BRAIN AND LANGUAGE **5**, 265–285 (1978)

Parameters for Vowel Substitutions in Broca's Aphasia

ERIC KELLER

Université du Québec à Montréal

Most phonological investigations of aphasic speech have focused on consonants. In this study, the vowel substitutions of five English-speaking Broca's aphasics were investigated with respect to several major explanatory hypotheses. An important possible motivating factor for aphasic substitutions, phonological environment, is an unlikely origin for these errors, since most substitutions occur along the paradigmatic axis. Another prominent hypothesis, markedness, also has no predictive power for the data of this sample. However, an analysis of the five Chomsky and Halle (1968, *The Sound Pattern of English*, New York: Harper and Row) vowel features indicates that the two features for vowel height are selectively impaired: There is a strong tendency for lower vowels to replace higher targets. Moreover, the substitution sounds tend to be close to their target sounds along the height axis. Four possible hypotheses are advanced to account for this consistent lowering tendency.

Of the various functional symptoms of Broca's aphasia (Weisenburg & McBride, 1935, "Expressive Aphasia"; Johns & Darley, 1970, "Apraxia of Speech"), phonological substitutions are one of the most refractory problems in speech therapy, at the same time as they are one of the richest sources of insight concerning the nature and origin of this type of aphasia. A number of authors have analyzed in depth these so-called literal paraphasias in order to characterize such language errors and to offer hypotheses for their likely origin (Alajouanine, Obredane, & Durand, 1939; Fry, 1959; Blumstein, 1973; Trost & Canter, 1974). The nature of these substitutions, as it has emerged from these studies, may in the main be summarized as the following three constraints:

1. Aphasic misarticulations are phonemically different from their targets. This distinguishes them from dysarthric misarticulations which are probably best described as phonetically deviant or distorted (cf. Lehiste, 1965).

2. Aphasic errors generally, but not always, are sounds from the patient's native sound inventory. At the same time, patterns of breakdown

Grateful acknowledgment is made to Professors P. Reich and P. R. Léon, University of Toronto, and H. H. Kornhuber, University of Ulm, for the use of their laboratory equipment. During the preparation of this manuscript, the author held a fellowship of the Canadian Medical Research Council in the Department of Neurology of the University of Ulm, West Germany. Address requests for reprints to Eric Keller, Ph.D., Dépt. de Linguistique, UQAM, CP 8888, Montréal, Qué. H3C 3P8, Canada.

0093-934X/78/0053-0265$02.00/0

are similar for one language or another. For instance affricates and fricatives are the most heavily impaired types of consonants in both English and French (Blumstein, 1973; Dubois, Hécaen, Angelergues, Maufras de Chatelier, & Marcie, 1964).

3. The erroneous sound is typically closely related to the target, no matter which system of phonological description is used (Jakobsonian features, Blumstein, 1973; a "conventional" feature system, Trost & Canter, 1974; Martinet-type features, Martin & Ridrodsky, 1974).

These concepts have primarily been formulated on the basis of consonant paraphasias (because substitutions of consonants are far more frequent than those of vowels). However, such constraints appear to apply equally well to vowel substitutions. Since vowel and consonant paraphasias are functionally comparable, it seems particularly appropriate and worthwhile to find out if the explanatory hypotheses that have been proposed for consonant substitutions will also account for substitution trends in vowel paraphasias.

The first part of this study will examine two such hypotheses: environmental influence and the degree of markedness of sounds. Since neither hypothesis proves adequate to account for the large majority of errors in the present sample, two further analyses will be conducted. These will demonstrate in some detail what is clearly the major parameter of breakdown in this sample, namely vowel height. It will be shown that the pathology consists chiefly of substituting lower for higher vowels, and that several distinct hypotheses may be advanced for this tendency.

METHOD

Patients

Five right-handed aphasic patients from the Metropolitan Toronto region were included in the sample. All patients were native speakers of English. The main criteria for inclusion in the sample were the presence of relatively frequent vowel errors in their speech and comparatively good auditory comprehension. They were tested with the Western Aphasia Battery (Kertesz & Poole, 1974), a slightly modified and shortened version of the Boston Aphasia Battery (Goodglass & Kaplan, 1972). All patients scored considerably lower on fluency than on comprehension (Fig. 1) and thus can be considered to be Broca's aphasics. All five patients were suspected to be victims of cardiovascular accidents, but neurological localization information was either uninformative or unavailable. However, other neurological deficits, such as hemianopia, hemiplegia, and sensory loss in all of the patients would seem to indicate that cortical tissue was affected over an area larger than Broca's area. The term Broca's aphasia must thus be understood as characterizing the syndrome rather than the extent or focus of the lesion.

Tasks, Recording, Transcription, and Computation

There were two tasks, spontaneous speech and the repetition of single words. In the repetition task, stimulus words were varied for familiarity and length to adjust for the patients' different levels of speaking competence. Since vowel errors are relatively rare, even in these

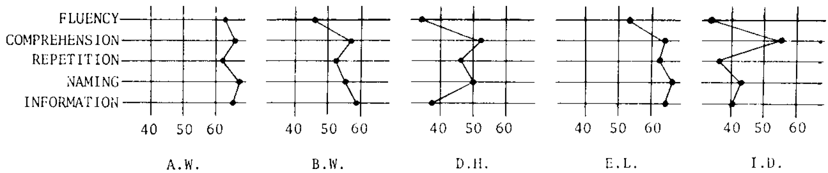

FIG. 1. t scores (mean = 50, SD = 10) for the five patients of the sample, as measured by the Western Aphasia Battery (Kertesz & Poole, 1974). All patients were tested 6 months or more after insult.

patients, a great deal of spoken material (about 35 hr of tape) was collected. It was thus impossible to control for the frequency of the vowels occurring in the two tasks.

Recordings were made in quiet surroundings, using a Shure lavalier microphone with an essentially flat response between 90 and 15,000 Hz and a UHER Report 4200 tape recorder running at 7.5 ips (19 cm/s).

Transcriptions were made by three linguistics students from the University of Toronto and Carleton University, Ottawa, after an initial training period to explain transcription criteria. The author went over the entire data base twice, with a time difference of half a year. Interjudgmental agreement with a sample of 323 randomly selected vowels (both errors and targets) from a transcriber who was unaware of the hypotheses of the project was 76.5%. An analysis of the disagreements indicated that most of the variance could be ascribed to the unaware (and least experienced) judge who was assigned to retranscribe the random samples.

Since transcription systems for English vowels differ in their theoretical assumptions concerning the status of offglides and diphthongs, a preliminary analysis was made of which system corresponded best with aphasic vowel behavior. It was found that vowels with offglides and the diphthongs /e^{i}/ and /o^{u}/ behaved like vowel nuclei in that they were often used as substitution sounds for the latter and vice versa. However the diphthongs /ay/, /aw/, and /oy/ were seldom observed as substitution sounds for the remaining vowel sounds. Errors involving these diphthongs were thus not transcribed. This subdivision of vowel sounds corresponds to the transcription system of Pike (1947), which is essentially the system used here.

Because of the complexities of their theoretical interpretation, vowel errors involving addition and deletion of vowels were excluded. For every substitution, the whole successive approximation was transcribed. Approximations were excluded where either the intended target or the meaning of the target word was in doubt. Dialect variants such as /ə/ and /ɛ/ in "very" were transcribed as perceived. Vowel substitutions associated with a semantic error (e.g., /čɛr/→/te^{i}b/ "chair" → "table") were excluded; those found in morphological substitutions (e.g., /fɛl/→/fɔl/ "fell" → "fall") were included since it has been shown that random generation of errors by computer will create a similar percentage of these errors as found in aphasic speech (Lecours, Deloche, & Lhermitte, 1973).

The following criteria were used to decide which was the target vowel in the case where there were more vowels in the target word than in the erroneous word. In most cases the consonantal environment was the clue; in those cases where the consonantal environment was defective, the consonants which differed by the fewest features were aligned. Thus the error /disɛmbər/→/əz/ "December" was interpreted as a substitution /i/→/ə/. In the case of telescoping deletions the vowel was assumed to "belong" with its succeeding consonant, since a preliminary analysis of such errors indicated that the target error distance could be minimized in this fashion. Thus /ǰaŋkšən/→/ǰən/ "junction" was interpreted to be no substitution at all but a deletion of /-aŋkš-/.

Two levels of stress were differentiated, "stressed" or primary stress and "unstressed" or all other levels of stress. There was no disagreement at all between transcribers about stress differentiation, and aphasics did not show any errors in stress placement. Great care was taken in the transcription of the unstressed vowel /ə/. It was only transcribed in that form if it was perceived as completely neutralized. Operationally, that meant that a sound had to be judged as indistinguishable from a completely neutralized vowel such as found in unemphatic pronunciations of the words "b*a*nan*a*," "c*o*llect," and "*a*bout."

The final transcription was committed to computer cards, and error matrices were compiled by a SPITBOL program. Several string-sensitive tests were then run with SPITBOL, and the matrix permutation procedure (see below) involved a FORTRAN program.

Standardization for Vowel Frequencies

Since vowels occur in the language with unequal frequency, it was important to standardize the vowel substitution frequencies which are used in the calculations of this study. Three steps were followed in the standardization procedure. First, a 9.5-min segment of normal spontaneous speech was collected, yielding the frequencies for 488 stressed and 1202 unstressed vowels (see Keller, 1975, Appendix III). The two main published frequency studies, Denes (1963) and Roberts (1965), could not be used for this purpose for reasons of transcription system and dialect.

The second step was to collect smaller samples yielding a total of 166 stressed and 490 unstressed vowels used in spontaneous speech from the patients described in this study. The two frequency counts were then compared. It appears that the vowel frequency distribution for vowels in each stress category is similar for normals and aphasics. A Pearson r of .933, $p < .001$, indicates high correlation, and a χ^2_{21} of 29.5 shows no significant difference at $p < .05$. This is in accordance with evidence collected about consonants (Blumstein, 1973).

We may thus assume that the *targets available* to this type of patient do not differ significantly in their frequency distribution within each stress category from those of normals. Thus, as step three, a standardization formula was designed to apply the relative frequencies for vowels in the normal speech sample to the substitution frequencies listed in the *target rows* of the substitution matrices. The formula is

$$(\Sigma X_i/X_i)\left(N/\Sigma\ \frac{\Sigma X_i}{X_i}\right),$$

where X_i is the frequency of a vowel in the normal spontaneous speech sample and N is the number of vowels differentiated (in this study, 11 in each stress category). Multiplying the observed error frequencies by the factor derived through this formula yields standardized frequencies which are directly comparable to observed ones.

RESULTS

Hypothesis 1: Environmental Influence

One of the fundamental differentiations to be made in an analysis of speech is between syntagmatic and paradigmatic errors (Derouesne, Beauvois, & Ranty, 1977, "successive" and "simultaneous"). Put into the most general terms, errors which are ostensibly due to the phonological environment are syntagmatic and those which are not are paradigmatic. For example, the consonant substitution /*wh*ayl/→/*l*ayl/ "while" is a syntagmatic (i.e., "horizontal") error and the vowel substitution /m*æ*n/→/m*a*n/ "man," spoken in isolation, is a paradigmatic ("vertical") error.

Syntagmatic errors, at the level of the speech production mechanism, are clearly errors in the serial integration of speech; the mechanism somehow anticipates or perseveres on the production of a surrounding sound. By far, most slips of the tongue in normal speakers can be accounted for in these terms (see Fromkin, 1973, Appendix). But in aphasia, both syntagmatic and paradigmatic errors may occur freely. In fact, Luria (1966) distinguishes two types of motor aphasia primarily along this axis. If a patient speaks in telegram style and has difficulties in transferring rapidly from one word to another, his impairment is considered to be syntagmatic in nature, since it affects the ("horizontal") chaining of articulatory events (Luria, "Efferent Motor Aphasia"). If the main difficulty lies in finding the correct phonemes and not in the chaining of words into an utterance, the paradigmatic axis is said to be impaired ("Afferent Motor Aphasia"). Derouesne et al. (1977) have recently presented supporting evidence that patients whose main difficulty lies in articulation can be impaired selectively along either of the two axes. When they varied the level of syntagmatic difficulty while holding the level of paradigmatic difficulty constant, three of their five patients showed significant differences in accuracy of repetition. On the reverse paradigm (paradigmatic variation with a constant syntagmatic level of difficulty), the two other patients showed significant differences.

Jakobson (1956, 1963) has offered the most poignant interpretation of this difference in terms of a model of speech production. Paradigmatic errors, he says, are errors of selection from an internal store, while syntagmatic errors are difficulties in combining units into an output chain. In view of these fertile hypotheses, it will be interesting to find out whether the vowel errors of this sample are predominantly paradigmatic or syntagmatic in nature.

To start, it will be necessary to separate syntagmatic from paradigmatic errors. The procedure followed here will be one of identifying all those substitutions where the syntagmatic environment could very well have been the main factor and of separating these from the total sample of substitution errors. All those errors that remain will be considered to be paradigmatic errors.

There are two basic types of syntagmatic environment that can be investigated in a substitution. The first is the consonantal (or null) environment that immediately adjoins the vowel. For instance in the substitution /orgənize'šən/→/orgənɪzɪšən/ "organization," the consonants /z/ and /š/ provide the immediate consonantal environment to the substitution vowel /ɪ/. There is moreover a larger vocalic environment to investigate, that of the preceding vowel /ɪ/ and of the succeeding vowel /ə/.

Both types of environment can conceivably influence the syntagmatic substitution process. For instance, it can be imagined that in the substitution /ðə/→/ðɛ/ "the," the fronting of the vowel is due to the dental (and thus frontal) nature of the immediately preceding consonant /ð/. This

TABLE 1

SYNTAGMATIC AND PARADIGMATIC VOWEL ERRORS IN SPONTANEOUS SPEECH AND REPETITION

Patient	Syntagmatic N	Syntagmatic %	Paradigmatic N	Paradigmatic %	Total N
A.W.	53	26.8	145	73.2	198
B.W.	54	19.7	220	80.3	274
D.H.	2	6.5	29	93.5	31
E.L.	42	15.7	226	84.3	268
I.D.	3	2.3	126	97.7	129
Total	154	17.1	746	82.9	900

possibility was investigated in the present sample. All substitutions of the type /ə/→/any other vowel/ were looked at with respect to systematic consonantal environments. The hypothesis was that dental or alveolar consonants would be correlated with a predominance of frontal substitution vowels, and velar consonants would be correlated with back vowels. No indication of such a relationship was found.

The larger vocalic environment can also conceivably influence the substitution across the consonant barrier, as suggested by a certain body of systematic aphasic data (Martin & Ridrodsky, 1974). It is also the only type of environment evident in the data on the slips of the tongue of normals (Fromkin, 1973, Appendix). For this sample, it was thus assumed that if the preceding or succeeding vowel was identical with the substitution vowel, the substitution in question was syntagmatic. A total of 17.1% of the substitutions of this sample were of this type.

This procedure for separating syntagmatic from paradigmatic errors is necessarily approximate. Some of the substitution vowels may be identical with environmental vowels by chance. This would lead to an overestimation of the number of syntagmatic errors. But there could also be some degree of underestimation. The syntagmatic vowel environment beyond the immediately adjoining vowels (two or more steps away) could also influence the substitution, as could any environmental vowel which is merely similar but not identical to the substitution vowel. Both possibilities had to be ignored for the time being for lack of empirical testability. The substitutions where a vowel was two or more steps away from the substitution vowel were too few for assessment, and "vowel similarity" in terms of an aphasic's speech is not yet a given parameter but one to be established in this study (see below).

The results of the separation of errors are given in Table 1. The five patients presented here made far more paradigmatic than syntagmatic errors. We must therefore assume that for the large majority of these errors, environmental influence cannot be claimed to be the motivating factor. We must therefore examine further hypotheses. But before proceeding to the next section, we will briefly examine a major theoretical consideration concerning syntagmatic errors.

Lecours and Lhermitte's (1969) model for consonantal syntagmatic errors suggests as an explanation for this type of error that there may be an "overlap" between the neural activation circuits of two succeeding consonants. The more similar, or the closer, the two consonants, the greater is the "overlap." Aphasic patients are then seen as having lost full control to distinguish the two circuits. One of the intriguing aspects of the model is that no distinction needs to be made between perseveration and anticipation errors: The same overlapping pre- or postactivation mechanism is seen to be at work, whether a patient perseverates on a preceding sound or anticipates a succeeding one.

However, in the vowel errors of this sample, a clear difference between stressed and unstressed vowels was found with respect to perseveration and anticipation errors (Table 2). In perseveration errors, there were about as many stressed and unstressed vowels as would be expected by chance of occurrence alone. But in anticipation errors, nearly twice as many stressed vowels were found as would have been expected. The difference between the two error categories was significant at $p < .001$, with a χ^2 of 28.01.

This suggests that in anticipation, stressed vowels take a special position, while in perseveration they do not. MacKay's (1970) model for anticipation-type spoonerisms in normals would predict the precise finding observed here. It suggests that "the speech motor units are preprimed in proportion to their degree of stress" (p. 182), whereby stressed vowels have a greater chance to be anticipated than unstressed ones. By contrast, perseveration errors are considered to be possible instances where an inhibition mechanism for damping the neuronal circuits of a particular

TABLE 2

Stressed and Unstressed Vowel Substitutions with Respect to Perseveration and Anticipation

	Stressed		Unstressed		
	Observed N	Expected N	Observed N	Expected N	Total (observed N)
Perseveration	18	19.6	50	48.4	68
Anticipation	47	24.8	39	61.2	86
Total	65	44.5	89	109.5	154

phoneme is temporarily impaired. The present data from aphasia support a differentiation of the two mechanisms and are in accord with the general outline of MacKay's hypothesis.

Hypothesis 2: Markedness

A prominent linguistic hypothesis concerning aphasia has been the now widely questioned notion that it is the reverse process of acquisition (Jakobson, 1941; contrary evidence, Fry, 1959; De Villiers, 1974). According to that hypothesis, sounds which are common in the world's languages (so-called "unmarked sounds") are learned earliest and are most resistant in aphasia, and those which are less common ("marked sounds") are learned last and affected the most immediately in aphasia. Blumstein (1973) has presented generally supportive evidence for the latter part of the hypothesis with an analysis of aphasic consonants. It is thus interesting to see if this markedness tendency is also found in vowels.

The revised markedness scheme presented in Chomsky and Halle (1968, p. 402) was used for this study. In their analysis, there are four degrees of markedness complexity. The sound /a/ is considered to be the least marked vowel ("Complexity 0"), /i/ and /u/ are slightly more marked ("Complexity 1"), even more marked are the sounds /ɪ/, /e^{ɪ}/, /ʊ/, and /o^{u}/ ("Complexity 2"), and the most marked sounds ("Complexity 3") are the sounds /ɛ/, /æ/, and /ɔ/. These marking levels are applied to vowels in their underlying (basic) form which in the present set of vowels is also the stressed form. In Chomsky and Halle's scheme, unstressed sounds, and the stressed sound /ɚ/ (as in "burr"), are derived from stressed sounds by various further phonological rules. It will therefore be necessary to restrict the markedness analysis to stressed vowels in order to exclude the possibility of interference from such rules. A similar restriction will also apply in the case of the further analyses in this paper, since theoretical parameters for vowels have generally been set up with stressed vowels in mind.

The specific hypothesis investigated here is that the more marked sounds would tend to be replaced by less marked sounds ("unmarking"). It was thus determined what proportion of the standardized errors represented an unmarking tendency and what proportion a marking tendency. Table 3 shows that the two proportions were very close to 50% and thus showed no tendency at all with respect to markedness. The proportions were not significantly different from 50% at $p < .05$ by a test of proportionality (Glass & Stanley, 1970, p. 321).

It therefore appears that the substitution tendencies in the stressed vowels of this sample do not support the markedness hypothesis. It will now be useful to examine some vowel parameters in detail, in order to determine if one of them may have particularly good predictive value for the errors of this sample.

TABLE 3

MARKEDNESS ANALYSIS[a]

	Marked to unmarked (%)	Unmarked to marked (%)	Probability
Spontaneous speech	50.8	49.2	Not significant at $p < .05$
Repetition	47.7	52.3	Not significant at $p < .05$

[a] Based on standardized paradigmatic substitution scores of stressed vowels.

Analysis 1: Direction

Several phonological feature systems have been devised over the last 30 years to capture the parameters considered to be active in a variety of phonological rules as well as in processes of historical sound change and of language acquisition. These parameters are seen to be operational at a central (nonperipheral) level, and since Broca's aphasia probably impairs processes at that level, it could well be that one or several of these parameters are impaired selectively. The binary-valued feature system by Chomsky and Halle (1968) has gained wide acceptance among North American linguists and will thus be used here to ferret out those aspects of the present data which will be of further interest.

Using each of the five features specific to the vowel system (High, Low, Back, Round, and Tense) and applying them to the perceived sounds at the systematic phonetic level, the standardized matrices were examined for frequencies of change in the value of that feature. For instance, the substitution /sīt/→/seʻt/ "seat" represents a change in the value of the feature High (+High → −High), but the values of the other four features remain unchanged (−Low, −Back, −Round, +Tense). The results of this analysis are given in Table 4. It can be seen that the most consistent

TABLE 4

DIRECTION: FEATURE ANALYSIS

	Spontaneous speech			Repetition		
Feature	Percentage[a]	Result	Probability (p)	Percentage[a]	Result	Probability (p)
High	65.4	Lowering	n.s.[b]	73.4	Lowering	<.001
Low	87.2	Lowering	<.001	80.0	Lowering	<.001
Back	76.6	Backing	n.s.	61.5	Backing	n.s.[b]
Round	54.1	Unrounding	n.s.	70.5	Unrounding	<.025
Tense	54.8	Tensing	n.s.	69.3	Tensing	<.001

[a] Based on standardized paradigmatic substitution scores of stressed vowels.
[b] Not significant at $p < .05$.

tendency reported in Table 4 is the substitution of "lower" vowels for "higher" ones.

Before attempting an interpretation, it would clearly be useful to examine substitution tendencies in additional ways to find out how general this lowering phenomenon is. A feature analysis seeks to distinguish just the main linguistic differentiations and necessarily obscures a great deal of relevant data. For instance, the vowels /æ/ and /a/ are both considered to be +Low in Chomsky and Halle's feature system. But there were 27 errors (standardized, 16.41) of the type target /æ/→/a/ and three errors (standardized, 1.29) of the type target /a/→/æ/. Since /a/ is considered to be lower than /æ/ by a number of authors (e.g., Pike, 1947; Jones, 1956), it should be possible to include these numbers in a height analysis. Some way of arranging all vowels in high–low order should be available, so that much more of the substitution matrix could be evaluated for the analysis of this parameter.

The question is which order is the "correct" one. At the peripheral level, "height" is not as clear-cut a parameter as we would wish it to be. It has been repeatedly emphasized in the literature (Stevens & House, 1955; Ladefoged, 1971; Lieberman, 1976) that the vocal tract is capable of differentiating vowels which are traditionally distinguished by "height" in a variety of ways. Early authors considered the highest point on the tongue dorsum to be the determining factor (Jones, 1956); "high" vowels resulted from placing this point close to the palate, and "low" vowels required a lowering of this point away from the palate. But with some speakers, on some occasions which have been recorded cineradiographically (Ladefoged, DeClerk, Lindau, & Papcun, 1972), the tongue remained in the same general position for all vowels, while adjustments in vocal tract length and lip protrusion or retraction were responsible for acoustically differentiating the vowels. Even in acoustic analysis, one articulation of a vowel may look quite unlike another articulation of the same vowel in the same phonological environment. For instance, the acoustic parameter that correlates best with height is the frequency of a spectral line called Formant_1. This frequency shows great variation, even with vowels which are unanimously classified by a large number of listeners (Peterson & Barney, 1952).

If vowels are not clearly arranged in order of height at the peripheral level, are they perhaps ordered in an invariant fashion at the internal level? It is an implicit assumption of much of modern phonology that this is so, but opinions diverge on what the ordering might be. As we have seen, Chomsky and Halle's analysis of minimal distinctions of vowels in English has resulted in a differentiation of just three levels of height $\begin{pmatrix} +\text{High} & -\text{High} & -\text{High} \\ -\text{Low}, & -\text{Low}, & -\text{Low} \end{pmatrix}$, as has the earlier analysis of the taxonomists (Gleason, 1961). Other theoretical arrangements are possible

(Lieberman, 1976) but have not yet been subjected to extended empirical application.

Instead of looking to linguistic theory for the empirical underpinnings of an internal arrangement for vowels according to height, we could perhaps look to aphasia. If we may assume that the parameter Height is the main parameter affected by aphasia in this sample, it should be possible to arrange vowels in the substitution matrix in such a fashion that the lowering tendency is maximally evident.

A relatively primitive procedure will reliably accomplish this goal. The vowel arrangement of the substitution matrices can be permuted as many times as is mathematically possible and, each time, the whole substitution matrix can be evaluated. For instance in Table 5, we see the combined data for spontaneous speech and repetition in a matrix where the vowel arrangement is /u, i, ɪ, ʊ, ɚ, eᶥ, oᵘ, ɛ, æ, ɔ, a/. The arrangement reflects, in a general way, a high-to-low arrangement of vowels and, therefore, the values in the upper right triangle of the matrix represent lowering while the ones in the lower left triangle represent raising. The two values are 70.6 and 29.4%, respectively (based on the standardized values in italics), and we can thus say that the matrix exhibits a lowering tendency. Now what happens if we exchange the positions of /i/ and /u/? Is the lowering result improved? We could check by again adding the two triangles in the permuted matrix and by comparing the two proportions. This procedure could be continued until all the possible 39,916,800 (factorial of 11, the number of vowels) permutations of the matrix have been calculated. Conservatively estimated, that would take about 5 months of continuous computing time on a small laboratory computer.

To escape this technical limitation, the vowels were grouped into three separate series, each radiating out from the low vowel /a/ (Table 6). The front series contains the sounds /i, ɪ, eᶥ, ɛ, æ, and a/, the central series contains /ɚ and a/, and the back series consists of /u, ʊ, oᵘ, ɔ, and a/. The lowering tendency can now be examined by permuting each series as many times as possible (front series, 720 times; back series, 120 times). Those matrices which give the best lowering results should show vowel arrangements according to height.

In fact, it is the arrangements given in Table 6 which yield the greatest lowering tendencies. These arrangements are shown in graphic form in Fig. 2. The result is quite surprising. The vowel arrangements obtained in this empirical fashion show a one-to-one correspondence with the height distinctions proposed by a number of prominent authors, such as Pike (1947) and Jones (1956) (Fig. 3).

These vowel arrangements also capture the substitution tendencies of individual patients in individual tasks. An analysis of the four single cells with more than 20 substitutions shows that lowering is evident in all conditions where there are enough data to make a judgment (Table 7).

It thus appears that height is indeed the major parameter for vowel

TABLE 5

SUBSTITUTION MATRIX FOR STRESSED VOWELS IN SPONTANEOUS SPEECH AND REPETITION[a]

Target	Substitution											
	u	i	ɪ	ʊ	ɚ	eᶦ	oᵘ	ɛ	æ	ɔ	a	Total
u		4 *5.16*	2 2.58	10 *12.89*	2 2.58	0 *.00*	10 *12.89*	0 *.00*	0 *.00*	1 *1.29*	5 *6.44*	34 *43.83*
i	2 .99		8 3.97	2 .99	6 2.97	7 3.47	2 .99	10 *4.96*	2 .99	2 .99	3 *1.49*	44 *21.81*
ɪ	0 .00	7 3.22		1 .46	11 5.06	6 2.76	0 .00	24 *11.05*	3 *1.38*	5 2.30	8 3.68	65 29.91
ʊ	2 5.86	0 .00	2 5.86		2 5.86	0 .00	3 8.79	0 .00	0 .00	3 8.79	0 .00	12 35.16
ɚ	1 *1.34*	6 8.06	5 6.71	3 4.03		3 4.03	6 8.06	6 8.06	2 2.69	9 12.08	5 6.71	46 61.77
eᶦ	1 .66	5 3.29	4 2.63	2 *1.32*	3 *1.97*		1 .66	5 3.29	0 .00	3 *1.97*	2 *1.32*	26 *17.11*
oᵘ	1 *1.04*	1 *1.04*	2 2.08	2 2.08	9 9.35	0 .00		1 *1.04*	2 2.08	14 14.55	6 6.24	38 39.50
ɛ	0 .00	1 .56	1 .56	2 *1.11*	16 8.89	2 *1.11*	0 .00		18 *10.00*	5 2.78	20 *11.11*	65 36.12
æ	0 .00	2 *1.22*	3 *1.82*	0 .00	8 4.86	2 *1.22*	2 *1.22*	6 3.65		1 .61	27 *16.41*	51 *31.01*
ɔ	0 .00	1 *1.19*	0 .00	0 .00	0 .00	0 .00	0 .00	0 .00	0 .00		6 *7.14*	7 8.33
a	0 .00	3 *1.29*	4 *1.72*	0 .00	2 .86	1 .43	0 .00	4 *1.72*	3 *1.29*	4 *1.72*		21 9.03
Total	7 9.89	30 *25.03*	31 27.93	22 22.88	59 *42.40*	21 *13.02*	24 *32.61*	56 33.77	30 *18.43*	47 *47.08*	82 *60.54*	409 *333.58*

[a] The lowering tendency in this matrix is 70.6% of the standardized values in italics ($p < .001$). Only paradigmatic substitutions are represented.

TABLE 6

SEPARATE SUBSTITUTION MATRICES FOR STRESSED FRONT, CENTRAL, AND BACK VOWELS AFTER PERMUTATION TO SHOW MAXIMAL LOWERING[a]

Front vowels[b] substitution

Target	i	ɪ	eᶥ	ɛ	æ	a	Total
i		8 *3.97*	7 *3.47*	10 *4.96*	2 *.99*	3 *1.49*	30 *14.88*
ɪ	7 *3.22*		6 *2.76*	24 *11.05*	3 *1.38*	8 *3.68*	48 *22.09*
eᶥ	5 *3.29*	4 *2.63*		5 *3.29*	0 *.00*	2 *1.32*	16 *10.53*
ɛ	1 *.56*	1 *.56*	2 *1.11*		18 *10.00*	20 *11.11*	42 *23.34*
æ	2 *1.22*	3 *1.82*	2 *1.22*	6 *3.65*		27 *16.41*	40 *24.32*
a	3 *1.29*	4 *1.72*	1 *.43*	4 *1.72*	3 *1.29*		15 *6.45*
T	18 *9.58*	20 *10.70*	18 *8.99*	49 *24.67*	26 *13.66*	60 *34.01*	191 *101.61*

Central vowels[c] substitution

Target	ɚ	a	Total
ɚ		5 *6.71*	5 *6.71*
a	2 *.86*		2 *.86*
T	2 *.86*	5 *6.71*	7 *7.57*

Back vowels[d] substitution

Target	u	ʊ	oᵘ	ɔ	a	Total
u		10 *12.89*	10 *12.89*	1 *1.29*	5 *6.44*	26 *33.51*
ʊ	2 *5.86*		3 *8.79*	3 *8.79*	0 *.00*	8 *23.44*
oᵘ	1 *1.04*	2 *2.08*		14 *14.55*	6 *6.24*	23 *23.91*
ɔ	0 *.00*	0 *.00*	0 *.00*		6 *7.14*	6 *7.14*
a	0 *.00*	0 *.00*	0 *.00*	4 *1.72*		4 *1.72*
T	3 *6.90*	12 *14.97*	13 *21.68*	22 *26.35*	17 *19.82*	67 *89.72*

[a] All computations are based on the standardized values in italics.
[b] The lowering tendency is 74.7%, $p < .001$.
[c] The lowering tendency is 88.6%, $p < .025$.
[d] The lowering tendency is 88.1%, $p < .001$.

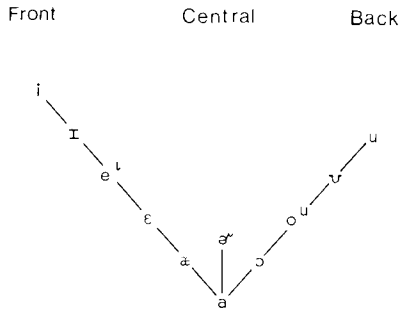

FIG. 2. The arrangement of front, central, and back vowels which showed the greatest lowering tendency when the three substitution matrices were fully permuted (see text).

substitution tendencies in this sample. In fact, it is the only parameter which clearly emerges from the substitution data when the three vowel series are treated individually. It suggests that low vowels are in some sense "easier" for these aphasics than higher vowels. Moreover, these results imply the fascinating possibility that something like Fig. 3 may be our mental map or invariant internal organization for these stressed vowels. This theme will be taken up again in the discussion.

Analysis 2: Similarity

Several studies about consonant substitutions in aphasia have demonstrated that substitution sounds tend to be similar to their targets (Lecours & Lhermitte, 1969; Blumstein, 1973; Trost & Canter, 1974; Martin & Ridrodsky, 1974). This result is interesting in two respects. First, it indicates that the aphasic's loss of control over his phonological space is only partial and not total because, if it were total, the substitution sounds would need to bear no resemblance to their targets.

Second, it demonstrates, much as the previous section did, that some phonological parameters of nonpathological speech are also relevant to

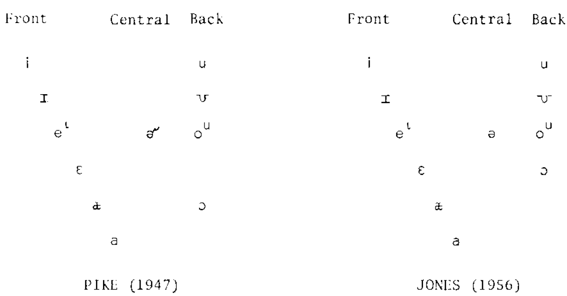

FIG. 3. The vowels distinguished in this study as arranged in Pike (1947, p. 5) and Jones (1956, p. xvii).

TABLE 7

SINGLE CELLS (OBSERVED $N > 20$) ANALYZED ACCORDING TO THE MAXIMIZED ARRANGEMENTS FOR STRESSED VOWELS

Subject	Task	Observed N / *Standardized N*	Lowering in: Front vowels	Central vowels	Back vowels
B.W.	Repetition	66 *50.08*	89.9% $p < .001$	no data	95.8% $p < .001$
E.L.	Spontaneous speech	48 *33.87*	76.7% $p < .01$	75.7% N too small	95.1% $p < .01$
E.L.	Repetition	23 *15.60*	86.8% $p < .025$	no data	93.3% $p < .025$
I.D.	Repetition	84 *60.36*	55.2% n.s. at $p < .05$	100.0% N too small	96.7% $p < .001$

aphasic breakdown. In each of the above studies, similarity was measured by counting the number of phonological features that differentiated the substitution sound from its target. All studies showed an inverse relationship between features and errors. The greatest number of errors involved a single feature and, as the number of differentiating features increased, there was a decrease of errors. This result was independent of the exact theoretical definition of the features or of the native language of the aphasic patient.

It will thus be interesting to see whether a feature analysis of vowel substitutions yields a similar result to that found in these studies on consonants. If so, the specific feature of vowel height, which is apparently of special relevance to aphasia, can be further evaluated. In the previous section it was argued that height is a six-valued feature in the front series of vowels and a five-valued feature in the back series. This notion could receive further support if it can be shown that there is a systematic decrease in the number of errors as there is an increase in the number of values differentiating the substitution vowel from its target.

To answer the first question, the standardized substitution scores (Table 5, values in italics) were grouped according to whether they represented a change of one, two, three, four, or five Chomsky and Halle-type features. The sound /ɚ/ was again left out of this analysis, since Chomsky and Halle treat it differently from the way it is treated here. The hypothesis examined was whether there were more errors which represent a change of a single feature than would be expected by chance alone, and whether the converse case becomes true as the number of features increases. A chance distribution of errors in a matrix corresponds to the distribution of cells representing the various numbers of feature changes. For instance, 18 of the 90 cells (or 20%) in the whole matrix represent a change in a single feature. Accordingly, the percentage of expected errors was derived from the distribution of the various types of cells in the matrix.

The results shown in Fig. 4 indicate that the vowel data support the hypothesis. There were significantly more standardized errors involving a single feature change than expected ($p < .001$ by binomial test). There were about as many errors as expected involving two feature changes (not significantly different at $p < .05$), and there were fewer errors than expected involving three or more feature changes ($p < .001$ each time). We may thus assume that the aphasic patient retains partial control of his phonological vowel space, even when he makes a substitution error.

The two height value matrices for front and back vowels (Table 6) were evaluated in an analogous manner, and the results were plotted in Fig. 5. The similarity between Figs. 4 and 5 is striking. As in the previous analysis, there are significantly more errors involving a change in a single value along the height axis than expected (front vowels, $p < .01$; back vowels, $p < .001$). There were about as many errors as expected involving a change over two values (neither front nor back was significant at $p < .05$), and there were fewer errors than expected involving changes of more than two values (front, three values, $p < .01$; four values, $p < .05$; five values, not significant at $p < .05$; back, three values, $p < .001$; four values, not significant at $p < .05$). We thus find the notion of a multivalued feature Height further supported by this set of data.

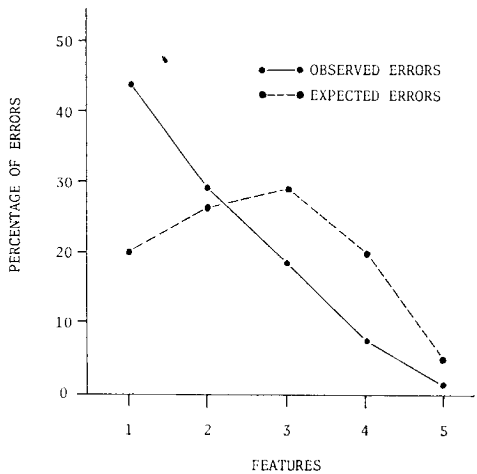

FIG. 4. The percentages of paradigmatic stressed vowel substitutions which differ from their targets by one to five features. Expected values are derived from the number of cells of that type in the matrix.

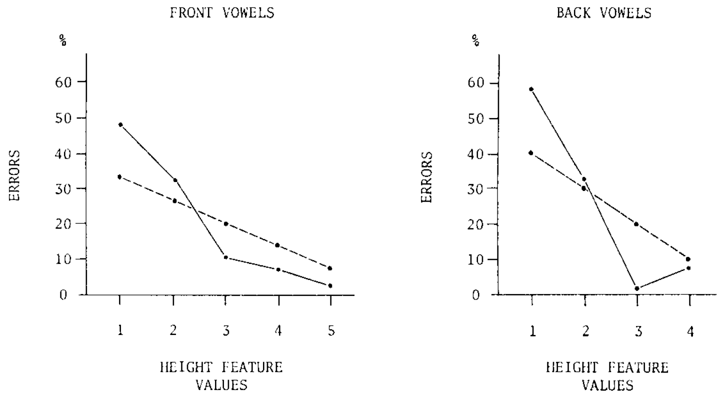

FIG. 5. The percentages of stressed vowel substitutions which differ from their targets by one to five values along the height axis.

DISCUSSION

This study has led to the following findings:

1. Two major explanatory hypotheses, environmental influence and markedness, have been shown to have no predictive value for the majority of vowel substitutions of this sample of vowel errors in Broca's aphasia.
2. The major substitution tendency in the vowels of this sample appears to be the use of lower sounds in the place of higher target sounds. This must be considered to be an important clue in the search for an adequate hypothesis for the origin of vowel paraphasias.
3. As a subsidiary result of these analyses it was found that the height axis in vowels is very likely multivalued rather than merely trivalued, as has been assumed in many traditional linguistic analyses.
4. A further subsidiary result of these analyses has been the finding that vowel substitutions, just like consonant paraphasias, conform to the constraint of similarity: Vowels which are similar to the intended target are far more likely to be used as substitution sounds than dissimilar sounds.

Since neither environmental influence nor markedness adequately accounts for the origin of most of the errors of this sample, an attempt must be made to limit the range of possible hypotheses that can be claimed to account for the data and to examine the most likely remaining candidates in some detail.

The nature of Broca's aphasia and the constraints acting on phonological substitutions serve to circumscribe the field. Since these substitutions are neither semantic in nature nor peripheral in origin, we must assume that they are errors in phonological processing at a central level or, in a different terminology, errors in the selection *or* activation of whole muscle programs for the articulation of vowel sounds. It is well known that such processes must be under fairly constant control of, and are to some degree determined by, various reafference mechanisms, such as proprioceptive and auditory feedback. Out of these considerations it appears that the most likely sources for these aphasic vowel substitutions are to be found in one of the following areas of phonological processing: the programming or activation of articulatory patterns, the selection of pattern programs from an internal store, or the integration of proprioceptive or auditory feedback information. These different possibilities merit some closer examination.

Hypothesis 1. Vowel errors are due to a neuromuscular programming error. This hypothesis has been advanced by Keller (1975). It was argued on the basis of electromyographic and cineradiographic evidence (Mac Neilage & Sholes, 1964; Perkell, 1969) that there is strong simultaneous contraction of the two main extrinsic tongue muscle groups (genioglossus and hyoglossus) for low vowels, in particular for the sound /a/. For high vowels like /i/ or /u/, on the other hand, there must be selective contraction of a few single muscles, such as the genioglossus or the styloglossus, with concurrent relaxation of the antagonist muscles. If aphasics had lost full control to select individual muscles while articulating, they would tend to activate all muscles simultaneously, which would perforce result in a great number of lowering errors. The hypothesis receives some support from electromyographic results reported in Luria (1966, p. 181) where such pathological simultaneous activation patterns are described for rapid finger movements as a result of a lesion in the lower sensory cortex.

Hypothesis 2. Paradigmatic errors are errors in selection from an internal store. This notion, proposed by Jakobson (1956, 1971) with respect to morphemic errors along the paradigmatic axis, can be extended to phoneme selection. It would mean that there is a central store of vowel images which is accessed every time a vowel phoneme is needed for articulation. Since these patients showed a lowering tendency, one would have to assume an internal vowel arrangement along the height axes (perhaps as illustrated in Fig. 2 or in Lieberman, 1976, p. 104). Entry to the internal store would be via the low vowels if one assumed "undershoot" of the target in aphasia or via the high vowels if one assumed "overshoot."

Hypothesis 3. Patients have incomplete or inaccurate proprioceptive feedback. Since any motoric activation has to be based on computations of the present state of contraction of the various muscle groups (Kornhuber, 1974), a systematic inaccuracy in such feedback could result in a systematic tendency to substitute lower for higher vowels. This hypothesis would draw support from Luria's (1966) opinion that paradigmatic difficulties at the phonemic level are an indicator of a disturbance of the proprioceptive feedback information. It is for this reason that Luria calls this form of aphasia "afferent motor aphasia."

Hypothesis 4. Auditory phonological perception feedback is incomplete or inaccurate. Since the goal of vowel articulation is the realization of an acoustic target, no matter how implemented, it follows that a systematic error in acoustic perception of phonemic targets could result in a systematic lowering tendency. This could for instance mean that there is a shift in the perception of Formant$_1$, the closest acoustic correlate of height, such that higher vowels are perceived as lower, and that lower-sounding vowels thus by mistake become acoustic targets to the patient. Recently it has been demonstrated (Blumstein, Baker, & Goodglass, 1977) that mixed anterior aphasics (patients possibly comparable to those of the present sample) have a greater acoustic perception deficit than posterior aphasics on a task involving the discrimination of consonants. An acoustic feedback deficit for vowels is thus not inconceivable, especially if one assumed relatively unimpaired proprioceptive feedback in the face of an acoustic perception difficulty.

At present it is impossible to assert which of these hypotheses is the one applicable to the data at hand. Yet it is clearly important for an understanding of the nature of this type of aphasia to investigate these theoretical possibilities. Most immediately accessible to empirical research is Hypothesis 4, for instance by means of a perception test using minimal pairs of words which are solely distinguished by vowels of various heights.

Finally, it is also possible that several of these hypotheses apply at the same time. In that case we would be faced once more with the realization that the causes of aphasia, even in respect to a single, well-defined phenomenon such as paradigmatic vowel substitutions, can be multiple and heterogeneous.

REFERENCES

Alajouanine, Th., Obredane, A., & Durand, M. 1939. *Le syndrôme de désintégration phonétique dans l'aphasie.* Paris: Masson.

Blumstein, S. 1973. *A phonological investigation of aphasic speech.* The Hague: Mouton.

Blumstein, S., Baker, E., & Goodglass, H. 1977. Phonological factors in auditory comprehension in aphasia. *Neuropsychologia,* **15,** 19–30.

Chomsky, N., & Halle, M. 1968. *The sound pattern of English.* New York: Harper and Row.

Denes, P. B. 1963. On the statistics of spoken English. *The Journal of the Acoustical Society of America,* **35,** 892–904.

Derouesne, J., Beauvois, M. F., & Ranty, C. 1977. Deux composantes dans l'articulation du langage oral: Preuve expérimentale de leur indépendance. *Neuropsychologia,* **15,** 143–153.

De Villiers, J. 1974. Quantitative aspects of agrammatism in aphasia. *Cortex,* **10,** 36–54.

Dubois, J., Hécaen, H., Angelergues, R., Maufras de Chatelier, A., & Marcie, P. 1964. Étude neurolinguistique de l'aphasie de conduction. *Neuropsychologia,* **2,** 9–44. [Translated as Neurolinguistic study of conduction aphasia. In H. Goodglass & S. Blumstein (Eds.). 1973. *Psycholinguistics and aphasia.* Baltimore: The Johns Hopkins University Press. Pp. 283–300.]

Fromkin, V. A. (Ed.) 1973. *Speech errors as linguistic evidence.* The Hague: Mouton.

Fry, D. B. 1959. Phonemic substitutions in an aphasic patient. *Language and Speech,* **2,** 52–61.

Glass, G. V., & Stanley, J. C. 1970. *Statistical methods in education and psychology*. Englewood Cliffs, N. J.: Prentice-Hall.

Gleason, H. A., Jr. 1961. *An introduction to descriptive linguistics*. New York: Holt, Rinehart & Winston. 2nd rev. ed.

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

Jakobson, R. 1941. *Kindersprache, Aphasie und allgemeine Lautgesetze*. Uppsala. [Keiler, A. R. (trans). 1968. Child language, aphasia and phonological universals. The Hague: Mouton.]

Jakobson, R. 1956. Two aspects of language and two types of aphasic disturbances. In R. Jakobson. 1971. *Studies on child language and aphasia*. The Hague: Mouton, Pp. 49–73.

Jakobson, R. 1963. Linguistic types of aphasia. In R. Jakobson. 1971. *Studies on child language and aphasia*. The Hague: Mouton. Pp. 95–125.

Johns, D. F., & Darley, F. L. 1970. Phonemic variability in apraxia of speech. *Journal of Speech and Hearing Research*, **13**, 556–583.

Jones, D. 1956. *An outline of English phonetics*. Cambridge, England: W. Heffer. 8th rev. ed.

Keller, E. 1975. *Vowel errors in aphasia*. Unpublished Ph.D. dissertation, University of Toronto.

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

Kornhuber, H. H. 1974. Cerebral cortex, cerebellum, and basal ganglia: An introduction to their motor functions. In F. O. Schmitt & F. G. Worden (Eds.). 1974. *The Neurosciences, Vol. 3*. Cambridge, Mass.: The MIT Press. Pp. 267–280.

Ladefoged, P. 1971. *Preliminaries to linguistic phonetics*. Chicago: The University of Chicago Press.

Ladefoged, P., DeClerk, J., Lindau, M., & Papcun, G. 1972. An auditory–motor theory of speech production. *UCLA Working Papers in Phonetics*, **22.**

Lecours, A. R., Deloche, G., & Lhermitte, F. 1973. Paraphasies phonémiques; description et simulation sur ordinateur. In *Colloques IRIA—Informatique médicale*. Rocquencourt: Institut de Recherche d'Informatique et d'Automatique. Pp. 311–350.

Lecours, A. R., & Lhermitte, F. 1969. Phonemic paraphasias: Linguistic structures and tentative hypotheses. *Cortex*, **5**, 193–228. [Reprinted in H. Goodglass & S. Blumstein (Eds.). 1973. *Psycholinguistics and aphasia*. Baltimore: The Johns Hopkins University Press. Pp. 69–105.]

Lehiste, I. 1965. *Some acoustic characteristics of dysarthria*. Basel: Bibliotheca Phonetica.

Lieberman, P., 1976. Phonetic features and physiology: A reappraisal. *Journal of Phonetics*, **4**, 91–112.

Luria, A. R. 1966. *Higher cortical functions in man*. New York: Basic Books.

MacKay, D. G. 1970. Spoonerisms: The structure of errors in the serial order of speech. *Neuropsychologia*, **8**, 323–350. [Reprinted in V. A. Fromkin (Ed.). 1973. *Speech errors as linguistic evidence*. The Hague: Mouton. Pp. 164–194.]

Mac Neilage, P. F., & Sholes, G. N. 1964. An electromyographic study of the tongue during vowel production. *Journal of Speech and Hearing Research*, **7**, 209–232.

Martin, A. D., & Ridrodsky, S. 1974. An investigation of phonological impairment in aphasia, part 2: Distinctive feature analysis of phonemic commutation errors in aphasia. *Cortex*, **10**, 329–346.

Perkell, J. S. 1969. *Physiology of speech production: Results and implications of a quantitative cineradiographic study*. Cambridge, Mass.: The MIT Press.

Peterson, G. E., & Barney, H. L. 1952. Control methods used in a study of the vowels. *Journal of the Acoustical Society of America*, **24**, 175–184.

Pike, K. L. 1947. *Phonemics.* Ann Arbor: The University of Michigan Press.

Roberts, A. H. 1965. *A statistical linguistic analysis of American English.* The Hague: Mouton.

Stevens, K. N., & House, A. S. 1955. Development of a quantitative description of vowel articulation. *Journal of the Acoustical Society of America,* **27,** 484–493.

Trost, J., & Canter, C. J. 1974. Apraxia of speech in patients with Broca's aphasia: A study of phoneme production accuracy and error patterns. *Brain and Language,* **1,** 63–79.

Weisenburg, T. H., & McBride, K. E. 1935. *Aphasia.* New York: Commonwealth Fund.