Language Function and Dysfunction among Chinese- and English-Speaking Polyglots: Cortical Stimulation, Wada Testing, and Clinical Studies

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Language functions in a group of Chinese- and English-speaking polyglots living in a multiracial society have been investigated by several methods: the effects of cortical stimulation on object-naming and reading tasks in patients who required awake craniotomy, lateralization of cerebral dominance for speech by the Wada Test, and the pattern of language loss and recovery following stroke. The data indicate that these polyglots were all left hemisphere dominant for the languages tested; no consistent evidence for increased participation by the right hemisphere for language functions was found. The cortical stimulation experiments provided data most compatible with the "differential localization" model of cerebral localization in bilingualism. The variable which most influenced performance in all of these investigations was which language was used primarily for speaking as well as reading and writing at the time of the study.

INTRODUCTION

A question frequently asked about bilingualism is whether two or more languages occupy a different brain space than a single language. Reviewing the literature that discusses polyglot aphasia where languages are differentially impaired or recovered highlights the issue of neuroanatomic

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localization (Paradis, 1977). At least four anatomic models of the multilingual brain have been discussed over the past century: "available space," "modality-performance," "lateralization," and "differential localization."

The "available space" theory suggests that the volume of brain damage affects multiple language use by simply limiting the total brain available for language functions (discussed by Minkowski, 1927; Halpern, 1950; Krapf, 1957; Charlton, 1964). The "modality-performance" model holds that brain damage may differentially affect visual (writing and reading) versus auditory (speaking and hearing) modalities, thus altering the premorbid patterns of multiple language skills (Minkowski, 1927; Halpern, 1941, 1949, 1950; Luria, 1956; Hinselwood, 1902). The "lateralization" model states that there are different degrees of left- and right-hemisphere participation in the languages of the polyglot; asymmetrical brain damage may differentially affect the premorbid patterns of multiple language skills. In addition, there may be differential recovery in each hemisphere after brain injury (see Albert Obler, 1978; Halpern, 1950; Minkowski, 1927; Anastoasopoulos, 1959). The "differential localization" model holds that two (or more) languages occupy different loci within the language hemisphere (Scoresby-Jackson, 1867; Ojemann and Whitaker, 1978a, 1978b). Scoresby-Jackson anecdotally reported the case of an Englishman who had lost his knowledge of Greek after head trauma, asking, "Where was that gentleman's Greek deposited that it could be blotted out by a single stroke whilst his native language and all else remained?" Scoresby-Jackson speculated that since the foot of the third frontal convolution is used to learn the mother tongue, the remaining portion might be available for other languages. However, Pitres (1895) argued that it is unnecessary to propose the existence of new centers specifically for each new language learned by polyglots. Potzl (1925), Minkowski (1927), Veyrac (1931), and Ombredane (1951) all argue against anatomically separate regions for different languages. In spite of their extensive experience with bilingual patients, Penfield and his colleagues did no systematic testing of the differential localization hypothesis. They did report one case in which electrical stimulation of different cortical sites evidently affected the two languages (French and English) of their subject differently; nevertheless, Penfield and Roberts (1959) concluded that the cortical representation of language is the same regardless of whether one, two, or more languages are acquired.

On the other hand, there are data supporting the differential localization model. Ojemann and Whitaker (1978a) reported the cases of two bilinguals, one Dutch-English and one English-Spanish, undergoing craniotomy and cortical resection as treatment for medically intractable epilepsy. In this procedure, electrical stimulation mapping of cortical sites involved in language is carried out; in these two cases, mapping of sites was done in both languages of each patient. Sites toward the center of the language zone were more involved in both languages than sites to the periphery of the zone; a number of sites were found in which one but not the other language was represented, and vice versa, indicating a pattern of partial overlap of the areas for each language. The present study replicates and extends these findings in a group of Chinese- and English-speaking polyglot subjects.

The study of brain-language relationships among non-Indo-European language speakers is of special theoretical interest in neurolinguistics. Most of the small body of data on such subjects is presented in the form of reviews or select case history studies (e.g., April & Tse, 1977; April & Han, 1980; Critchley, 1974; Paradis, 1977; Lyman, Kwan & Chao, 1938; Watamori & Sasanuma, 1976, 1978) based on variable and frequently extensive brain pathology. We have prospectively studied the language functions of a group of Chinese- and English-speaking polyglot subjects who were raised in a multicultural-multiracial society.

A variety of complex variables influence the acquisition of a second language; Paradis has reviewed this subject concisely (Paradis, 1977). We have summarized some of the variables inherent in language acquisition for our individual patients in their language profiles outlined in Table 1. but a general comment about the structure of the society where this study was done seems important. Malaysia is a multiracial society in which polyglotism is the rule rather than the exception. Most of the Chinese city dwellers who formed the base population for these investigations speak at least one Chinese dialect in addition to English and sometimes Malay. The English language is important in the economy and therefore is introduced early to children both at home and at school by the Chinese. This timing should be considered because several authors have recently recognized the importance of age at the time of second language acquisition with reference to cerebral dominance (Genesee, Hamers, Lambert, Mononen, Seitz, & Starck, 1978; Sussman, Franklin, & Simon, 1982; Vaid, 1981). Written English is likely to be taught in most schools, and written Chinese (Mandarin) in the Chinese medium schools. The extent to which these factors may foster compound versus coordinate polyglots is conjectural; there are probably elements of both kinds of learning (Lambert, Havelka, & Crosby 1958; Lambert & Fillenbaum, 1959).

Aside from one case mentioned, but not detailed, by Penfield and Roberts (1959) and the careful study of two patients by Ojemann and Whitaker (1978a), there have been no cortical stimulation studies conducted on polyglots. There are no reports of cortical stimulation experiments in Chinese-speaking patients at all. As one part of this report, we describe the effects of left-hemisphere cortical stimulation on object-naming and

				Case			
	_	c i	3	4	Ś	6	7
Father's primary language	CAN	HOK	НОК	нок	CAN	HOK	HOK
Mother's primary language	CAN	нок	НОК	НОК	CAN	нок	НОК
rust tanguage rearined (''mother tongue'')	CAN	НОК	НОК	НОК	CAN	НОК	HOK
Community language (child)	CAN	НОК	HOK	HOK	CAN	HOK	HOK
Primary education	ENG	MAN	ENG	MAN	ENG	ENG	¢.
Secondary education	ENG	MAN/CAN	ENG/CAN	MAN/ENG	ENG	ENG	¢.
University education	ENG	MAN/ENG	ENG		1	ł	ļ
Primary language, work	ENG/MAL	ENG/MAL	ENG	-	ENG		MAN
Primary language, reading	ENG	MAN	ENG	(MAN)	ENG	(ENG)	(NAN)
Primary language, thinking	ENG	MAN	ENG	MAN	ENG	HOK	MAN
Primary language, family	CAN/ENG	MAN/HOK	ENG/HOK	HOK	CAN	HOK	MAN
Primary language, friends	ENG	MAN	ENG/CAN	MAN/HOK	ENG	HOK/ENG	MAN
Community language (adult)	CAN	CAN	НОК	HOK	CAN/ENG	CAN	нок
Subjective proficiency	ENG	MAN	ENG	MAN	ENG	HOK	MAN
(decreasing order of fluency at	CAN	НОК	НОК	HOK	CAN	CAN	НОК
time of study)	MAL	CAN	CAN	ENG		ENG	(ENG)
		ENG					
		MAL					

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reading tasks in three Chinese- and English-speaking polyglots operated upon while awake.

A second aspect of this study investigates lateralization of cerebral dominance for speech by determining the effect of intracarotid injection of sodium Amytal (Wada & Rasmussen, 1960). This technique has been most often used to establish dominance in candidates for epilepsy surgery, who have almost always spoken a single alphabetically based language (Penfield & Roberts, 1959). There is a single paper which reports Wada testing (done only in English) in two bilingual patients, both of whom spoke English and another alphabetic language (Ojemann & Whitaker, 1978a). We are not aware of any reports that systematically evaluate, using Wada testing, patterns of language loss and recovery among polyglots. It has been theorized that polyglots may have a greater incidence of bilateral language representation (Paradis, 1977; Obler, Zatorre, Gallaway, et al., 1982; Sussman et al., 1982; Vaid, 1981). Furthermore, the right hemisphere is believed by some to play an increased role in the language functions of Chinese-speaking patients because the written characters are based on ideograms with few phonetic clues (April & Tse, 1977; April & Han, 1980). It is recognized that, following the onset of clinical dysphasia, most polyglots have all languages equally affected (Charlton, 1964: Paradis, 1977: Rajasekharan & Vermani, 1973). Preferential recovery of one or more languages may occur in several patterns. This has given rise to a variety of rules, laws, and theories as to which of a polyglot's languages is most stable to insult in the language cortex (Paradis, 1977; Pitres, 1895; Paradis, Goldblum, & Abidi, 1982; Gloning & Gloning 1965). We have designed the Wada Test aspect of this study to evaluate patterns of language loss and recovery under controlled conditions in a group of Chinese- and English-speaking polyglots without profound dysphasia.

The third aspect of this study evaluates the recovery of language in four right-handed polyglot patients who survived a left-brain CVA with aphasia. These accidents of nature are, of course, the principal method by which data concerning the organization of neural mechanisms for language in Chinese-speaking patients and in polyglots have been obtained (April & Tse, 1977; April & Han, 1980; Charlton, 1964; Lambert et al., 1958; Lambert & Fillenbaum, 1959; Minkowski, 1927; Paradis, 1977; Rajasekharan & Vermani, 1973; Sasanuma, 1975; Sasanuma & Fujimura, 1971). As noted above, much of this evidence is conflicting. In several controlled studies, however, Sasanuma has shown differing abilities among Japanese-speaking patients who survived left-sided CVA to process kana (phonetic) and kanji (logographic) symbols (Sasanuma, 1975; Sasanuma & Fujimura, 1971). We have asked the same kind of questions of this subpopulation as we asked of patients undergoing cortical stimulation experiments and Wada testing. Doing so enabled us to compare patterns of recovery in the clinical situation with our own stimulation and Wada data, as well as to compare our results with other published series on aphasia among polyglots who survived a CVA.

METHODS

Wada Testing

All patients required cerebral angiography in the evaluation of their disease; informed consent was always obtained. In addition to general neurological examination, the four patients in this group had EEGs and isotope brain scans; three had CT scans. The language profile (Table 1) and laterality quotient (LQ) were determined in each case. The latter value was modified from Oldfield (1971), and was based on hand preference for a variety of activities, e.g., unscrewing a jar lid, opening a door, striking a match, hammering a nail, brushing the teeth, cleaning a table, cutting with scissors, hand raising, eating, and writing. Each activity was scored to distinguish habitual use of the right or left hand from interchangeable handedness; one point was assigned for exclusive handedness and $\frac{1}{2}$ point to each hand for ambidexterity. The LQ was then determined by subtracting the right–left difference and multiplying by 10. Thus, an LQ of +100 indicates exclusive right handedness, -100 is exclusive left handedness, and 0 is perfect ambidexterity.

One day prior to angiography, the Wada procedure was rehearsed with the patient. Any item which could not be correctly named within 5 sec was deleted from the acutal examination. The test objects were selected for simplicity and common occurrence within the culture.

Retrograde femoral catheterization was performed in the routine fashion, tip position confirmed, and one carotid artery injected with sodium Amytal. The side of the first injection was random. Language testing was then performed, followed by the angiogram. At least one-half hour was allowed to elapse prior to injection of the contralateral carotid artery. As solution of 75–100 mg/2 cc of sodium Amytal was injected, depending on the patient's weight. The patient was instructed to raise both arms and the drug was then hand-injected into the internal carotid artery over 4 sec. When the contralateral arm dropped, language testing was begun. Twenty-four objects were sequentially presented, and the patient instructed to name each in different languages. When a test object was presented, the examiner said "English." "Cantonese," "Hokkien." etc.. to identify in which language the response was to be given. Five seconds were allowed for the answer: responses were graded as correct, incorrect, or mute. The language used to make an incorrect response was also noted. Testing ended when all items were correctly named over a period of at least one minute. The entire procedure was taped.

Stimulation Experiments

The three patients in this group required awake craniotomy for the surgical treatment of a left-hemisphere lesion. Local anesthesia was supplemented with intravenous neuroleptic anesthesia which was reversed at the time of the cortical stimulation studies. This technique is more completely described by Ojemann and Whitaker (1978a, 1978b), as well as by Penfield and Roberts (1959). All three patients were dextral with LQs of \pm 100. All spoke at least one Chinese dialect plus English; all read English and one read Chinese (Mandarin) as well. Patients rehearsed the test protocol with the examiners at least twice prior to operation. The stimuli were presented by projecting 35-mm slides on a screen 2 ft from the patient's eyes. Any object that a patient failed to name within 10 sec during the preoperative trial was removed from the test.

Two tasks were designed. The object-naming task was adapted from Ojemann (1979) and Ojemann and Whitaker (1978a, 1978b). It consisted of 35 achromatic line-drawing slides depicting familiar objects in the patient's culture. Each object was headed by the phrase "this is a" or the Mandarin translation:

這個是

The slides were presented at 10-sec intervals, and the responses recorded, both written and on tape, as correct, incorrect, or mute. The answer was called incorrect if the object was properly named but in the wrong language. The second task, reading, was projected via color slides. A single word or ideogram was presented on the same slide with color photographs of three familiar objects, one of which corresponded to the word or ideogram shown. The patient was required to identify the correct object with a pointer; no verbal response was given. Responses were scored as correct or incorrect.

Cortical stimulation was conducted in the standard fashion (Ojemann, 1979; Ojemann & Whitaker, 1978a, 1978b). Threshold for afterdischarge was first determined, and the sensorimotor areas identified and marked with sterile numbered tickets. Similar markers were then placed at random over the exposed cortical surface. A bipolar constant-current stimulator was then used to deliver biphasic 60-Hz square-wave pulses of 2.5-msec duration. Current was delivered during the language experiment at 1 mA less than the threshold for afterdischarge, and varied between 3 and 9 mA peak to peak. We attempted to stimulate each cortical site at least three times, and when a region was obviously related to language, more trials were conducted at that site. The languages were mapped sequentially; that is, the entire exposed cortex was first mapped in one language and then in the other, rather than alternating them. Stimulation was applied only if the previous response was correct; an error following an error produced by stimulation was not scored but assumed to be related to the prior trial.

We evaluated our data using the methods employed by Ojemann and Whitaker (1978a). The control error rate was determined for each patient. The one-tailed binomial sample test was used to analyze statistically the performance in each language during stimulation of specific sites. The results are presented diagrammatically by circles which identify the stimulated sites; the top half of each circle represents the dominant language for that patient at the time of the operation. These diagrams were constructed by projecting the operative photographs of the exposed cortex with tickets in place on the lateral venogram obtained at angiography.

Clinical Studies

Four aphasic patients who survived a left-brain CVA (documented by either CT scan or isotope brain scan) were periodically examined by one of the authors (CTT) until the clinical state stabilized or the patient was lost to follow-up. Although the language profiles and LQs were often difficult to establish in these aphasic patients, most details could be gathered in retrospect. Data were collected in all languages and dialects spoken by the patient prior to the CVA. The same abilities investigated by Wada testing and cortical stimulation were studied. Object-naming and the comprehension of English words or Mandarin characters were evaluated using the same tasks as described above. The patient was asked to repeat, to read aloud, and to discuss what had been read. The occurrence of neologisms, paraphasias, or synonyms was noted.

RESULTS

Wada Testing

Throughout these studies, responses were verified by one of the authors (CTT) fluent in all languages and dialects tested. Several of the patients are included in more than one kind of testing, so that cases are presented

sequentially and the same case number applied to a given patient throughout. When a case appears more than once, the patient is briefly described for identification and the complete history referred to.

Case 1. A Chinese male mathematics teacher, age 32, complained of a left-sided headache progressive over 2 years. During a single episode of headache, he noted hesitancy of speech which lasted a few hours, but he had no motor seizures. Neurological examination was normal. Studies, including isotope brain scan, CT scan, and EEG, suggested a vascular lesion in the posterior, inferior left temporal lobe. This was confirmed by angiography (Fig. 1). At operation, a 5×5 -cm vascular tumor was found attached to the tentorium. Histologically, this tumor was a meningioma.

The patient was dextral with an LQ of +100. He was fluent in spoken English, Cantonese, and Malay as follows: Cantonese was his mother tongue and was used in his immediate family, but he did not read or write Chinese (Mandarin). He was able to read and write both English and Malay. His dominant language was English, in which he had been educated through the university level. He thought, read, wrote, worked, and conversed primarily in English (see Table 1).

English and Cantonese were evaluated. Sodium Amytal, 75 mg/2 cc, was injected into each carotid artery. Following the right-sided injection, all of 48 responses were correct. After the left-sided injection, there were a total of 72 responses. These could be arbitrarily divided into three periods. During the first, there were four incorrect responses in both languages. Thirty-six items were queried during the second period; 14 of 18 were correctly named in English, and 5 of 18 correctly named in Cantonese. When errors were made in Cantonese, the response was almost always given in English. He was never mute. During the third period, there were 32 correct responses in both languages. English was, therefore, recovered before Cantonese.

Case 2. A 41-year-old Chinese male, owner of a small business, described occasional right side of body focal motor seizures without aura which began at age 29. By age 31, he had noted occasional difficulty in "finding" certain words and in writing letters. This was exacerbated after a seizure, and he felt that Mandarin was the most affected language. Examination showed only a minimal nonfluent nominal dysphasia noted in all the languages he spoke; this was quite subtle. He could read both Mandarin and English with unimpaired comprehension. An EEG revealed left frontal and anterior temporal focal slowing. An isotope brain scan suggested a deep left, inferior frontal mass, but cerebral angiography was normal. A CT scan showed an area of decreased density which was enhanced following contrast injection in the left, inferior frontal region (Fig. 2). At surgery, a firm mass was found in the white matter of the middle and inferior frontal convolutions; histologically, this was a grade II astrocytoma.



FIG. 1. Lateral (left) and AP (right) angiograms of Case 1. Arrows mark limits of a large left tentorial meningioma supplied by both the carotid and vertebral arteries. The sylvian triangle is displaced anteriorly and superiorly.



FIG. 2. CT scan of Case 2. Asterisk marks a deep frontal contrast-enhanced left-sided glioma.

The patient was dextral with an LQ of +100. He was fluent in both spoken and written Mandarin and English. He could also speak Hokkien, Cantonese, and Malay as shown in his language profile (Table 1). Hokkien was his mother tongue. However, he was educated entirely in Mandarin and English, including a few years at a Chinese university. He thought, did leisure reading, and spoke to his family in Mandarin. He used English in his work and at the university, where lectures were conducted in Mandarin, but texts were written in English. The patient felt that his dominant language was Mandarin.

The Wada Test was conducted in Mandarin, Hokkien, and English. Following the injection of 100 mg sodium Amytal into the right internal carotid artery, he correctly named 45 of 48 items. He made a single incorrect response in each of the three languages tested.

Following the left-sided injection, there were a total of 116 responses. During the first period, 38 responses were mute in all languages. During the second period, there were 69 responses; 16 of 23 were correct in English, 4 were mute, and 3 were incorrect; 15 of 23 were correct in Hokkien, and 3 of 23 correct in Mandarin. The majority of incorrect responses requested in Mandarin were correctly named in English. He did not make errors by answering in Mandarin when English or Hokkien were requested. During the third period, 9 responses were correct in all languages. He therefore recovered English first, followed by Hokkien and then Mandarin.

Case 3. A 30-year-old Chinese accountant complained of a 4-year seizure disorder characterized by impaired consciousness and increased salivation. Neurological examination was normal. EEG revealed a right temporal lobe focus of epileptiform discharges. CT scan showed only mild, symmetrical hydrocephalus confirmed by angiography.

The patient was dextral with an LQ of +100. He was fluent in English, Hokkien, Cantonese, and Malay as follows: He could read and write English but not Chinese (Mandarin). Hokkien was his mother tongue and the local dialect where he lived. He learned Cantonese in secondary school, and became fluent while studying in England (where the majority of the Chinese community spoke Cantonese). He was educated primarily in English, however, and at the time of the examination this was his dominant language. He usually thought in English, used it at work, for leisure reading, and in conversation with most of his friends (see Table 1).

The Wada Test was conducted in English, Cantonese, and Hokkien. Following injection of 100 mg of sodium Amytal into the right internal carotid artery, he correctly named all of 48 items in the three languages tested. After the left-sided injection, there were a total of 80 responses. During the first period, all of 35 responses were incorrect (3) or mute (32). During the second period, he made 37 responses; 10 of 12 were correct in English, 7 of 13 were correct in Hokkien, and 4 of 12 were correct in Cantonese. During the third period, 8 items were named correctly in all three languages. Therefore, recovery of English occurred first, followed by Hokkien and then Cantonese; this was the order of his subjective fluency in the three languages.

Case 4. A 24-year-old Chinese unemployed woman presented first at age 21 with a subarachnoid hemorrhage. She was found to have subacute bacterial endocarditis with mitral incompetence and a presumed mycotic aneurysm. She was treated with antibiotics and recovered. At age 23 she was readmitted for two episodes of psychosis. An EEG suggested right frontal slowing, and a repeat tracing taken 6 months later showed progression of this focal slowing. A CT scan suggested an aneurysm in the distal anterior cerebral artery distribution. An angiogram confirmed an aneurysm of the frontopolar branch of the right anterior cerebral artery which was subsequently clipped.

The patient was dextral with an LQ of +75. She was fluent in Mandarin, Hokkien, Cantonese, and English as follows: She could read Mandarin and English. Hokkien was her mother tongue and was spoken where she lived; it was spoken by her family and some of her friends as well. She attended Chinese primary and secondary school where instruction was in Mandarin. She did leisure reading in Mandarin and spoke it with most of her friends. She studied English as a second language in school, and was able to converse easily in English. She felt that Mandarin was her dominant language (see Table 1).

The Wada Test was conducted in Mandarin, Hokkien, and English. Following the injection of 100 mg sodium Amytal into the right internal carotid artery, the patient became slightly drowsy, and made 5 of 48 incorrect responses. Three of the errors were responses requested in Hokkien but correctly named in Mandarin. One mute error was made in Mandarin and one in English.

Following left-sided injection, there were a total of 82 responses. During the first period, all of 39 responses were mute or incorrect. During the second period, there were 33 responses; 5 of 11 were correct in English, and 2 of 11 were correct in both Mandarin and Hokkien. Most of her incorrect responses were objects properly named but in the wrong language. Responses requested in Mandarin or Hokkien were usually given correctly but in English. The third period consisted of 10 correct responses in all three languages. It therefore appeared that, even though Mandarin was the dominant language, English was better preserved than either Mandarin or Hokkien.

Cortical Stimulation

Case 1. The mathematics teacher with a left tentorial meningioma (see above) was examined. Twenty-one sites were stimulated during surgery as shown in Fig. 3a. Broca's area included a rather large region of cortex in the expected location. Stimulation at these sites always produced arrest of speech in both languages. Three additional points of stimulation sometimes produced arrest: at the site on the posterior temporo-parietal junction just superior to the tumor (represented by the circle with a hatch above and an asterisk below), arrest of speech was produced by stimulation during naming twice in English and once in Cantonese; at the site immediately adjacent and posterior, mutism resulted once during naming in Cantonese; at the parietal site just behind the sensory cortex, (circle with block above and asterisk below) arrest of speech occurred once during testing in English. Errors made during trials in English were often paraphasias in English, e.g., egg for axe, kettle for cat. Most errors in Cantonese were failures to name objects but with preserved ability to read the leading phrase.

In general, stimulation at sites around the posterior sylvian fissure resulted in a reproducible pattern of errors in English. Stimulation at some of these sites produced mutism during object-naming in English, but seemed relatively unrelated to Cantonese. Errors in the latter language were less reproducible and resulted from stimulation at scattered sites which tended to be more remote from the usually described posterior language regions.



FIG. 3. Cortical stimulation maps of Case 1 (a), Case 2 (b), and Case 5 (c). The upper half of the circle always represents the dominant language. Open circles show areas that were stimulated but were apparently unrelated to motor, sensory, or language systems. The large dashed circles represent tumor (a,b) or intracerebral hematoma (c). The solid, heavy line in (c) outlines the AVM; the arrow marking the dashed circle in the same case indicates a point of stimulation on the temporal operculum 1 cm deep to the cortical surface. Probability of errors occurring by chance: \bigcirc , 1% or less: \bigoplus 5% or less: \bigoplus , 10% or less. (*), Single error; (*), motor effects.

The error rate (not including arrest of speech resulting from stimulation along the posterior inferior frontal convolution) was 50% in English and 60% in Cantonese. The control error rate in this patient was high as a result of oversedation: 28% in English and 18% in Cantonese.

Case 2. The owner of a small business with a left frontal astrocytoma (see above) was examined. Mandarin was his dominant language: Mandarin and English were tested. Twenty-eight sites were stimulated (Fig. 3b). Broca's area was identified as a single point of stimulation where all trials in both languages produced arrest of speech. This site was immediately adjacent to the tumor. Mutism was also produced by stimulation at three other sites: at the most superior point in the parietal region which was related to language (circle with hatch above and below), mutism was the result in three of five English and two of four Mandarin trials. At this site, all responses were either mute or correct; there was no incorrect naming, nor was there retained ability to read the leading phrase. At a point posterior along the superior temporal gyrus (circle with block above and hatch below) mutism was produced two of four times during testing in English and four of four times in Mandarin. Stimulation just posterior and superior to this site (circle with white above and hatch below) was characterized by mutism during testing in English in two of five trials. The overall error rate during stimulation in Mandarin was 39% and in English 42%. He made a single error in Mandarin which was unassociated with stimulation.

All of the sites shown in Fig. 3b were also tested by stimulation during the reading task in both languages. There were no sites identified which, when stimulated, interfered with his ability to perform the reading task in either English or Mandarin.

In this case, the dominant language was Mandarin and the errors produced by stimulation during testing in Mandarin were most densely concentrated around the posterior sylvian fissure. There were five sites which seemed related to both languages, and in two of these stimulation sometimes resulted in mutism in both languages. English errors were, in general, less reproducible than errors in Mandarin and, as a rule, occurred following stimulation at sites more peripheral than the sylvian cortex which was strongly related to Mandarin.

Case 5. A 23-year-old Chinese male had the sudden onset of rightbody hemiparesis involving face, arm, and leg without associated headache, nausea, vomiting, stiff neck, seizure, or loss of consciousness. He was mute on admission. A CT scan and angiogram were diagnostic of a small left middle cerebral artery distribution arteriovenous malformation (AVM) associated with a large fronto-parietal intracerebral hematoma (Fig. 4). Because he was initially densely aphasic in all languages he spoke, a Wada Test was not done at the time of angiography. In retrospect, the patient believed that his aphasia was greatest in Cantonese.





This patient was dextral with an LQ of +100. He was fluent in spoken and written English and could speak Cantonese, as shown in his language profile (Table 1). Following the vascular accident, he recovered English faster than Cantonese, but by 1 week after the ictus he could converse well in both languages; he could read English throughout his hospitalization. At the time of surgery, which was 13 days after the ictus, he made no baseline errors in object-naming. He felt that English was his dominant language. English and Cantonese were tested.

Thirty-one sites were stimulated as shown in Fig. 3c. In spite of a wide area of stimulation. Broca's area could not be identified. Mutism was occasionally produced, however, by stimulation at five other sites. Along the superior temporal gyrus, stimulation during testing in English resulted in mutism once at each of the four anterior sites. This included the point marked with an arrow on the superior surface of the temporal operculum, which had been exposed by splitting the sylvian fissure during excision of the malformation. Stimulation of the frontal lobe along the superior margin of the cortex overlying the hematoma (represented by the circle showing white above and an asterisk below) resulted in mutism once. This patient made few errors in either language: 26% in English and 22%in Cantonese. We found few points strongly associated with language, and the ones we did find were located along the superior temporal gyrus primarily, including the posterior temporal operculum. The English errors seemed more localized to this area, whereas errors in Cantonese were produced by stimulation at more scattered sites. Specific sites tended to be associated with either English or Cantonese, and only two sites were stimulated where errors were produced in both languages. He made no errors unassociated with stimulation. All of his errors were failure to name the object.

Clinical Studies

Case 2. The small businessman with a left frontal astrocytoma (see above) was examined. This 41-year-old man had a subtle preoperative expressive aphasia which he felt was worst in Mandarin. Within 24 hr of surgery for subtotal removal of his tumor, he developed a severe expressive aphasia secondary to local edema and was unable to name in Mandarin, Hokkien, or English. Reading was unimpaired in either Mandarin or English. He was tested weekly in all three languages, and recovered within 1 month (Table 2). While this case does not represent a structural CVA, it is included here because the transient effect of the postoperative swelling was similar to a CVA.

We also determined how often a naming response (either correct or incorrect) for a certain object was associated with the same success or failure in the other languages tested. Of the 30 pooled trials, 22 were the same in Mandarin and Hokkien, 18 the same in English and Mandarin,

Case	Weeks after CVA	Language				
		MAN	нок	CAN	ENG	
2	1	10/10	0/10		6/10	
	2	9/10	7/10		5/10	
	3	10/10	10/10		8/10	
3	1			31/32	30/32	
6	1		1/10	0/10	0/10	
	2		1/10	0/10	0/10	
	4		12/20	12/20	8/20	
7	1	0/10	0/10			
	2	7/10	7/10			

 TABLE 2

 Naming Objects following CVA

Note. Number of objects correctly named over number of trials at various times following CVA in four cases. In Case 2, the patient did not have a CVA per se, but developed a dense postoperative aphasia related to edema; the clinical result was similar to a vascular occlusion. Abbreviations are the same as in Table 1.

and 16 the same in Hokkien and English. This may imply that the regions related to the two Chinese dialects were more closely related than either dialect with English.

Case 5. The 23-year-old clerk with an AVM and an intracerebral hematoma (see above) was examined. Following the hemorrhage, he was initially mute and obtunded. However, comprehension in both English and Cantonese returned within 24 hr and by 13 days posthemorrhage he was able to cooperate well enough to undergo awake craniotomy with language testing. The postoperative evaluation of his ability to name objects is shown in Table 2. His ability to read English following recovery from the ictus was unimpaired; he could not read Mandarin. These clinical findings combined with the stimulation studies suggest mixed cerebral dominance for language in this patient, perhaps as a result of congenital vascular anomaly in the left posterior temporal and parietal cortex.

Case 6. A 45-year-old housewife with known rheumatic heart disease developed a sudden onset of headache, confusion, and right hemiparesis. CT scan confirmed the diagnosis of a left fronto-parietal intracerebral hematoma presumed to be secondary to a ruptured mycotic aneurysm.

She was dextral with an LQ of +100. She was fluent in Hokkien, Cantonese, and English as follows: She had been educated in English through lower secondary school, spoke English to some friends, and could read English. Cantonese was the local dialect where she lived and she used it in daily commerce. Hokkien was her mother tongue and her dominant language at the time of study in that she used it for thinking, most of her daily activities, and with her family (Table 1). For 2 weeks she had a dense global aphasia, but by 4 weeks had improved (see Table 2). Of 30 trials, similar naming errors were associated with the two languages as follows: 16 errors were the same in Hokkien and Cantonese, 13 the same in Cantonese and English, and 12 the same in English and Hokkien. She was lost to follow-up 4 weeks after the CVA.

Case 7. A 39-year-old fishmonger had a 4-week history of headache, deterioration of vision, incontinence of urine, and dementia. On admission, he was comatose with bilateral papilledema, hyperreflexia, and bilateral extensor plantar responses. A CT scan and angiogram suggested a left temporal lobe intraventricular tumor. A meningioma was subsequently removed under general anesthesia from the temporal horn of the left lateral ventricle. Three weeks postoperatively, he had a right homonymous hemianopia and a mild right hemiparesis.

After recovery, he was determined to be dextral with an LQ of +50. He was fluent in Mandarin and Hokkien as follows: Mandarin was his dominant language in that he used it for thinking, reading, and talking to most friends. Hokkien was his mother tongue and the common dialect in his community. He understood simple English, but was not fluent enough to test (see Table 1).

His language skills were first formally tested 1 week following surgery (Table 2). At 2 weeks, reading was unimpaired in Mandarin; comprehension was good and he used no neologisms or paraphasias. His simple abilities in English returned to the premorbid level, according to his family. He was lost to follow-up 2 weeks after the operation.

DISCUSSION

We have evaluated the language functions of seven Chinese- and Englishspeaking polyglots by Wada Test, cortical stimulation, and clinical examination. To explain the selective loss and recovery of one or more languages among dysphasic polyglots, right-sided or mixed cerebral dominance for language has been proposed (Paradis, 1977; Obler, et al., 1982). Nielsen (1946) cites the case report of a German polyglot with a right temporal lobe tumor who postoperatively developed dysphasia in some, but not all, of the languages he knew. April (April & Tse, 1977; April & Han, 1980) has reported two cases of bilingual Chinese dextrals with right-sided middle cerebral artery distribution infarction who developed a dysphasia greater in Cantonese in one and in English in the other, although the mother tongue was Cantonese in both instances. Both of April's patients spoke, read, and wrote English and both could read Chinese (Mandarin). In 1938, Lyman et al. reported the only other case we are aware of involving dysphasia in a Chinese- and English-speaking polyglot. This patient who spoke, read, and wrote both Mandarin and English had a left parieto-occipital tumor and exhibited dysphasia which

improved postoperatively in both languages; English was recovered more fully than Mandarin. Their report does not state the mother tongue, but it probably was Mandarin in view of the place of birth. Neither is the dominant language at the time of surgery stated, but it probably was English as the patient had been educated in England and conducted his business in English. Vildomec (1963) has claimed that the role of the nondominant hemisphere is increased in those who are multilingual from infancy compared to those who learn a second language later. More recent studies suggest that the nondominant hemisphere participates more significantly in the language functions of bilinguals whose second language is acquired after the age of 5 or 6 (Genesee et al., 1978; Sussman et al., 1982; Vaid, 1981). In his excellent review, Paradis (1977), cited evidence that the nondominant hemisphere may be especially important in comprehension of a "quasi-ideogrammatic" written language (Hebrew); he has also cited evidence to support the idea that the nondominant hemisphere may play a role in recovery following contralateral injury. He concludes by stating that while speculation concerning this subject is great, data are scarce and often unreliable.

To explain the crossed aphasia in his two cases of Chinese- and Englishspeaking dextrals, April (April & Tse, 1977; April & Han, 1980) has reasonably speculated that the right hemisphere was dominant, and offers as support the fact that written Chinese (Mandarin) is an "ideographic" language. If a character, or group of characters, is unknown, then there are few phonetic clues to meaning. It has been reasoned that "ideographic" languages may therefore require increased visual-spatial processing of information, either in the nondominant hemisphere, or by participation of more occipital cortex than is usually included in the "language centers" of the posterior sylvian fissure. Others have discussed this thesis (Critchley, 1974; Vaid, 1981); however, analysis of our data does not support this concept.

Our first case is of special interest because the patient was neurologically intact and did not have a seizure disorder. All of Penfield and Roberts' 569 patients had focal epilepsy (Penfield & Roberts, 1959), as did both of the bilingual patients reported by Ojemann and Whitaker (1978a). Since it could be argued that the abnormal electrical discharges from a dominanthemisphere seizure disorder might influence the organization of cortex related to language, the absence of seizures in this case is significant. Further, his lesion was extrinsic to brain itself, causing compression but not invasion of the temporal lobe. Broca's area was identified in the expected location. Although four sites seemed related to both English and Cantonese, there were also regions where stimulation produced naming errors in only one language. Errors in English, the dominant language but not the mother tongue, were produced by stimulation in a relatively more confined locus than were errors in Cantonese. Though the background error rate was high, more total errors were produced during testing in Cantonese than in English. Also, the errors made in English during stimulation were often paraphasias in English, whereas the errors in Cantonese were more often failures to name. During Wada testing, English was recovered first, and errors made in Cantonese tended to be objects named correctly in English.

Our second case is also of particular interest because the patient was fluent in spoken Mandarin and English and could also read and write both languages. His versatility presented an opportunity to examine the proposed differences in processing of ideogrammatic and phonetic symbols (April & Tse, 1977; April & Han, 1980; Critchley, 1974). Broca's region was easily identified, was quite focal, and behaved the same way during testing in both languages. As in the first case, reproducible errors in the dominant language resulted from stimulation at sites in the posterior superior temporal gyrus and the supramarginal/angular gyri. Five sites seemed related to both languages, but errors in English were less reproducible and in general resulted from stimulation at sites more peripheral than errors in Mandarin, the dominant language. During the reading task, no errors were produced by stimulation at any site in either language (the occipital lobe was not exposed at operation). Although Penfield apparently did study reading during his stimulation experiments, the results are not discussed (Penfield & Roberts, 1959). Our inability to influence reading as measured by a nonverbal (pointing) response has at least three possible explanations: reading functions might be related to sites in the occipital lobe which were not exposed, the stimulation current may have been too low to affect these functions, or reading measured by a nonverbal task may simply not be influenceable by cortical stimulation. However, it seems significant that this patient did retain his ability to read the leading phrase in both languages during stimulation of the same sites where object-naming was interrupted; this phenomenon could be automatic speech. In any case, he could apparently process both Mandarin and English written symbols and make the appropriate nonverbal response during the reading task, as well as read the leading phrase aloud but not verbalize the name during the object-naming task. This implies that the posterior temporal and parietal "association" cortex related to language in this patient was involved with his ability to name, but not with his ability to interpret either ideographic or phonetic symbols.

The only evidence for bilateral representation of the language cortex was from our fifth case, and seems more likely related to the presence of an AVM arising in the left sylvian fissure than to either his bilingualism or to the fact that he spoke Cantonese. Although initially aphasic in both English and Cantonese, the patient was well recovered by the time of surgery and was able to perform the practice tests with almost no errors. We can know neither how long the AVM existed, or what its effect was on the development of speech mechanisms prior to the vascular accident. It seems significant, however, that Broca's area was unidentifiable and that the superior temporal gyrus, including regions usually called primary auditory cortex, seemed to play an increased role in language functions in this case. Since Wada testing was not done, we cannot be sure how much, if any, language function was located in the right hemisphere. Considering the rapid recovery of language functions after the CVA and the scanty number of sites related to language functions during the stimulation studies, it may be that this patient had some bilateral representation of language because of the presumed congenital nature of his lesion.

Further evidence for left-brain dominance for language in these patients comes from the Wada Test data. All of our patients were Chinese; all were fluent in English and at least one Chinese dialect; and all had learned the dialect as their mother tongue. Two could read and write Mandarin. The effect on English and at least one Chinese dialect was studied during the course of eight internal carotid artery injections of sodium Amytal. In all cases, the left hemisphere appeared dominant for all languages tested. These data are in agreement with the tachistoscopic studies in Chinese- and English-speaking polyglots which demonstrate left-hemisphere dominance for both languages (Kerschner & Jeng, 1972). Similar results have been obtained in bilingual native Americans (Hynd, Teeter, & Stewart, 1980). In two cases, all responses were correct following right internal carotid artery injection. In Case 2, when 3 of 48 responses were errors (one in each language tested), the patient had a mild preexisting nominal dysphasia and occasionally made naming errors in conversation, which he usually corrected. His 3 errors might be expected considering the added stress of the examination. Case 4 was different in that the patient was less strongly lateralized to the left hemisphere according to her LQ of +75. After right-sided injection, she made 5 errors out of 48 trials in naming. Two of these were items requested in Hokkien but named correctly in Mandarin, her dominant language. She also became slightly confused after right-sided injection of Amytal. This case may represent some very minor features of mixed dominance. This patient was the only woman, and less asymmetry for language has been reported in women than men (McGlone, 1980), another conceivable explanation.

A variety of mechanisms have been invoked to explain preferential loss and recovery of languages in dysphasic polyglots. The "rule of Ribot" suggests that the mother tongue is the most resistant to later damage regardless of fluency (Paradis, 1977). Some support for this view may be found in studies of monolingual children indicating that hemispheral specialization for language is achieved before age 5 (Geffen, 1976). On the other hand, Pitres observed that it was often the language most familiar to the patient at the time of the insult which recovered best. Minkowski emphasized the influence of underlying emotional factors on recovery (Minkowski, 1927). He also pointed out that those languages which are both written and read as well as spoken will be recovered better than "dialect" or those languages which are spoken only. Our data seems to support this claim. Luria (1956) has added that the degree of disturbance in reading and writing among polyglot aphasics may be a function of the degree to which the script of the language is phonetic. Thus, lesions in the posterior superior temporal lobe might be most significant in those patients with a highly phonetic language, while lesions of the parieto-occipital regions may be more damaging to patients with ideographic languages like Chinese. The case report by Lyman et al. (1938) is an example of the latter pattern. Paradis (1977) has summarized a variety of other variables which may contribute to the manner in which language skills are recovered in polyglot aphasics: the automaticity factor, the severity factor, the appropriateness factor, the switch mechanism, and finally, the multiple factor view. He concludes by saying that "one is easily convinced that several factors interact-so many in fact that it may be impossible to disentangle them for the purpose of formulating a rule with any sort of predictive value." We agree.

With Wada testing, however, we have been able to create transient global aphasia in fluently multilingual patients manipulating only one variable, intracarotid sodium Amytal. During the left-sided injection, preferential recovery of English occurred in two patients who read and wrote English but not Chinese (Mandarin). In both cases, a Chinese dialect was the mother tongue although each patient normally thought in English and identified it as his dominant language at the time of the study. These two cases provide further support for the idea that it is the ability to read and write as well as to speak a language which reinforces the organization of cortex required not only to name objects, but also to make speech resistant to interference (Minkowski, 1927). In Case 2, the patient read, wrote, and spoke fluently in both Mandarin and English. We were surprised by his better preserved ability in English even though Mandarin was clearly the dominant language. It is possible that this result is due, at least in part, to the manner in which the questions were asked: in presenting the Wada Test objects, the examiner mistakenly said "Mandarin," an English word, rather than "Kuoyu," the correct pronunciation of the word for the official Chinese language. Requesting his response in English rather than Mandarin may have reinforced his tendency to name the object correctly but in the wrong language and thus be scored incorrect. A similar situation existed in Case 4 in which Mandarin was the dominant language and Hokkien the mother tongue. The patient spoke English well, but used it less often than the Chinese dialects. As mentioned above, she was the only woman tested, a fact which may be relevant. and also demonstrated some degree of ambidexterity, having an LO of +75. She scored better in English during the test period than in either

Chinese dialect, and her errors when asked to name in Chinese were usually correct responses in English. She was seldom mute. While "Kuoyu" was this time used to request Mandarin, the tester was an American and this might also have biased her. In clinical situations, factors such as the examiner's appearance and manner, the setting, and the language of the hospital environment may influence the formulation of the patient's responses (Charlton, 1964). The major variable which influenced loss and recovery of language during Wada testing in our material was, however, which language was dominant (defined as the language primarily used for reading, writing, and/or thinking) at the time of the examination.

Following left-brain CVAs in four Chinese-speaking, dextral polyglots, all languages that each patient knew were similarly affected. As with the Wada Test data, recovery of the dominant language occurred first or more completely, at least in the short run. When a patient spoke two Chinese dialects and English, the dialects were recovered in a similar way and usually before English, according to the results of object-naming tasks. Similar responses (either correct or incorrect) were more likely to occur between two dialects than between a dialect and English.

The anatomic substrate for clinical dysphasia rarely corresponds to the entire anterior two thirds of the hemisphere (or more) that is anesthetized with intracarotid sodium Amytal. Neither does the simple model of interference with naming or reading during cortical stimulation correspond to the complexities of language in a normal person. In the clinical situation, the site of the lesion, intelligence, motivation, and the environment may be important in influencing language, making prediction of selective recovery difficult. These points seem obvious. In our stimulation experiments, however, we have reproduced the work of Ojemann and Whitaker (1978a, 1978b) showing variation in the cortical representation of different languages in polyglots. Sasanuma's results showing differences in kana and kanji also imply different cortical organization for interpretation of phonetic and ideographic symbols (Sasanuma, 1975; Sasanuma & Fujimura, 1971). This differential localization may also play a role in recovery. We found no support for the theory that people who speak Chinese or polyglots in general have an increased participation by the right hemisphere in their language functions.

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