb of the internal capsule.

Damage to the region of the middle temporal gyrus produced the most deficient confrontation, responsive, and BP naming. Although little is known of the functional significance of the middle temporal gyrus, stimulation of this cortical field produces a significant reduction of CN (Ojemann, 1983; Penfield & Roberts, 1959), and a "pure" word-selection anomia has been identified following damage to the posterior aspect of the middle temporal gyrus (Benson, 1979).

The reduction of GN with caudate lesions merits further discussion. Damasio and Van Hoesen (1981), using CT scan localization studies,

reported the appearance of transcortical motor aphasia with lesions of a white matter zone anterior to the frontal horn and the head of the caudate, a region that probably projects onto the anterior caudate. Note that one of the major defects encountered in patients with transcortical motor aphasia is a deficiency of fluency in controlled association (GN). Metter, Riege, Hanson, Phelps, and Kuhl (1982) described defects of aphasic language with PETT scan localizing information, including identification of semantic materials that involved the caudate nucleus. Further, patients with Huntington's disease have a significant reduction of GN (Butters, Sax, Montgomery, & Tarlow, 1978) but a sparing of visual CN.

Storage versus retrieval of lexical information

Method. An attempt to dissociate storage from retrieval was initiated by contrasting performance for the same lexical categories of WD and CN tests (Gordon, 1985b). As noted in WD, patients were asked to point to a single picture at a time corresponding to a word named by the examiner. These lexical categories included actions, colors, geometric forms, numbers, and letters. In CN the examiner pointed to selected items of the same lexical categories and the patient attempted to name them. Since all patients were capable of correct performance for at least a few items of the WD and CN tests, it is highly probable that comprehension of the nature of the task was not a problem. A failure of CN is most likely to be regarded as a deficit of retrieval, unless the patient was unable to identify the target initially, which could reflect a failure of storage. Although an apraxic disorder could interfere with the WD task, it would not explain why some categories were correctly identified and not others.

The storage (WD) and retrieval (CN) scores for each lexical category were converted into percentiles. A repeated-measures (2×2) analysis of variance (ANOVA) was performed for the lesioned and nonlesioned groups for loci in which a significant t value had been obtained by multiple dissociation. Mean comparisons, when appropriate, were computed using post hoc t tests. A more complete description of this method is available (Gordon & Rosencrantz, 1982).

Results. Retrieval was significantly more impaired than storage for objects, colors, and numbers following damage to the middle temporal, Heschl's, and posterior superior temporal gyri. In contrast, storage was more impaired for letters following damage to the anterior limb of the internal capsule, angular gyrus, and corona radiata. The latter results are consistent with the concept that the left dominant angular gyrus subserves aspects of crossmodal visual–auditory processing as is necessary for reading.

These results address a fundamental issue: whether aphasia is most likely to impair the storage or retrieval of lexical information. The evidence presented suggests that retrieval is most likely to be impaired. The

loci where damage was most significantly related to deficits of retrieval rather than to impoverished storage involved portions of the superior and middle temporal gyri that had been found to be related to retrieval deficits following electrocortical stimulation (Penfield & Roberts, 1959).

Broca's area and Broca's aphasia

The posterior region of the inferior frontal convolution, Brodmann's area 44 or Broca's area, has been regarded as essential for language output. In view of the general acceptance of this concept, it is of interest that actual studies supporting the theory are not overwhelming. Marie performed his own anatomical investigation of Broca's specimens and did not come to the conclusion that Broca's area was necessary for Broca to have communicated his ideas to his colleagues (Marie, 1906). Marie was impressed by the fact that the lesions were never confined to area 44 and often extended as far posterior as the parietal lobe or as deep as the basal ganglia. Marie proposed that there was only a single aphasia, which followed damage to a region termed the *quadrilateral zone*. This zone includes the caudate and lenticular nuclei, and the external and internal capsules (Cole, 1968).

Contemporary evidence supporting the role of area 44 in language processing includes mainly electrical stimulation studies (Penfield & Roberts, 1959). Stimulation of Broca's region does interrupt speech. Only epileptic patients, however, are amenable to this technique and therefore the spread of current to other loci must be considered (Ojemann, 1983). For example, stimulation of the medial frontal region inhibited language processing (Van Buren & Fedio, 1976).

Many studies have failed to demonstrate that Broca's area is necessary or sufficient for language processing:

- Mohr and colleagues (1973, 1976, 1978) demonstrated that infarction affecting Broca's area and its immediate environs causes a mutism that is replaced by a rapidly improving dyspraxic and effortful articulation, without a persisting and significant disturbance of language.
- Two patients that had received anterior frontal resections in psychosurgical procedures that included Broca's area never developed a Broca's aphasia (Pool, Collins, Kessler, Vernon, & Feiring, 1949). Moreover, Metter and Rowland showed that standard Freeman-Watts lobotomies were done through Broca's area and no defect in language resulted (see Pribram, 1982).
- Radioisotope studies by Kertesz and McCabe (1977) of patients with Broca's aphasia revealed a convergence of lesion sites upon the region of the precentral gyrus subserving the articulatory apparatus.

- During spontaneous speech, regional blood flow studies (Larsen, Skinhoj, & Lassen, 1978) did not reveal differential blood flow changes in Broca's area.
- CT scan studies (Bruner, Kornhuber, Seemuller, Suger, & Wallesch, 1982) failed to reveal evidence that an enduring Broca's aphasia follows small lesions of Broca's area.

If Broca's area is not the critical locus for producing Broca's aphasia, what structures are most likely to be involved? According to the Schiff, Alexander, Naeser, and Galaburda, (1983), the pathologic basis of an enduring Broca's aphasia is apparently a large lesion in the posterior frontal and anterior parietal cortical regions with deep extension including insular cortex and underlying white matter including the anterior limb of the internal capsule, the anterior external capsule, and the putamen. In order to further explore this question, multiple dissociation was performed for indices characteristic of Broca's aphasia.

Method. The Boston Diagnostic Aphasia Exam contains a rating scale profile. This profile differs for each aphasic syndrome and is based on a 7-point scale of ratings or test scores. The following four scales are most characteristic of the deficits encountered in Broca's aphasia: (1) melodic line (ML) including intonational contour is severely reduced. (2) phrase length (PL) is reduced to 1–4 words. (3) Articulatory agility (AG), including facility at the phonemic and syllable level, varies in severity from profound or total impairment to a restricted ability for familar words or phrases. (4) Grammatical form (GF) (the variety of grammatical constructions produced) ranges from entirely absent to simple declaratives and stereotypes.

Results and discussion. The results of these four indices are presented in Table 6-2. AG was strongly identified with damage to the head of the caudate and lenticular nuclei as well as to the entire internal capsule and the corona radiata. ML included all of the preceding loci as well as the insula and the middle temporal and postcentral gyri. GF included the striatal loci, the anterior limb (but not the remaining internal capsule) and corona radiata, as well as the insula and the middle temporal and postcentral gyri. PL included loci similar to that of digit span, with predominantly postrolandic perisylvian structures. The structures identified with auditory comprehension have already been presented in separate scales. The overall size of the lesions producing a Broca's aphasia were much larger in the present study than the lesions producing a Wernicke's aphasia. Despite the overall larger size of the lesions, Broca's area was not significantly identified with any of the rating scales.

A relatively rare condition diagnosed as aphemia includes severe dysarthria in the absence of agrammatism, anomia, and specific syntactic comprehension deficits. CT scans in such patients revealed small lesions of the motor system for articulation including the pars opercularis, inferior prerolandic gyrus, or white matter deep to those regions such as the anterior limb of the internal capsule that would damage pathways to the striatum (Schiff et al., 1983). In the present study, a deficit of oral agility was the most significantly identified with damage to the anterior limb of the internal capsule. In contrast, the postcentral gyrus rather than the precentral gyrus was identified in the present studies with some of the rating scales.

The results in this report support the view that Marie's quadrilateral space is strikingly related to deficient AG, ML, and GF, essential deficits encountered in Broca's aphasia. In particular, the caudate and the lenticular nuclei were frequently involved as was the anterior limb of the internal capsule. The presence of insular and external capsule lesions is consistent with the lesion sites proposed by Schiff et al. (1983) for an enduring Broca's aphasia. The processing of information related to language expression is more likely to occur within the neostriatum than the pallidum, the latter mainly serving as an output system for the caudate–putamen (Szabo, 1967).

Other investigators have found aphasia with neostriatal damage. Hier, Davis, Richardson, and Mohr (1977) identified cases of aphasia following hypertensive left putamenal hemorrhage; additional cases were reported by Alexander and Lo Verme (1980). In 1982, Naeser and colleagues described three syndromes involving predominantly subcortical lesion sites including the internal capsule and putamen. Patients with anterior superior putamenal damage had good comprehension, grammatical but slow, dysarthric speech, and enduring right hemiplegia. Except for sparing of grammar, the other features are consistent with a Broca's aphasia. On the other hand, patients with more posterior loci, with extension across auditory radiations in the temporal isthmus, had poorer aural comprehension and fluent Wernicke-type speech. Additionally, Naeser, Alexander, Helm-Estabrooks, Levine, Laughlin, & Geschwind (1982) reported that location rather than the estimated volume of the putamenal/capsular infarct was most critical in producing the deficit.

Caudate Nucleus

Aphasia produced by nonhemorrhagic lesions of the anterior caudate and of the anterior limb of the internal capsule have been studied by T. Damasio and colleagues (1982). Dysarthria occurred in most cases and hemiparesis occurred in all cases. Other studies supporting anterior caudate pathology include the dementia of Huntington's disease. This de-

mentia initially follows degeneration of the head of the caudate nucleus (Kuhl, Phelps, Markham, Metter, Reige, & Winter, 1982) and perhaps its cortical afferents (i.e., mainly the anterior frontal cortex but also auditory association cortex). Cambrier, Elghozi, and Strube (1979) studied a patient with infarction revealed on CT to be limited to the head of the left caudate. The lesion produced incoherence of speech, perseveration of ideas, semantic inconsistencies, and inability to keep a stable objective during speech. The symptoms identified by Cambrier et al. (1979) are consistent with cognitive deficits occurring in Huntington's disease. In studies of 12 cases of Huntington's disease (Illes & Gordon, 1985), the patients manifested significantly deficient ML, PL, AG, and impairment of GF. Note that these findings are compatible with some defects occurring in Broca's aphasia and further substantiate the idea that the caudate may be related to some aspects of Broca's aphasia.

Putamen

The putamen and its afferents also seem to be important in articulation as indicated in the nonfluent aphasia Naeser and associates (1982) identified as anterior capsular/putamenal aphasia. In the present study, the caudate as well as the putamen were identified with the deficits of Broca's aphasia. Nevertheless, much is unknown about the loci contributing to Broca's aphasia. For example, lesions producing a selective deficit of GF have not as yet been established.

Internal Capsule and Corona Radiata

Fibers from the far frontal cortex to the caudate via the anterior limb of the internal capsule carry information that may be critically related to various features of Broca's aphasia. These fibers, as described by Damasio et al. (1982), include the projections between anterior frontal cortex and caudate, between premotor cortex and ventral anterior nucleus of the thalamus, between auditory association cortex and caudate and putamen, and between caudate and globus pallidus. For these reasons, it is not surprising that anterior limb lesions were significantly identified on every test of language function except those involving only immediate memory (DS). The anatomy of the corona radiata also constitutes a complex convergence of fibers of passage. It includes fibers composing the anterior and posterior limbs of the internal capsule. Naeser (1983) proposed that one plausible cause of the anterior putamenal aphasia was damage to the fibers of the corona radiata constituting the periventricular white matter of the corticobulbar system. The patients exhibited grammatic, sentence-length spoken output but slow, severe dysarthria.

Cortico–Neostriatal Disconnection Syndromes?

The cortico–cortical theory of disconnection syndromes, most explicitly theorized by Geschwind (1965), states that the interruption of cortico–cortical connections are critical for production of aphasias. For example, a conduction aphasia putatively follows disconnection of the fibers constituting the arcuate fasciculus that connects Wernicke's area to Broca's area. This theory is the most widely accepted conception of how language is processed. There are, however, substantial difficulties with this theoretical model of the disconnection syndromes (see Kolb & Whishaw, 1980). As noted, one major problem is that Broca's area is not obviously related to Broca's aphasia. Enduring fluent and nonfluent aphasic deficits follow neostriatal damage. Furthermore, syndromes that resemble transcortical motor, Wernicke's, and even global aphasia are produced by damage to the neostriatum and internal capsule. These data suggest that pathways for the formulation and expression of language require projections from neocortex onto neostriatum. The recent wealth of studies reporting striatal aphasias is a significant departure from the classical connectionistic views of Wernicke and his 20th-century proponents. In order to explain language disturbances that follow damage to the neostriatum and its efferents, a proposal is detailed that describes the existence of cortico–neostriatal disconnection syndromes.

Neuroanatomical Studies

Direct cortico–neostriatal projections of the monkey have been anatomically described (Kemp & Powell, 1970; Van Hoesen, Yeterian, & Lavizzo-Mourey, 1981; Yeterian & Van Hoesen, 1978). Findings of Selemon and Goldman-Rakic (1983) support a mediolateral topography of cortico–striatal terminal fields. Portions of the head of the caudate nucleus have been demonstrated to be closely related anatomically and functionally to the anterior frontal cortex (Goldman & Nauta, 1977), although projections from frontal cortex include portions of the body and tail of the caudate.

Projections from area 4 terminate almost entirely upon portions of the putamen. Projections of the "face" area cover the anterior portions of the putamen (Kunzle, 1975). Moreover, cortical projections from precentral and postcentral gyri are located laterally but are restricted largely to the putamen (Goldman & Nauta, 1977).

Area 22 projects mainly to the caudate nucleus, including portions of the head and body as well as much of the tail. A part of the ventral putamen is also involved.

spared auditory comprehension. According to the present model, such defects could arise as the result of damage to the cortico–striatal fibers or to the region of the superior anterior putamen that receives premotor and motor fibers. A nonfluent aphasia acquired in childhood involving the putamen, anterior limb, and lateral aspect of the head of the caudate has recently been reported (Aram, Rose, Rekate, & Whitaker, 1983).

The posterior capsular putamenal aphasia described by Naeser et al. (1982), which produces a fluent, Wernicke's-like aphasia, was attributed to posterior putamenal/capsular damage in which the temporal isthmus was implicated. According to the present model, such an aphasia could arise from damage to parts of the neostriatum receiving direct projections from the posterior aspect of the superior temporal gyrus, primarily the medial aspect of the tail and body of the caudate, and the ventrocaudal putamen.

Kornhuber (1977) first identified global aphasia with damage to the basal ganglia. Naeser et al. (1982) presented cases of global aphasia when both the posterior capsular/putamenal and the anterior capsular/putamenal regions were damaged. The finding of global aphasia is consistent with the concept that there is disconnection of prerolandic and postrolandic cortical fields to their neostriatal projections.

There are many other possible forms of disconnection patterns that could result from circumscribed damage to portions of the striatum, but there is insufficient space to detail these possibilities.

How might connections occur between various cortical fields as they are represented within the neostriatum? Yeterian and Van Hoesen (1976) proposed that the cortico–cortical projections that have reciprocal connections, i.e., the precentral and postcentral gyri, have projections to virtually the same part of the neostriatum. The same principle has held for fibers interconnecting anterior frontal, temporal, and inferior parietal lobule cortices as represented by certain corticostriate projections to similar parts of both the rostral and caudal striatum (Van Hoesen, Yeterian, & Lavizzo-Mourey, 1981). Regions with powerful cortico–cortical connectivities demonstrated by white matter projections thus may have a parallel representation within the gray matter of the caudate–putamen. These connections would probably occur between spiny type I cells, which make up 95 percent of all the neurons of the neostriatum. Although spiny type I neurons form outputs to the pallidum, they have sufficient dendritic spines (8,000–10,000/cell) to also act as interneurons (see Penny & Young, 1983).

Language deficits related to pallidal and thalamic loci

The major output of neostriatum is the pallidum, which in turn projects to the ventral lateral, ventral anterior, and centre median thalamic

nuclei. The cortico–striate disconnection theory would predict language defects resulting from damage to neostriatal efferents.

Dysarthria, dysphasia, and deterioration of voice volume followed unilateral left lesions of the globus pallidus (Hermann, Turner, Gillingham, & Gaze, 1966), and word-finding difficulties and dysarthria followed stereotaxic lesions of the posteromedial part of the pallidum (Svennilson, Torvik, Lowe, & Leksell, 1960) in patients with Parkinson's disease.

Stereotactic lesions of the left ventral lateral (VL) thalamic nucleus produce a syndrome involving anomia, dysarthria, dysphonia, and intact comprehension (Ojemann, 1983). Additionally, stimulation of the VL during speech or memory tasks can induce perseveration of the first syllable or production of the wrong word and reduction of rate of articulation. Ojemann proposed (1983) that one of the functions of the left VL is to focus attention on verbal material in the external environment while simultaneously blocking retrieval of already internalized verbal information.

The projections between the pallidum and centre median nucleus have been described (Nauta & Mehler, 1966). Observations from human pathology in cases of the hereditary form of torsion dystonia (dystonia musculorum deformans) demonstrate destruction of small cells of the centre median projecting to the putamen (Jung & Hassler, 1960). Torsion dystonia is characterized by involuntary movements with dementia and incomprehensible speech (Spillane, 1968). Anomia and other memory defects follow stimulation of the left pulvinar (Ojemann, Fedio, & Van Buren, 1968) that projects onto the auditory intrinsic cortex.

If disconnection of basal ganglia afferents and efferents, or destruction of the basal ganglia, produce a disturbance of higher functions including language, pathology of regions of the neostriatum receiving distinct configurations of cortical projections should result in varying profiles of cognitive impairments. It is now clearly established that most dementias involve pathology of the basal ganglia. The dementia occurring in some forms of Parkinson's disease (Martin, 1968) and in Huntington's disease initially involve the neostriatum. The medial globus pallidus is at least partially involved in the dementias of Wilson's disease, progressive supranuclear palsy (Albert, Feldman, & Willis, 1974) and the mental retardation arising in Hallervorden-Spatz disease (Penny & Young, 1983). The degenerative process of Alzheimer's disease originates within a region immediately below the pallidum known as the nucleus basalis of Meynert (Whitehouse, Price, Struble, Clark, Coyle, & DeLong, 1982). Later in this dementia, there is reportedly extensive pathology of the amygdala, also a part of the basal ganglia (Herzog & Kemper, 1980). Although it is generally believed that dementias result mainly when these pathologies involve the cortex, review of literature

concerning focal lesions of the basal ganglia in animals and huma supports the view that damage limited to the basal ganglia is sufficien produce a cognitive disturbance.

CONCLUSION

The use of multiple dissociation was discussed as a means to fac tate the investigation of brain–behavior relationships. Various neu psychologic instruments of relevance to the study of language were viewed. Application of multiple dissociation for patients with fo lesions is amenable to the investigation of other neuropsychologic a neurolinguistic variables.

By applying multiple dissociation with CT scan findings in patie with focal vascular lesions and aphasia, it was possible to distingui configurations of lesions identified with impairment of immediate me ory and of aspects of the storage and retrieval of lexical information. T importance of the neostriatum and its relationship to lexical retrie and speech production were described. In order to integrate many rec findings relating aphasic disorders to pathology of the internal capsu caudate, and putamen, it was proposed that cortico–neostriatal disc nection syndromes responsible for language and other cognitive defe occur. This concept was supported by the present series of studies and review of research concerning (1) nonhuman investigations; (2) langua deficits resulting from striatal and capsular damage; (3) language distu bances following damage to the pallidum and thalamus; and (4) deme ing disorders where pathology initially involves the striatum.

REFERENCES

Adams, K. (1979). Linear discriminant analysis in clinical neuropsychology search. *Journal of Clinical Neuropsychology, 1,* 259–272.

Adams, K. (1980a). In search of Luria's battery: A false start. *Journal of Consu ing and Clinical Psychology, 48,* 511–516.

Adams, K. (1980b). An age of innocence for behavioral neurology? Adams repli *Journal of Consulting and Clinical Psychology, 48,* 522–524.

Albert, M. L. (1973). Auditory sequencing and left cerebral dominance for la guage. *Neuropsychologia, 10,* 245–248.

Albert, M. L., Feldman, R. G., & Willis, A. L. (1974). The subcortical dementia progressive supranuclear palsy. *Journal of Neurology, Neurosurgery, a Psychiatry, 37,* 121–130.

Aldrige, J. W., Anderson, R. J., & Murphy, J. T. (1980). The role of the ba

ganglia in controlling a movement initiated by a visually presented cue. *Brain Research, 192,* 3–16.

Alexander, M. P., & LoVerme, S. R. (1980). Aphasia after left hemispheric intracerebral hemorrhage. *Neurology, 30,* 1193–1201.

Aram, D. W., Rose, D. F., Rekate, H. L., & Whitaker, H. A. (1983). Acquired capsular/striatal aphasia in childhood. *Archives of Neurology, 40,* 614–617.

Basso, A., Casati, G., & Vignolo, L. A. (1977). Phonemic identification defect in aphasia. *Cortex, 13,* 85–95.

Beaubaton, D., Amato, G., Trouche, E., & Legallet, E. (1980). Effects of putamen cooling on the latency, speed and accuracy of a pointing movement in the baboon. *Brain Research, 196,* 572–576.

Benson, D. F. (1967). Fluency in aphasia: Correlation with radioactive scan localization. *Cortex, 3,* 373–394.

Benson, D. F. (1979). *Aphasia, alexia and agraphia.* New York: Churchill Livingstone.

Benson, D. F., & Geschwind, N. (1971). Aphasia and related cortical disturbances. In A. B. Baker & L. H. Baker (Eds.), *Clinical neurology.* New York: Harper & Row.

Benton, A. L. (1967). Problems of test construction in the field of aphasia. *Cortex, 3,* 32–53.

Benton, A. L. (1974). Psychological testing, in A. B. Baker & L. H. Baker (Eds.), *Clinical neurology.* New York: Harper & Row.

Benton, A. L., Hamsher, K., Varney, N. R., & Spreen O. (1983). *Contributions to neuropsychological assessment: A clinical manual.* New York: Oxford University Press.

Blumstein, S. E., Baker, E., & Goodglass, H. (1981). Phonological factors in auditory comprehension in aphasia. *Neuropsychologia, 15,* 19–30.

Boll, T. J. (1978). Diagnosing brain impairment. In B. B. Wolman (Ed.), *Diagnosis of mental disorders: A handbook.* New York: Plenum Press.

Boll, T. J. (1981). The Halstead-Reitan Neuropsychology Battery. In S. B. Filskov & T. J. Boll (Eds.), *Handbook of clinical neuropsychology.* New York: John Wiley.

Boone, D. R. (1978). Review of the Halstead Aphasia Test. *8th Mental Measurements Yearbook.* Highland Park, NJ: Cryphon Press.

Bruner, R. J., Kornhuber, H. H., Seemuller, E., Suger, G., & Wallesch, C. W. (1982). Basal ganglia participation in language pathology. *Brain and Language, 16,* 281–299.

Buros, O. (1978). *Eighth Mental Measurement Handbook.* Highland Park, NJ: Cryphon Press.

Buenger, A. A., Gross, C. G., & Rocha-Miranda, C. E. (1974). Effects of ventral putamen lesions on discrimination learning in monkeys. *Journal of Comparative Physiology and Psychology, 83,* 440–446.

Butters, N., Sax, D., Montgomery, K., & Tarlow, S. (1978). Comparison of the neuropsychological deficits associated with early and advanced Huntington's disease. *Archives of Neurology, 35,* 585–589.

Cambrier, J., Elghozi, D., & Strube, E. (1979). Hemorragie de la tete du noyau caude gauche. *Revue Neurologique, 135,* 11, 763–714.

Christensen, A. L. (1974). *Luria's neuropsychological investigation.* Copenhagen: Munksgaard.

Cohen, S. (1972). Electrical stimulation of cortical-caudate pairs during delayed successive visual discrimination in monkeys. *Acta Neurobiologiae Experimentalis, 32,* 211–233.

Cole, M. (1968). The anatomical basis of aphasia as seen by Pierre Marie. *Cortex, 4,* 172–183.

Cummings, J. L., & Duchen, L. W. (1981). The Kluver-Bucy syndrome in Pick's disease: Clinical and pathological correlations. *Neurology, 31,* 1415–1422.

Damasio, A. R., Damasio, H., Rizzo, M., Varney, N., & Gersh, F. (1982). Aphasia with nonhemorrhagic lesions in the basal ganglia and internal capsule. *Archives of Neurology, 39,* 15–23.

Damasio, H., & Van Hoesen, W. (1982). Anatomic basis of some subcortical aphasias. *Neurology, 32,* A95.

DeRenzi, E., & Vignolo, L. A. (1962). The Token Test: A sensitive test to detect receptive disturbances in aphasics. *Brain, 85,* 665–678.

Divac, I. (1972). Neostriatum and functions of prefrontal cortex. *Acta Neurobiologica Experimentalis, 32,* 461–477.

Divac, I., Rosvold, H., & Szwarchbart, M. (1967). Behavioral effects of selective ablation of the caudate nucleus. *Journal of Comparative Physiological Psychology, 63,* 184–190.

Eisenson, J. (1954). *Examining for aphasia.* New York: Psychological Corp.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198.

Gazzaniga, M. S., & Ledoux, J. E. (1978). *The integrated mind.* New York: Plenum Press.

Geschwind, N. (1979). Specializations of the human brain. In *Scientific American* (Ed.), *The Brain,* 108–117. San Francisco: W. H. Freeman.

Geschwind, N. (1965). Disconnextion syndromes in animals and man. *Brain, 88,* 237–294, 585–644.

Golden, C. J. (1978). *Diagnosis and rehabilitation in clinical neuropsychology.* Springfield, IL: Charles C. Thomas.

Golden, C. J., Hammeke, T. A., & Purisch, A. D. (1978). Diagnostic validity of a standardized neuropsychological battery derived from Luria's neuropsychological tests. *Journal of Consulting and Clinical Psychology, 46,* 1258–1265.

Goldman, P. S., & Nauta, W. H. H. (1977). An intricately patterned prefrontocaudate projection in the rhesus monkey. *Journal of Comparative Neurology, 171,* 369–386.

Goodglass, H., & Kaplan, E. (1972). *The assessment of aphasia and related disorders.* Philadelphia: Lea & Febiger.

Gordon, W. P. (1981). Lesions related to deficits of immediate and long-term memory in aphasia. *International Journal of Neuroscience, 12,* 185–186.

Gordon, W. P. (1983). Memory disorders in aphasia: 1. Auditory immediate memory. *Neuropsychologia, 4,* 325–339.

Gordon, W. P. (1985a). Memory disorders in aphasia: 2. Auditory comprehension. *Neuropsychologia, 15.*

Gordon, W. P. (1985b). Memory disorders in aphasia: 3. Long term memory. *Neuropsychologia, 15.*

Gordon, W. P., & Naeser, M. A. (1977). Frequency discrimination deficits in three word-deaf patients with bilateral temporal lobe lesions. *Proceedings of the Academy of Aphasia, 15,* 54–57.

Gordon, W. P., & Rosencrantz, P. (1982). *Statistical methods of analyzing CT scans data based upon neuroradiological localization.* Paper presented at the 11th annual meeting of the International Neuropsychological Society, Pittsburgh.

Halstead, W. C. (1947). *Brain and intelligence.* Chicago: University of Chicago Press.

Hayward, R. W., Naeser, M. A., & Zatz, L. M. (1977). Cranial computed tomography in aphasia. *Radiology, 123,* 653–660.

Hermann, K., Turner, J. W., Gillingham, F. J., & Gaze, R. M. (1966). The effects of destructive lesions and stimulation of the basal ganglia on speech mechanisms. *Confinia Neurologica 27,* 197–207.

Herzog, A. G., & Kemper, T. L. (1980). Amygdaloid changes in aging and dementia. *Archives of Neurology, 37,* 625–629.

Hier, D. B., Davis, K. R., Richardson, E. P., & Mohr, J. P. (1977). Hypertensive putaminal hemorrhage. *Annals of Neurology, 1,* 152–159.

Illes, J., & Gordon, W. P. (1985). Neurolinguistic defects of Huntington's disease. Submitted to the *Brain and Language.*

Jung, R., & Hassler, R. (1960). The extrapyramidal motor system. *Handbook of physiology Section 1: Neurophysiology, Vol. II* (pp. 837–949). Washington, DC: American Physiological Society.

Kemp, J. M., & Powell, T. P. S. (1970). The cortico-striate projection in the monkey. *Brain, 93,* 525–546.

Kertesz, A. (1983). Issues in localization. In A. Kertesz (Ed.), *Localization in neuropsychology* (pp. 1–17). New York: Academic Press.

Kertesz, A., & McCabe, P. (1977). Recovery patterns and prognosis in aphasia. *Brain, 100,* 1–10.

Kertesz, A., & Poole, E. (1974). The aphasia quotient: The taxonomic approach to measurement of aphasic disability. *Canadian Journal of Neurological Sciences, 1,* 7–16.

Kiernan, R. (1983). *Neurobehavioral Mental Status Examination.* Northern California Neurobehavioral Group.

Kolb, B., & Whishaw, I. Q. (1980). *Fundamentals of human neuropsychology.* San Francisco: Freeman.

Kornhuber, H. H. (1977). A reconsideration of the cortical and subcortical mechanisms involved in speech and aphasia. In J. E. Desmedt (Ed.), *Language and hemispheric specialization in man: Cerebral ERPs. Progress in clinical neurophysiology, Vol. 3* (pp. 28–35). Basel: Karger.

Kuhl, D. E., Phelps, M. E., Markham, C. H., Metter, E. J., Riege, W. H., & Winter, J. (1982). Cerebral metabolism and atrophy in Huntington's disease determined by 18 FDG and computed tomographic scan. *Annals of Neurology, 12,* 425–434.

Kunze, W., McKenzie, J. S., & Bendrups, A. P. (1979). An electrophysiological

study of thalamo-caudate neurones in the cat. *Experimental Brain Research, 36,* 233–244.

Kunzle, H. (1975). Bilateral projections from precentral motor cortex to the putamen and other parts of the basal ganglia: An autoradiographic study in Macaca Fasicularis. *Brain Research, 88,* 196–209.

Larsen, B., Skinhoj, E., & Lassen, N. A. (1978). Variations in regional cortical blood flow in the right and left hemispheres during automatic speech. *Brain, 101,* 193–209.

Lashley, K. S., Hebb, D. O., Morgan, C. T., & Nissen, H. W. (Eds.). (1960). *The neuropsychology of Lashley: Selected papers of K. S. Lashley.* New York: McGraw-Hill.

Lesser, R. (1976). Verbal and non-verbal memory components in the token test. *Neuropsychologia, 14,* 79–85.

Levine, M. S., Hull, C. D., Villablanca, J. R., Buchwald, N. A., & Garcia-Rill, E. (1982). Effects of caudate nuclear or frontal ablation in neonatal kittens or adult cats on the spontaneous firing of forebrain neurons. *Developmental Brain Research, 4,* 129–138.

Luria, A. R. (1976). *The neuropsychology of memory.* New York: John Wiley.

Marie, P. (1906). Revision de la question de l'aphasie: L'aphasie de 1861 a 1866; essai de critique historique sur la genese de la doctrine de Broca. *Semaine Medicale, 26,* 265–571.

Martin, J. P. (1968). Wilson's disease. In P. H. Vinken & G. W. Bruyn, (Eds.), *Handbook of clinical neurology: Diseases of the basal ganglia, Vol. 6* (pp. 267–278).

McNeil, M. R., & Prescott, T. E. (1978). *Revised Token Test.* Baltimore: University Park Press.

Metter, E. J., Riege, W. H., Hanson, W. R., Phelps, M. E., & Kuhl, D. E. (1982). Role of the caudate in aphasic language: Evidence from FDG positron emission CT. *Neurology, 32,* A94.

Mohr, J. P. (1973). Rapid amelioration of motor aphasia. *Archives of Neurology, 28,* 77–82.

Mohr, J. P. (1976). Broca's area and Broca's aphasia. In H. Whitaker & H. A. Whitaker (Eds.), *Studies in neurolinguistics, Vol. 3* (pp. 201–235). New York: Academic Press.

Mohr, J. P., Pessin, M. S., Finkelstein, S., Funkenstein, H. H., Duncan, G. W., & Davis, K. R. (1978). Broca's aphasia: Pathologic and clinical. *Neurology, 28,* 311–324.

Naeser, M. A. (1983). CT scan lesion size and lesion locus in cortical and subcortical aphasias. In A. Kertesz (Ed.), *Localization in neuropsychology* (pp. 63–119).

Naeser, M. A., Alexander, M. P., Helm-Estabrooks, N., Levine, H. L., Laughlin, S. A., & Geschwind, N. (1982). Aphasia with predominantly subcortical lesion sites: Description of three capsular/putaminal aphasia syndromes. *Archives of Neurology, 39,* 2–14.

Naeser, M. A., Hayward, R. W., Laughlin, S. A., & Zatz, L. M. (1981a). Quantitative CT scan studies in aphasia. I. Infarct size and CT numbers. *Brain and Language, 12,* 140–164.

Naeser, M. A., Hayward, R. W., Laughlin, S., Becker, J. M. T., Jernigan, T., &

Zatz, L. M. (1981b). Quantitative CT scan studies in aphasia. II. Comparison of the right and left hemispheres. *Brain and Language, 12,* 165–189.

Nauta, W. J., & Mehler, W. R. (1966). Projections of the lentiform nucleus in the monkey. *Brain Research, 1,* 3–42.

Ojemann, G. A. (1983). Brain organization for language from the perspective of electrical stimulation mapping. *The Behavioral and Brain Sciences, 2,* 189–230.

Ojemann, G. A., Fedio, P., & Van Buren, J. M. (1968). Anomia from pulvinar and subcortical parietal stimulation. *Brain, 91,* 99–117.

Penfield, W., & Roberts, L. (1959). *Speech and brain mechanisms.* Princeton, NJ: Princeton University Press.

Pool, J. L., Collins, L. M., Kessler, E., Vernon, L. J. & Feiring, E. (1949). Surgical procedure. In F. A. Mettler (Ed.), *Selective partial ablation of the frontal cortex* (pp. 34–47). New York: Paul B. Hoeber, medical division of Harper & Brothers.

Porch, B. E. (1967). *Porch Index of Communicative Ability.* Palo Alto, Ca: Consulting Psychologists Press.

Pribram, K. H. (1954). Towards a science of neuropsychology (method and data). In R. A. Patton (Ed.), *Current trends in psychology and the behavioral sciences* (pp. 118–142). Pittsburgh: University of Pittsburgh Press.

Pribram, K. H. (1982). *Languages of the Brain.* Brandon House, New York.

Pribram, K. H. (1977). New dimensions in the functions of the basal ganglia. In C. Shagass, S. Gershon, & A. J. Friedhoff (Eds.), *Psychopathology and brain dysfunction.* New York: Raven Press.

Pribram, K. H. (1982). Functional organization of the cerebral isocortex. In G. Schaltenbrand & E. Walker (Eds.), *Stereotaxy of the human brain* (2nd ed.) (pp. 306–328). Stuttgart, Germany: Verlag.

Reitan, R. M., & Davison, L. A. (1974). *Clinical neuropsychology: Current status and application.* New York: John Wiley.

Reitan, R., & Heimburger, R. F. (1955). *Halstead-Wepman Screening Test for Aphasia.* Chicago: University of Chicago, Industrial Relations Center.

Ross, E. (1980). Localization of the pyramidal tract in the internal capsule by whole brain dissection. *Neurology, 30,* 59–64.

Schiff, H. B., Alexander, M. P., Naeser, M. A., & Galaburda, A. M. (1983). Aphemia: Clinical-anatomic correlations. *Archives of Neurology, 40,* 720–727.

Schuell, H. M. (1965). *Minnesota Test for Differential Diagnosis of Aphasia.* Minneapolis: University of Minnesota.

Selemon, L. D., & Goldman-Rakic, P. S. (1983). *Medio-lateral topography of cortico-striatal terminal fields in rhesus monkey.* Boston: Society for Neuroscience Abstracts, 13th annual meeting (p. 659).

Selnes, O. A., Knopman, D., & Rubens, A. B. (1983). *Anatomical correlates of repetition deficits in aphasia.* Paper presented at the 11th Annual Meeting of the International Neuropsychologica Society, Mexico City.

Smith, A. (1975). Neuropsychological testing in neurological disorders. In W. J. Friedlander (ed.), *Advances in neurology, Vol. 7* (pp. 49–110). New York: Raven Press.

Smith, A. (1981). Principles underlying human brain functions in neuropsychological sequelae of different neuropathological processes. In S. B. Filskov &

T. J. Boll (Eds.), *Handbook of clinical neuropsychology* (pp. 175–226). New York: John Wiley.

Spiers, P. A. (1981). Have they come to praise Luria or to bury him?: The Luria-Nebraska battery controversy. *Journal of Consulting and Clinical Psychology, 49,* 331–341.

Spiers, P. A. (1982). The Luria-Nebraska neuropsychological battery revisited: A theory in practice or just practicing. *Journal of Consulting and Clinical Psychology, 50,* 301–306.

Spillane, J. D. (1968). *An atlas of clinical neurology.* New York: Oxford University Press.

Spreen, O., & Benton, A. L. (1969). *The Neurosensory Center Comprehensive Examination for Aphasia.* British Columbia, Candada: University of Victoria, Neuropsychology Laboratory.

Strub, R. C., & Black, F. W. (1977). *Mental status examination in neurology.* Philadelphia: F. A. Davis.

Svennilson, E., Torvik, A., Lowe, R., & Leksell, L. (1960). Treatment of Parkinsonism by stereotactic thermolesions in the pallidal region. *Acta Psychiatrica, 35,* 358–377.

Szabo, J. (1967). The efferent projections of the putamen in the monkey. *Experimental Neurology, 19,* 463–476.

Taylor, M. L. (1968). A measurement of functional communication in aphasia. *Archives of Physical Medicine and Rehabilitation, 46,* 101–107.

Van Buren, J. M., & Fedio, P. (1975). Functional representation of the medial aspect of the frontal lobes in man. *Journal of Neurosurgery, 44,* 275–289.

Van Hoesen, G. R., Yeterian, E. H., and Lavizzo-Mourey, R. (1981). Widespread corticostriate projections from temporal cortex of the rhesus monkey. *Journal of Comparative Neurology, 199,* 205–219.

Villablanca, J. R., Marcus, R. J., & Olmstead, C. E. (1976). Effects of caudate nuclei or frontal cortical ablations in cats. 1. Neurology and gross behavior. *Experimental Neurology, 52,* 389–420.

Villablanca, J. R., Olmstead, C. E., & De Andres, I. (1978). Effects of caudate nuclei or frontal cortical ablations in kittens: Responsiveness to auditory stimuli and comparisons with adult-operated littermates. *Experimental Neurology, 612,* 635–649.

Wepman, J. (1961). *Language Modalities Test for Aphasia.* Chicago: Education Industry Service.

Whitehouse, P. J., Price, D. L., Struble, R. G., Clark, A. W., Coyle, J. T., & DeLong, M. R. (1982). Alzheimer's disease and senile dementia: Loss of neurons in the basal forebrain. *Science, 215,* 1237–1239.

Yeterian, E. H., & Van Hoesen, G. W. (1976). Cortico-striate projections in the rhesus monkey: The organization of certain cortico-caudate connections *Brain Research, 139,* 43–63.

Zaidel, E. (1976). Auditory vocabulary of the right hemisphere after brain bisection or hemidecortication. *Cortex, 12,* 191–211.