

Dysprosody in Broca's Aphasia: A Case Study

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A detailed acoustic analysis of timing, intensity, and fundamental frequency (F_0) at different levels of linguistic structure was conducted on the speech output of a Broca's aphasic who was a native speaker of Thai. Timing was measured with respect to syllables, phrases, and sentences in connected speech. Intensity variation at the sentence level was measured in connected speech. F_0 variation associated with the five Thai tones was measured in both isolated words and connected speech. Results indicated that timing was differentially impaired depending upon complexity of articulatory gesture and size of the linguistic structure. Timing, as well as intensity, was aberrant at the sentence level. In contrast, F_0 contours of the five tones were spared at all levels of linguistic structure. Findings are interpreted to support the view that dysprosody in Broca's aphasia is more applicable to speech timing than to F_0 . © 1989 Academic Press, Inc.

Prosodic features of speech include three acoustical properties: timing, intensity, and fundamental frequency (F_0). The speech output of a Broca's aphasic has traditionally been described as *dysprosodic* (Benson, 1979; Goodglass & Kaplan, 1983). The clinical use of the term has gen-

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erally connoted a deficit in all aspects of prosody with perhaps a primary deficit in the programming of F_0 . However, recent findings from acoustical analysis of Broca's speech have indicated that not all aspects of prosody are equally disturbed. While some aspects of prosody are impaired, others are clearly intact. In particular, speech timing appears to be relatively more disturbed than F_0 (Danly & Shapiro, 1982). Based on a review of the acoustic phonetic literature on Broca's aphasia, Cooper and Klouda (1987) concluded that "as for the traditional clinical view that Broca's aphasics exhibit dysprosody, it now appears that this description is more applicable to speech timing . . . than to fundamental frequency" (p. 66).

In view of the possible dissociation of timing and F_0 in Broca's aphasia, it is imperative that we design studies that incorporate acoustic measures of both at different levels of linguistic structure for the same subject. Without such acoustic measures, we cannot determine the extent to which timing and F_0 , or other aspects of prosody, may be selectively disrupted, as well as the extent to which the prosodic disruption varies as a function of the size of the linguistic structure. Intersubject variability makes it difficult to interpret the group performance of aphasic patients (Caramazza & Martin, 1983). By adopting the method of single case study, we are able to conduct an extensive analysis of Broca's aphasia without the contaminating factor of heterogeneous variation.

Danly and Shapiro (1982) hypothesized that the dissociation between F_0 and timing in English-speaking Broca's aphasics resulted from their narrower-than-normal scope for linguistic planning. Because intonation production necessarily involves sentence- or phrase-sized linguistic units, the possibility remains that a deficit in F_0 production occurs only when higher levels of linguistic structure are involved. To help clarify this issue, F_0 production needs to be investigated in word-sized units in order to eliminate that confounding variable. What is required is a tone language in which F_0 production is linguistically significant at the word or syllable level. If control of F_0 and timing are independent, then we might expect F_0 patterns of tones to be preserved within syllables when they occur in polysyllabic words, phrases, and sentences in spite of abnormal timing between syllables. Such an acoustic phonetic investigation of speech prosody in Broca's aphasia has yet to be completed in a tone language.

As part of larger studies of consonant and vowel production in isolated words, timing data on word-initial stop consonants and short and long vowels in Thai have already been presented for a Broca's aphasic (hereafter referred to as B; Gandour & Dardarananda, 1984a, 1984b). These earlier findings on consonant and vowel timing in isolated, monosyllabic words provide a point of departure for the studies on speech timing presented in this report.

Thai is a language that has a maximum of three voicing categories of

stops in word-initial position: a three-way opposition (voiced unaspirated, voiceless unaspirated, voiceless aspirated) at the bilabial (/b, p, p^h/) and alveolar (/d, t, t^h/) places of articulation and a two-way opposition (voiceless unaspirated, voiceless aspirated) at the velar (/k, k^h/) place of articulation. VOT values for /b, d/ lie in the long voicing lead region, for /p^h, t^h, k^h/ in the long voicing lag region, and for /p, t, k/ at zero or in the short voicing lag region (Lisker & Abramson, 1964).

Gandour and Dardarananda (1984a) reported no overlap in VOT distribution between homorganic stops produced by normal speakers. B's distribution of VOT values, however, do not fall into distinct, non-overlapping regions. Her VOT continuum is considerably compressed. The majority of VOT values lie in the region at and just below zero. Her voiced unaspirated stops were produced with a shorter-than-normal voicing lead, voiceless aspirated stops with a shorter-than-normal voicing lag.

These findings are consistent with previous reports on VOT production deficits in Broca's aphasics or patients with apraxia of speech (e.g., Blumstein, Cooper, Goodglass, Statlender, & Gottlieb, 1980; Itoh, Sasanuma, Tatsumi, Murakami, Fukusako, & Suzuki, 1982; Ziegler & von Cramon, 1986). The production of VOT requires the coordination of two independent articulators, the tongue or lips and the larynx. The abnormal VOT patterns suggest that Broca's aphasics have an impairment in the temporal coordination of the release of the stop closure and the onset of vocal cord vibration. However, as emphasized by Baum and Blumstein (1987), "it is not possible to determine on the basis of the VOT studies alone whether the deficit displayed by Broca's aphasics reflects a pervasive phonetic disorder [in timing] . . . or whether it reflects a more selective timing impairment" (p. 10).

In Thai, differences in the duration of short and long vowels are used phonemically (e.g., /hàt/ "to practice" vs. /hàat/ "beach"; /bòt/ "to grind" vs. /bòt/ "temple"; /khun/ "you" vs. /khuun/ "to multiply"). Previous studies of the production of vowel length in normal adult speakers of Thai have shown that short and long vowel productions fall into distinct, nonoverlapping regions along the duration continuum (Abramson, 1962, 1974; Gandour, 1984).

Gandour and Dardarananda (1984b) reported no overlap on the duration continuum for short (/a/) and long (/aa/) vowels produced by Thai normal speakers. Similarly, B's short and long vowel productions were distributed into relatively distinct regions along the duration continuum with only sporadic occurrences of overlap. Her duration ratio of the means of long to short vowels (1.8) was robust. Albeit less than that of the four normal speakers (2.6) in Gandour and Dardarananda's (1984b) study, her duration ratio was identical to the mean duration ratio that Roberson (1982, p. 95) reported for six normal speakers.

These findings suggest that B's timing of vowel duration is spared in Thai monosyllabic words by either an absolute or relative standard of measurement. Yet, B exhibited a timing deficit in the production of VOT associated with word-initial stop consonants. The stimuli in both the VOT and vowel length studies were monosyllabic. Thus, we cannot ascribe B's inability to maintain timing control of VOT to variation in the size of the temporal domain. According to Baum and Blumstein (1987), Broca's aphasics "seem to be particularly vulnerable to those phonetic parameters requiring the temporal integration of the movement of two independent articulators" (p. 17).

Of previous studies of vowel duration in Broca's aphasia or apraxia of speech, some (Collins, Rosenbek, & Wertz, 1983; Kent & Rosenbek, 1982, 1983; Ryalls, 1981; Shankweiler, Harris, & Taylor, 1968) have reported longer-than-normal vowel durations, while others (Duffy & Gawle, 1984; Ryalls, 1986) have found no significant lengthening of vowels. Ryalls (1987) has pointed out that the target words were polysyllabic in all the studies that found longer vowel durations for anterior patients. B's vowel durations were not significantly different from normal. Indeed, her productions of /aa/ were, on average, somewhat shorter than those of normal speakers. The target words in the Thai study were monosyllabic. These combined findings suggest that, in addition to the complexity of articulatory implementation of temporal parameters, the degree of temporal disintegration in Broca's aphasia is dependent upon the size of the linguistic unit over which temporal parameters are defined.

In Thai, every syllable has a distinctive tone as a part of its phonemic makeup. Thai has five contrastive lexical tones on syllables ending in long vowels, diphthongs, or nasal consonants (Gandour, 1975), traditionally labeled *mid* (unmarked), *low* ('), *falling* ("), *high* ("), and *rising* ("). The mid tone can be described as mid level with a final drop, the low tone as low falling, the falling tone as high falling, the high tone as high rising, and the rising tone as low rising (Abramson, 1962).

As part of a larger study of tone production in isolated words, some F_0 data on the five Thai tones produced by B have already been reported in Gandour, Petty, and Dardarananda (1988). These earlier findings on F_0 in isolated, monosyllabic words provide a point of departure for the F_0 analysis presented in the current study.

Gandour et al. (1988) reported that listeners correctly identified the five Thai tones produced by normal speakers at a near-perfect level of accuracy. For B, the mean percentage of correct identification pooled across the five tones was 92%. The level of accuracy for all five, individual tones produced by normal speakers ranged from 95 to 100%. Of the five individual tones produced by B, mid, high, and rising were correctly identified at levels comparable to that of normals. Her productions of the low (84%) and falling (83%) tones were correctly identified

at levels only slightly lower than normal. Thus, B managed to achieve levels of proficiency in signaling tonal contrasts that were comparable to those of normal speakers.

B's pattern of tonal confusions differed from that of normal speakers primarily in degree rather than in kind. For the group of normal speakers, confusion between the mid and low tones accounted for 86% of the total number of listeners' errors; for B, 35%. The overwhelming majority (71%) of B's errors involved substitution of the mid tone for either low or falling.

These findings indicate that B's control of F_0 in the production of tones in monosyllabic citation forms is relatively spared. If control of F_0 and timing are independent, then we should expect F_0 contours of B's tones to be preserved within syllables when they occur in polysyllabic words, phrases, and sentences in spite of abnormal timing patterns between syllables. If so, these data would provide strong evidence in favor of the notion that dysprosody in Broca's aphasia is not solely a manifestation of articulatory or phonatory deficits, but instead a manifestation of timing disturbances over larger-sized linguistic units.

Only a few, acoustic investigations have been conducted on Thai tones in connected speech. F_0 contours of the five tones undergo perturbations induced by tonal coarticulation (Abramson, 1979a; Palmer, 1969) and sentence intonation (Abramson 1979b; Abramson & Svastikula, 1983). Although the shapes of the tonal contours are not identical to those that appear in monosyllabic citation forms, tonal contrasts are preserved.

In the present report, we present further detailed acoustic analysis of timing, intensity, and F_0 at different levels of linguistic structure for this same Thai-speaking Broca's aphasic. Specifically, we focus on features of timing related to rhythmic patterns at the sentence level; features of intensity at the sentence level; and features of F_0 at the word and sentence levels. With this particular constellation of acoustic features, we are able to evaluate the extent to which various elements of prosody may be separately disrupted in Broca's aphasia. In so doing, we bring evidence to bear on the notion that prosodic disturbance in Broca's aphasia results primarily from a deficit in timing.

CASE REPORT

B, a 60-year-old right-handed Thai female, approximately 3 years post-stroke, was referred to the Speech Clinic at Ramathibodi Hospital in June 1980 for speech therapy.

On 3 June 1977, while eating dinner, she noticed her right arm was weak. Her right leg dragged when she walked. Examination revealed an alert, cooperative patient whose speech was markedly limited to a few words or short sentences. Her fundi showed slightly narrow and tortuous retinal vessels. Eye movements were full. There was upper motor neuron

facial weakness of the right side. Her palate moved normally on phonation and the tongue was mid-line on protrusion. There was evidence of right hemiparesis with absent deep reflexes of the limbs and an extensor plantar response on that side. Sensory testing showed no abnormality. Her pulse rate was regular, 72/min, B.P. 160/100 mm Hg. There was a grade 2/6 ejection systolic murmur over the aortic area, but there were no arterial bruits audible in the neck. Other systems were otherwise normal.

Investigations including urinalysis, EKG, Hb, Hct, WBC and differential count, BUN, blood Cr, uric acid, cholesterol, SGOT and PT were within normal limits, but her fasting blood glucose was 145 mg%.

A CT scan was performed a week after clinical onset and showed evidence of infarction at the left lateral frontal region (see Fig. 1). When B was discharged from the hospital after 2 weeks, her right arm and leg improved slightly in strength but her speech was virtually unchanged.

Three days after leaving the hospital, B had convulsions which began in the right limbs. When examined on readmission to the hospital, she had a complete right hemiplegia and motor aphasia. Phenytoin and dexamethasone were given. She improved slowly, and when discharged from the hospital 3 weeks later, she was able to walk with support.

When seen at the out-patient clinic approximately 3 months after the stroke, B could say only a few isolated words. Another CT scan at 39 months postonset (17 September 1980) revealed an irregular area of decreased density at the left frontoparietal lobe with ipsilateral enlargement of left lateral ventricle and cortical sulci, compatible with the old infarct.

A Thai adaptation of the Boston Diagnostic Aphasia Examination (Gandour, 1982; Gandour, Dardarananda, Buckingham, & Viriyavejakul, 1986) was administered on 30 July 1980, approximately 3 years after the stroke. The results from the Thai aphasia exam were fully compatible with a diagnosis of Broca's aphasia (Gandour, Dardarananda, & Vejjajiva, 1985). Spontaneous speech was nonfluent, dysprosodic, and agrammatic; repetition was poor; however, comprehension of spoken language was relatively good in ordinary conversation.

B (= B1 in Gandour & Dardarananda, 1984a,b) was born in 1920 in Bangkok. She had completed the 10th grade in local schools. She was a monodialectal speaker of Central Thai, the official language of Thailand.

Timing

Method

Subjects. Data were obtained from B for this study. For comparison purposes, data were taken from a previously published report on five normal adult speakers (Luangthong-kum, 1977).

Speech materials. Four readings of a passage were obtained from B. Data based on one

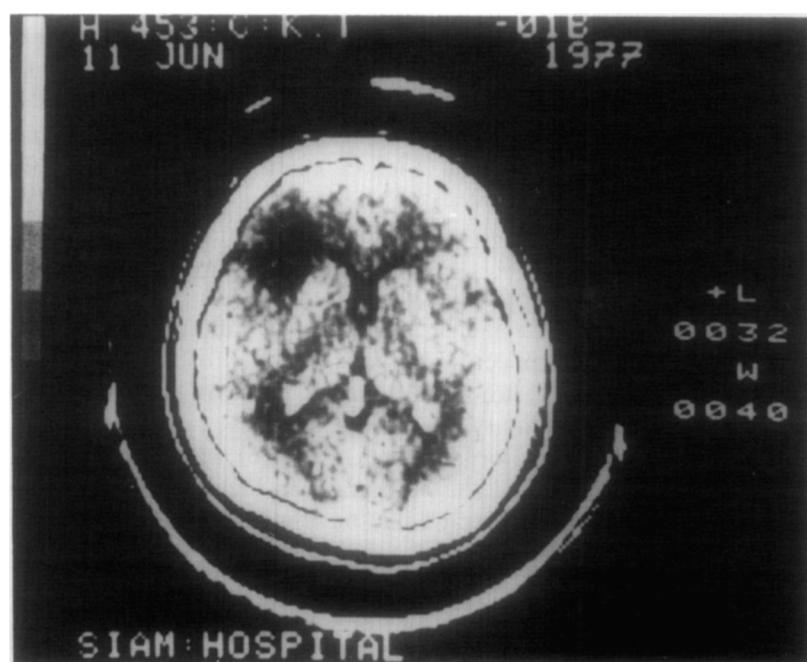
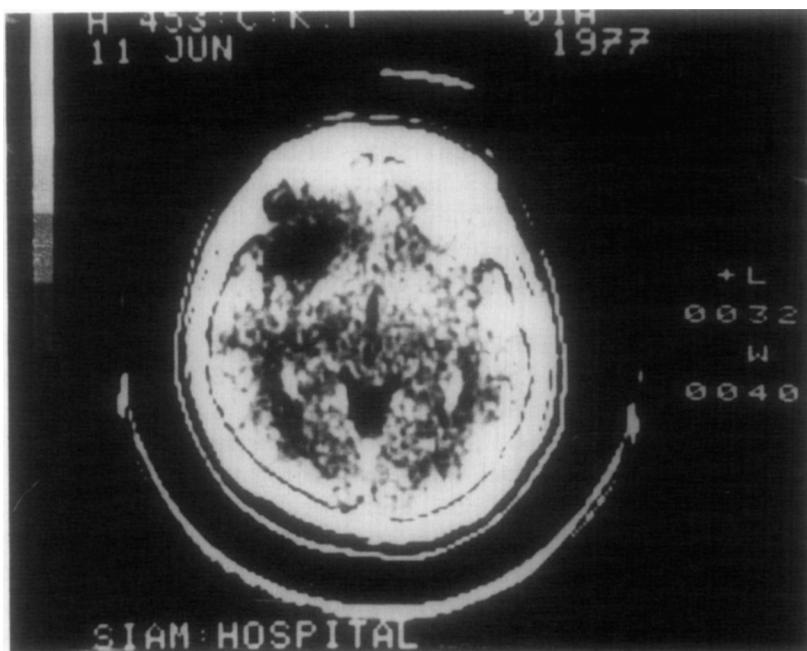


FIG. 1. CT scan showing area of decreased density in left lateral frontal lobe. No change in appearance was evident after enhancement with conray 420.

reading of the passage by each of five normal speakers were taken from Luangthongkum's (1977) study. The passage itself was a Thai adaptation of the story of a parrot as told by Blanche DuBois in Tennessee Williams' play *A Streetcar Named Desire*. The majority of words in the reading passage were monosyllabic. The Thai adaptation was carefully designed by Luangthongkum for the purpose of making syllable duration measurements. A phonemic transcription according to Haas (1964) and an English translation of the reading passage are presented in the Appendix.

Measurement procedure. Recordings of four readings of the passage by B were played into a Pitch Instruments F_0 -intensity meter. The audio, F_0 , and intensity signals were played into three different channels of a Honeywell 1508 oscillograph operating at a chart speech of 100 mm/sec.

Identification of syllable boundaries was determined from inspection of the audio, F_0 , and intensity-meter signals (cf. Gandour, Weinberg, Petty, & Dardarananda, 1986). For the majority of adjacent syllables in the passage either the offset of the first syllable or the onset of the second syllable was voiceless, or they were separated by a syntactic pause. In those cases, syllable onset was operationally defined to occur when there was a sharp increase in intensity from the baseline, syllable offset when there was a sharp decrease in intensity to the baseline. In the few remaining cases, adjacent syllables had different tones. Syllable onset and offset were determined on the basis of shifts in direction of F_0 associated with the different tones. A pause was operationally defined to occur when the speech waveform approached baseline for at least 200 msec. The portion of the waveform tracing between two pauses was designated as a phrase. In this context, phrases were phonetically structured entities that did not necessarily coincide with syntactic phrases. Syllable and pause durations were measured by the first author to the nearest centisecond using a transparent millimeter rule. All syllable and pause durations were reanalyzed on a separate occasion for an estimate of intrajudge reliability ($r = .99$). The total number of syllables subjected to duration measurements differed between readings because of the speaker's omissions of words in each of her four readings of the paragraph or the occurrence of unmeasurable portions of the oscillographic records.

Identification of stressed syllables in the readings of the passage by B was performed by the second author, a native speaker of Thai with a postgraduate degree in linguistics. She listened to the tape recordings of the reading passage and identified which syllables she perceived to be stressed. Each recording of the paragraph was presented in two separate sessions spaced approximately 1 week apart. Her stress judgments were identical for the two presentations of each recording of the paragraph. Stressed syllables in the readings of the passage by the five speakers were taken from Luangthongkum (1977).

Duration measurements of syllables and pauses in the readings of the passage by the five normal speakers were taken directly from Luangthongkum (1977). Her measurements to the nearest centisecond were determined in an identical manner from inspection of oscillographic records.

Results and Discussion

Mean durations of syllables and pauses based on four readings of the passage by B and one reading each of the passage by Luangthongkum's (1977) five normal speakers are summarized in Table 1. B took a longer time to read the passage aloud than normal speakers. Her total reading time was about four times greater than that for normal speakers. As measured in syllables per second, B and the normal speakers spoke at a rate of 0.9 and 3.3 syllables/sec, respectively. In terms of words per

TABLE 1
DURATION OF PAUSES AND SYLLABLES

Measure	Speakers			
	B		Normal	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Total duration of passage (sec)	208.4	16.6	54.5	2.5
Total number of pauses	130.8	8.9	23.2	1.3
Total duration of pauses (sec)	117.7	15.0	14.1	1.6
Mean pause duration (csec)	90.1	10.0	60.0	7.0
Percent pause duration	56.3	2.7	25.7	1.8
Total number of syllables	175.3	4.0	177.0	1.3
Total duration of syllable (sec)	87.7	3.3	40.4	1.2
Mean syllable duration (csec)	50.0	1.3	23.0	1.0
Syllables per second	0.9	0.1	3.3	0.1
Pause-to-syllable duration ratio	1.4	0.1	0.3	0.1

minute, B spoke at a rate of 46 wpm, while normal speakers spoke at a rate of 165 wpm.

All pause time measures for B were larger than for normal speakers (see Table 1). B exhibited a larger number of pauses, a greater amount of total pause time, a greater mean pause duration, and a greater percentage of pause time. B's pause-to-syllable duration ratio (total pause time divided by total phrase time) was almost five times as large as that for the normal speakers. Total duration of syllables and mean syllable duration for her were both about twice as large as those for normal speakers.

Phrase timing measures for B and the normal speakers are presented in Table 2. There is an inverse relationship between the total number of

TABLE 2
PHRASE TIMING

Measure	Speakers			
	B		Normal	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Total number of phrases	136.8	3.9	24.2	1.3
Total phrase duration (sec)	25.2	2.8	32.3	1.1
Mean phrase duration (csec)	18.3	2.1	134.0	8.0
Maximum syllables per phrase	4.3	0.9	19.0	0.0
Mean syllables per phrase	1.3	0.1	7.3	0.4

phrases and the total duration of phrases. B produced a greater number of phrases in a shorter total duration of phrase time, while the normal speakers produced fewer phrases in a longer total duration of phrase time. In terms of mean phrase duration, maximum number of syllables per phrase, and mean number of syllables per phrase, B produced clearly shorter phrases.

The time between the onset of one stressed syllable and the onset of the next stressed syllable was designated as an interstress interval. A one-syllable interstress interval indicates that two adjacent syllables are stressed; a two-syllable interstress interval indicates that an unstressed syllable occurs between two stressed syllables; and so on. To provide a measure of the extent to which the temporal speech patterns were syllable timed or stress timed, mean durations of interstress intervals were computed, as well as their frequencies of occurrence.

Important characteristics of interstress intervals are summarized in Table 3. All of B's interstress intervals were one syllable. While the majority of the normal speakers' interstress intervals were also one syllable, 35% of them were two syllable. B's one-syllable interstress intervals were, on average, three times longer than those of normal speakers.

A comparison of syllable durations as a function of stress is presented in Table 4. The ratio of stressed-to-unstressed syllables was 1.7 for the

TABLE 3
OCCURRENCE AND DURATION OF INTERSTRESS INTERVALS

Interstress interval	Speakers			
	B		Normal	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
One syllable				
Occurrence ^a	100	0	56.3	1.4
Duration ^b	119.0	6.9	39.2	1.9
Two syllable				
Occurrence	—	—	35.3	1.2
Duration	—	—	52.0	3.1
Three syllable				
Occurrence	—	—	3.9	0.5
Duration	—	—	107.4	7.3
Four syllable				
Occurrence	—	—	2.9	0.8
Duration	—	—	94.0	10.3

^a Values are expressed in percentages.

^b Values are expressed in centiseconds.

TABLE 4
EFFECT OF STRESS ON SYLLABLE DURATION

Measure	Speakers			
	B		Normal	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Total number of stressed syllables	175.3	4.0	112.0	2.3
Total number of unstressed syllables	—	—	65.0	2.3
Mean stressed syllable duration (csec)	50.0	1.3	28.0	0.2
Mean unstressed syllable duration (csec)	—	—	14.0	0.1

normal speakers; the stressed–unstressed duration ratio was 2.0. Because all of her syllables were stressed, no ratios were computed for B.

A comparison of syllable durations as a function of whether or not they preceded a pause is presented in Table 5. B produced about three times as many prepausal as nonprepausal syllables; normal speakers, on the other hand, produced about seven times as many nonprepausal as prepausal. The prepausal–nonprepausal duration ratio was 1.0 for B, 1.7 for the normal speakers.

These combined findings clearly indicate that B exhibited an impairment in timing in connected speech. In comparison to normal adults, B's temporal patterns in syllables and phrases were abnormal. Her slower overall speaking rate, shorter phrases, uniform syllable durations regardless of stress or sentence position, and exclusive use of one-syllable interstress intervals all contributed to the dysrhythmic quality of B's speech. These findings were not restricted to oral reading. The dysrhythmic quality of B's oral reading directly reflects her spontaneous speaking abilities. B tended to produce speech on a syllable-by-syllable basis. In so doing, an economy in timing patterns was achieved insomuch as temporal dependencies among syllables were minimized. Such timing patterns appear to reflect simplification of motor programming of larger sized linguistic units. Interestingly, B's syllable-by-syllable production is not unlike that reported in ataxic dysarthria (Kent, Netsell, & Abbs, 1979).

A few polysyllabic words, phrases, and sentences were selected from the passage to further illustrate the nature of B's breakdown in timing in larger sized temporal domains (Figs. 2–4). First, B's polysyllabic words, phrases, and sentences are markedly longer than normal on an absolute scale (see Figs. 2–4). Second, conspicuous, lengthy gaps of silence are evident between syllables in the majority of B's productions (see Figs. 2–4). Third, the relative temporal relationships among B's syllables deteriorate in larger sized linguistic units. In Thai, initial syllables in bisyllabic words are unstressed and final syllables are stressed.

TABLE 5
EFFECT OF POSITION ON SYLLABLE DURATION

Measure	Speakers			
	B		Normal	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Total number of prepausal syllables	130.8	8.9	23.2	1.3
Total number of nonprepausal syllables	44.5	6.2	154.2	2.5
Mean prepausal syllable duration (csec)	50.1	1.2	35.7	1.9
Mean nonprepausal syllable duration (csec)	50.0	1.9	20.8	0.6

The average duration ratio of final to initial syllable in the word /kaafææ/ was 3.2 for normal speakers, 1.1 for B (see Fig. 2); in the prepositional phrase /naj baân/ 3.1 for normal speakers, 0.8 for B (see Fig. 3). In the Thai sentence /man sâñ pen baâ lœaj wœaj/, an alternating stress pattern manifested by the differential lengthening of syllables is evident in normal speech only (see Fig. 4). The average duration ratio of last to first syllable in /man sâñ/, /pen baâ/, and /lœaj wœaj/, respectively, was 1.4, 2.1, and 1.9 for normal speakers and 0.9, 0.9, and 0.7 for B. In each case, the last syllable was longer than the first for the normal speakers, whereas the opposite was true for B. Following Kent and Rosenbek (1982, pp. 266-267), an estimate of degree of the temporal isolation of syllables in this sentence was obtained by dividing total syllable duration by the total sentence duration. The smaller the ratio, the greater the degree of separation of syllables. The average ratio was 1.0 for normal speakers, but

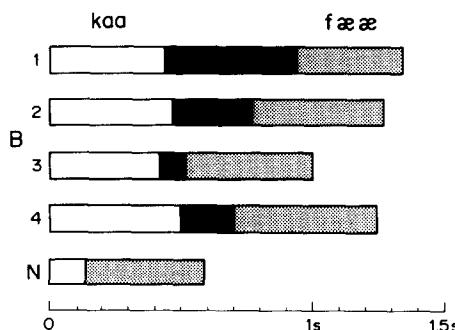


FIG. 2. Durations of syllables and silent intervals for the word /kaafææ/ "coffee" produced by a Thai Broca's aphasic (B) and five normal speakers (N). The duration of /kaa/ is shown by the white portion of the bar, /fææ/ by the stippled portion, and the silent interval by the black portion. For B, each of the numbered bars (1-4) represents an individual production; for N, the bar represents a mean based on one production from each of the five normal speakers.

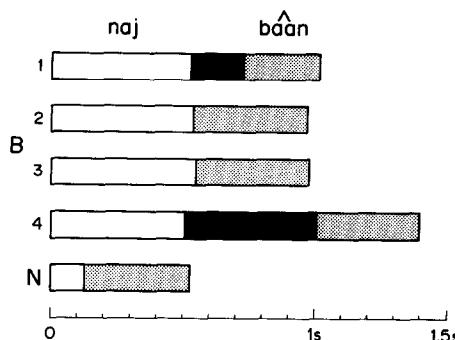


FIG. 3. Durations of syllables and silent intervals for the phrase /naj baān/ "in the house" produced by a Thai Broca's aphasic (B) and five normal speakers (N). The duration of /naj/ is shown by the white portion of the bar, /baān/ by the stippled portion, and the silent interval by the black portion. Also see caption for Fig. 2.

only 0.6 for B. Thus, her pattern of syllable dissociation clearly disrupted timing on a relative as well as absolute scale of measurement in multi-syllabic word-, phrase-, and sentence-sized linguistic units.

In contrast to the study of vowel duration in isolated, monosyllabic words, the present findings on timing control in larger sized linguistic units indicate that B exhibits a severe timing deficit. B's timing control is spared in the production of vowel duration within isolated, monosyllabic words, but impaired in the production of syllables that occur in series within words, phrases, and sentences. These results suggest that the degree of timing disintegration in Broca's aphasia depends, in part, on the length of the speech planning unit. Additional support for this hypothesis can be found in previous studies of duration in English-speaking Broca's aphasics and apraxia of speech patients. Danly and Shapiro

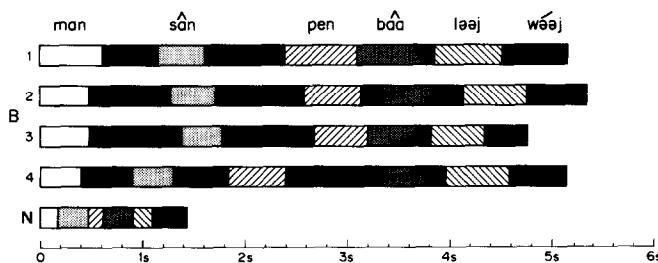


FIG. 4. Durations of syllables and silent intervals for the sentence /man sān pen baā lēej wāej/ "How come the day is so short" produced by a Thai Broca's aphasic (B) and five normal speakers (N). The duration of /man/ is shown by the white portion of the bar; /sān/, /baā/, and /wāej/ by stippled portions; /pen/ and /lēej/ by hatched portions; and the silent intervals by black portions. Also see caption for Fig. 2.

(1982) reported that sentence-final lengthening was absent in Broca's aphasics. Kent and Rosenbek (1983) found that the magnitude of the lengthening effect on vowel duration in apraxia of speech patients increased as the length of the utterance increased.

On the basis of the VOT, vowel duration, and rhythm studies, it appears that B's timing problem is a manifestation of a broader problem in the dynamics of speech production. Her speech timing difficulties lie not only in the integration of articulatory movements for a single phonetic segment (VOT study), but also in the integration of articulatory movements from one phonetic syllable to another (rhythm study). However, B's timing is relatively normal when no temporal integration between two independent articulators is required for a single phonetic segment within an isolated, single syllable (vowel duration study).

Intensity

Relative peak intensity was measured using the Kay Elemetrics Visi-Pitch Model 6095 interfaced to an Apple II microcomputer. Peak intensities were measured for each syllable in a test sentence selected from the same passage used in the rhythm study. In the sentence /k^hraj dəən p^haan maa p^hɔɔ dii/, intensity values were expressed relative to the syllable with the maximum peak intensity among the six syllables. The remaining syllables were assigned negative intensity levels in dB. As shown in Fig. 5, less variation in relative peak intensity across syllables was observed for B than for the normal speaker. Following Kent and

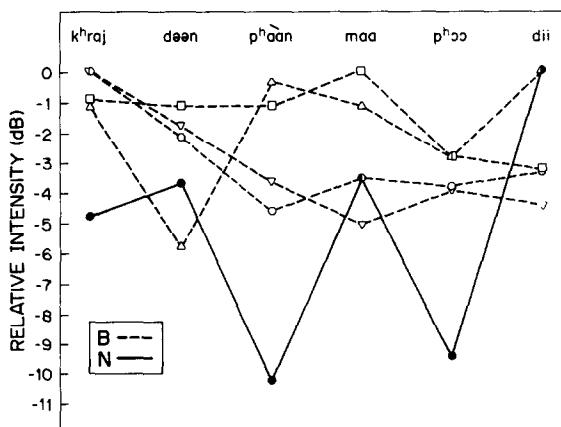


FIG. 5. Relative peak intensities for the words in the sentence /k^hraj dəən p^haan maa p^hɔɔ dii/ "Do you know who was passing by?" produced by a Thai Broca's aphasic (B) and a normal female adult speaker (N). For B, each of the four dashed lines represents an individual production; for N, the solid line represents a mean based on five productions.

Rosenbek (1983, p. 236), the intensity values for the syllables in the test sentence were averaged for each speaker to provide a quantitative measure of intensity variation from syllable to syllable. The smaller the negative number, the lesser the degree of intensity variation. The mean results were -2.3 and -5.3 for B and the normal speaker, respectively. Furthermore, B failed to give the greatest intensity to the same syllable as the normal speaker in three of her four productions. Thus, B's intensity envelope differed from that of the normal speaker both qualitatively and quantitatively. The observed flattening of B's intensity envelope presumably reflects her inability to produce appropriate variations in stress patterns in larger-sized temporal domains. Such abnormalities in B's intensity envelope are consistent with auditory impressions of her conversational speech as well. This tendency toward reduced intensity variation from syllable to syllable in B's speech has also been reported in earlier acoustic investigations of apraxia of speech (Kent & Rosenbek, 1983; Lebrun, Buyssens, & Henneaux, 1973).

Fundamental Frequency

Method

For comparison purposes, F_0 data on tones produced in isolation were taken from a previously published report on five normal adult speakers (Gandour et al., 1988). Further details regarding speech materials, recording procedure, and measurement procedure can be found therein.

A measure was obtained of intraspeaker variability in F_0 contours of each of the five Thai tones produced by B and one normal, female speaker. To compare the point-to-point variability of F_0 contours for repetitions of each tone from each speaker, an ensemble-averaging approach was taken (cf., Atkinson, 1976, pp. 441-442). All repetitions of each tone made up an ensemble of F_0 contours for that tone by that speaker. Since all repetitions of each tone were not of equal duration, the F_0 contours were normalized for duration on a percentage scale. The ensemble mean and standard deviation were determined at each 10% interval. These ensemble-averaged statistics made it possible to evaluate changes in ensemble characteristics of intraspeaker contours for each tone as a function of time.

Polysyllabic words, phrases, and sentences were selected from Luangthongkum's (1977) reading passage. Data were obtained from B and one normal, male adult speaker. F_0 contours were analyzed by means of F_0 displays from the Kay Elemetrics Visi-Pitch Model 6095 and narrow-band spectrograms from the Kay Elemetrics Digital Sona-Graph Model 7800.

Results and Discussion

Average F_0 contours normalized for time as a percentage of total duration of each of the five tones produced by one of the normal, female speakers and B are displayed in Fig. 6. For the normal speaker, F_0 contours associated with the mid and low tones fall steadily throughout. F_0 contours associated with the falling, high, and rising tones change in slope approximately halfway through their duration. The falling tone is relatively level and then falls sharply; the high and rising tones fall slightly

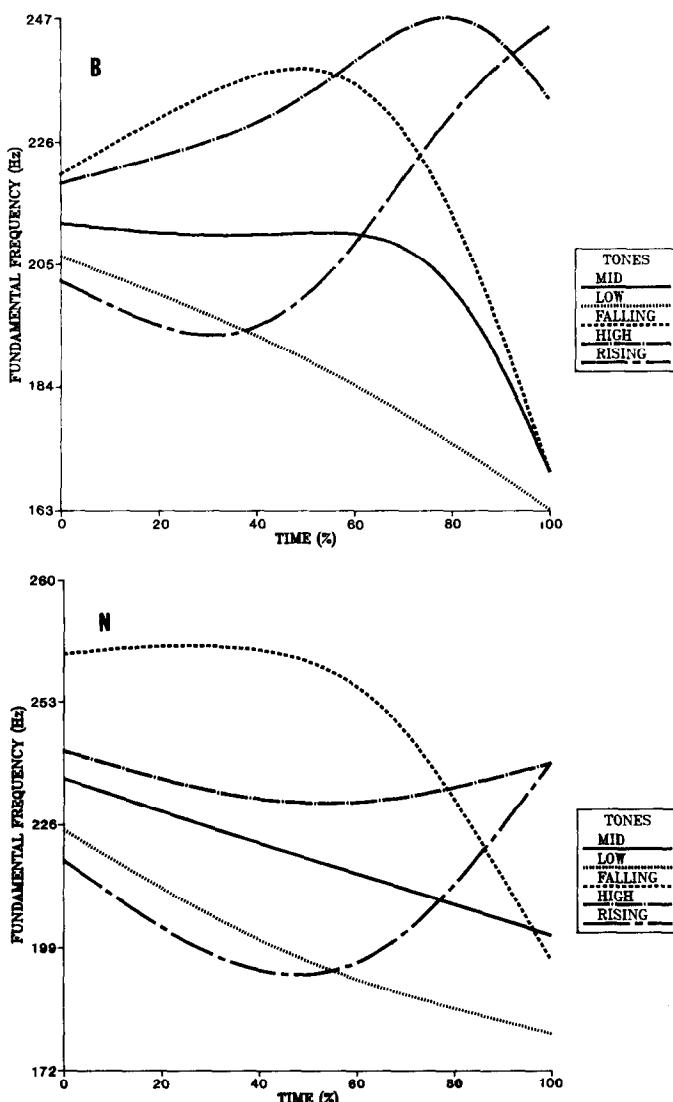


FIG. 6. Average F_0 contours of the Thai tones in Hz normalized for time on a percent scale for monosyllabic words produced in isolation by a Thai Broca's aphasic (B; top panel; adapted from Gandour, Petty, & Dardarananda, 1988) and a normal female adult speaker (N; bottom panel).

and then rise. Average F_0 contours for the other four normal speakers were similar.

B's average F_0 contours associated with all five tones are similar in shape and position within the tone space to those of normal speakers.

It is noted, however, that the shape of B's mid and high tones differ somewhat from those of the normal, female speaker depicted in Fig. 6. Instead of displaying a steadily falling slope, B's mid tone is relatively level for over half of its duration and then falls sharply. Instead of displaying a continuous rise in the terminal portion, B's high tone exhibits a falling slope. These F_0 contours associated with B's mid and high tones are not abnormal. Such contours have been reported in earlier studies of Thai tones produced by normal speakers in citation forms of monosyllabic words (Abramson 1962, 1976).

The mean F_0 and standard deviation of each tone for B and one normal, female speaker are given in Table 6. B's mean F_0 (212 Hz) across the five tones was significantly lower than that (221 Hz) of the normal female speaker, $t(100) = 2.38, p < .019$. Ryalls (1982) reported that the mean F_0 on a sentence-repetition task was of the same order of magnitude for French-speaking Broca's aphasics and normal speakers. However, Ryalls (1984) found that the overall F_0 of vowels on a read speech task produced by English-speaking anterior aphasics were significantly higher than those produced by normal speakers. It was suggested that the higher average F_0 of the anterior aphasics could be due to their higher psychological stress in read speech. In this study, B produced read speech, yet she did not exhibit a higher-than-normal mean F_0 . More research is required to resolve these conflicting findings with respect to the mean F_0 of Broca's aphasics and normal speakers.

The average F_0 ranges of the five tones for B and a group of five, normal adult speakers were of the same order of magnitude (see Table 7). B's F_0 ranges for the mid and high tones were slightly higher than normal, and for the low, falling, and rising tones were slightly lower than normal. None of B's F_0 ranges that were lower than normal fell outside minus one standard deviation of the normal range for that tone. Ryalls

TABLE 6
DESCRIPTIVE STATISTICS OF THAI TONES

Tone	Speaker		Normal ^a	
	B		M	SD
Mid	206	12	219	11
Low	189	13	199	14
Falling	222	24	249	23
High	234	12	235	7
Rising	211	20	207	15

Note. Values are expressed in F_0 (Hz).

^a Normal = one normal, female adult speaker.

TABLE 7
 F_0 RANGES OF TONES

Speaker	Tone				
	Mid	Low	Falling	High	Rising
B	4.1	4.1	6.2	2.4	4.4
Normal ^a	3.9	5.1	6.8	2.3	4.5

Note. Values are expressed in F_0 (semitones).

^a Normal = Five, normal adult speakers from Gandour et al. (in press).

(1982) and Cooper, Soares, Nicol, Michelow, and Goloskie (1984), on the other hand, in their production studies of sentence intonation in French- and English-speaking Broca's aphasics, respectively, both reported a restricted F_0 range for Broca's aphasics when compared to normals. Ryalls' measure of F_0 range was peak-to-valley fluctuation within sentences; Cooper et al.'s measure was differences among F_0 peaks within sentences. Interestingly, Danly and Shapiro (1982) reported that English-speaking Broca's aphasics actually produced more fluctuation in F_0 than normal speakers. They measured F_0 variation by summing valley-peak-valley F_0 differences within words embedded within sentences. Their findings suggest that "the perception of flat intonation in Broca's speech may be based on restricted word-to-word F_0 variation, while within-word variability may actually be increased" (Cooper & Klouda, 1987, p. 62). The absence of any compression of the F_0 range in B's production of tones on isolated, monosyllabic words supports the view that restricted F_0 variation in Broca's speech is a function of the size of the temporal domain rather than a function of F_0 itself.

The point-to-point variability in F_0 contours of each of the five tones produced by B and one normal, female speaker is displayed in Fig. 7. The ensemble mean can be considered as the target F_0 contour for a particular tone; the ensemble standard deviation as a measure of the random perturbations that result in deviations from the target contour. As shown in Fig. 7, B's intraspeaker contours appear to be more variable than those of the normal, female speaker for all tones except rising. To provide a quantitative comparison of intraspeaker variability, the ensemble standard deviations were averaged over the 11 measurement points of each tone for all five tones. Overall average variability in F_0 was significantly greater for B than for the normal, female speaker, $t(108) = 2.18$, $p < .03$. This finding is consistent with the increased variability reported in B's production of VOT (Gandour & Dardarananda, 1984a) and vowel duration (Gandour & Dardarananda, 1984b). And more generally, this finding agrees with earlier acoustic investigations that have revealed greater variability in speech produced by anterior aphasics,

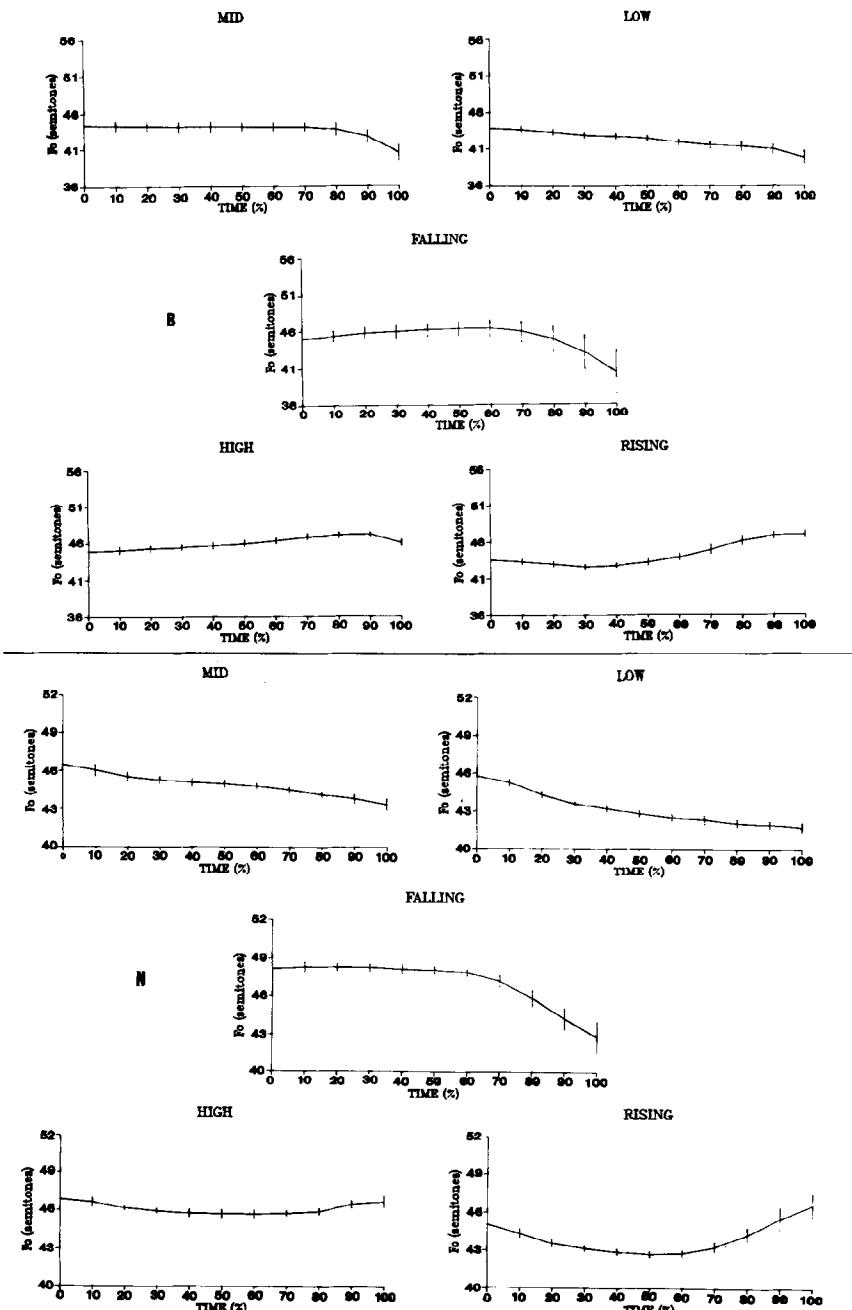


FIG. 7. Variability of F_0 contours of the Thai tones in semitones normalized for time on a percent scale for monosyllabic words produced in isolation by a Thai Broca's aphasic (B; top panel) and a normal female adult speaker (N; bottom panel). Vertical bars represent plus or minus one standard deviation about the ensemble average F_0 contour.

measured in terms of VOT (Blumstein et al., 1980), vowel duration (Ryalls, 1986), formant frequencies (Ryalls, 1981, 1986), and F_0 (Ryalls, 1984).

F_0 contours for a three-syllable noun compound /jaajsāawkææ/, a seven-syllable clause /man ca dâj k^hít wââ muûut læéew/, and a seven-syllable sentence /ruú k^hamjaáp määkmaaj lüuakæøn/ are shown in Figs. 8–10, respectively. In comparison to the normal speaker, B's speaking rate and rhythm were markedly impaired. Her utterances were considerably longer than normal. Lengthy pauses predominated at syllable boundaries. Timing adjustments required by stress patterns in a series of syllables were absent. This pattern of temporally isolated syllables supports the view that B's speech is produced on a syllable-by-syllable basis. These deviant timing patterns notwithstanding, B apparently had no difficulty in producing the F_0 contours of all five Thai tones in connected speech (see Figs. 8–10). She was able to do so regardless of sentence position or adjacent tone. In Fig. 8, the sequence of tones was mid-rising-low; in Fig. 9, mid-mid-falling-high-falling-falling-high; and in Fig. 10, high-mid-low-falling-mid-rising-mid.

When compared to the normal speaker, B's F_0 contours appear to resemble more closely the shape of tonal contours that occur prepausally or in monosyllabic citation forms (see Figs. 9 and 10). The temporal domain for Thai tones is the syllable. B is apparently able to plan and execute F_0 contours successfully within this unit of speech production. Because of F_0 perturbations induced by tonal coarticulation and sentence intonation, the normal speaker's tonal contours actually exhibit less F_0 modulation than those of B. The effects of tonal coarticulation and sentence intonation are minimized in B's speech due to her inability to control F_0 over a temporal domain larger than a single syllable. It is because Thai tones extend over a syllable-sized unit of speech programming that tonal contours are preserved in B's connected speech.

The findings of the present study are consistent with previous investigations of intonation and timing in English-speaking Broca's aphasics (see Cooper & Klouda, 1987, for review). Of particular interest is the study by Danly and Shapiro (1982). Based on three acoustic measures of speech prosody (sentence-final F_0 fall, declination of F_0 peaks throughout a sentence, and sentence-final segmental lengthening), they similarly found that speech timing was relatively more disturbed than F_0 . Broca's aphasics exhibited F_0 fall in utterance-final position. F_0 declination was present in short sentences, but absent in longer sentences. For longer sentences, Broca's aphasics reset their declination function many times within the sentence. Segmental lengthening in utterance-final position was absent. In fact, sentence-final words were actually shorter than their sentence-initial and sentence-medial counterparts. Their findings indicated that Broca's aphasics were able to carry out F_0 programming over

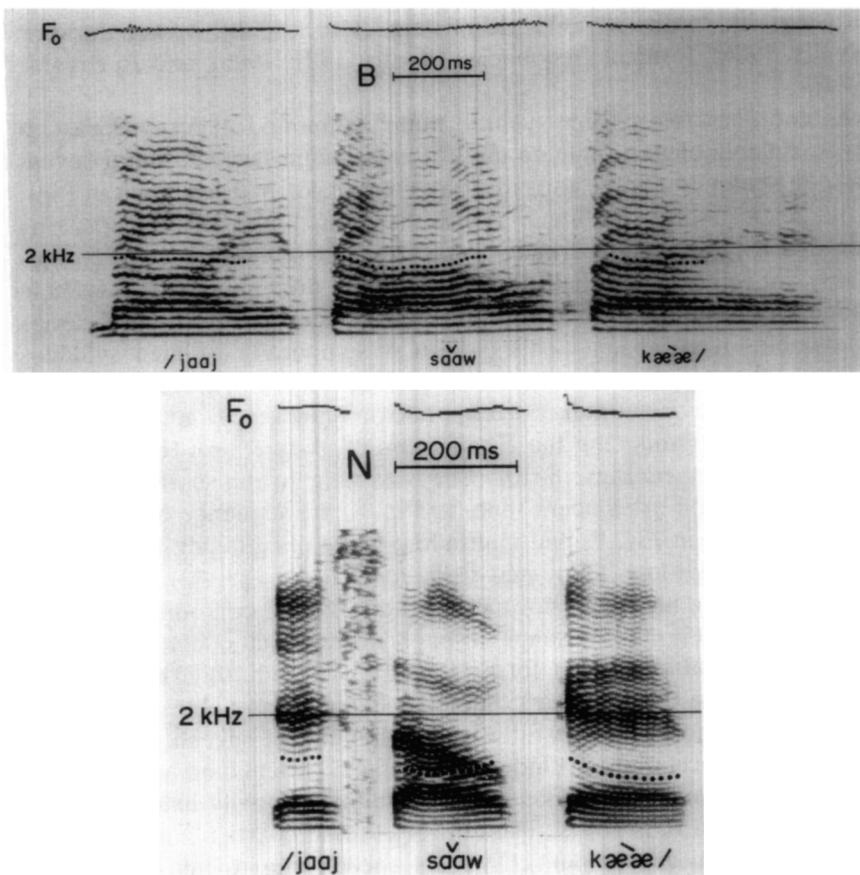


FIG. 8. F_0 contours of the compound word /jaajsaawkææ/ "spinster" produced by a Thai Broca's aphasic (B; top panel) and a normal male adult speaker (N; bottom panel). A dotted line is drawn through the tenth harmonic in the narrowband spectrograms (8 kHz frequency range; 45 Hz analysis filter).

domains that are much shorter than normal. Because of the shorter-than-normal domains of prosodic programming, Broca's aphasics were unable to carry out timing programming for segments in utterance-final position. The programming of F_0 necessarily intersects with temporal planning in sentence production. Thus, the disruption of intonation contours need not indicate a malfunction in F_0 mechanisms, but instead a secondary effect due to a malfunction in timing.

B's preservation of tones in isolated words and connected speech contrasts sharply with her impaired production of consonants. First, her production of the voicing contrast in word-initial stop consonants was aberrant (Gandour & Dardarananda, 1984a). Second, a phonological analysis of B's conversational speech revealed that consonant errors were

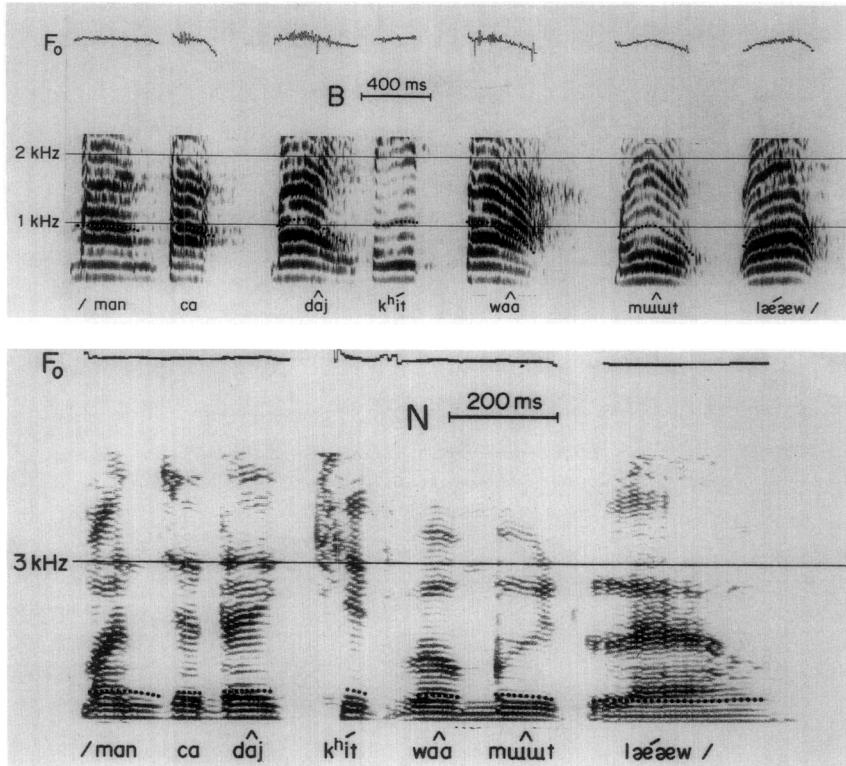


FIG. 9. F_0 contours of the clause /man ca dāj kʰít wāa mūw lǽæw/ "This would make him think that it was dark . . ." produced by a Thai Broca's aphasic (B; top panel) and a normal male adult speaker (N; bottom panel). A dotted line is drawn through the fifth harmonic in the narrowband spectrograms (4 kHz frequency range; 75 Hz analysis filter).

frequent, whereas tone errors rarely occurred (Gandour et al., 1985). All occurrences of velar stops were replaced with a voiceless unaspirated alveolar stop. Third, B produced the high and rising tones without regard to the phonological constraint of Central Thai which prohibits their occurrence on syllables beginning with voiceless unaspirated stops. These findings together point to a dissociation between segmental and suprasegmental aspects of B's speech. Despite deterioration of articulatory control of consonants, B maintained phonatory control of the five Thai tones.

GENERAL DISCUSSION

The unqualified use of the term *dysprosody* implies that the deficit is generalized to all prosodic aspects of speech, including F_0 , intensity, and timing. Characterizing B's speech as simply dysprosodic would be inaccurate and misleading. Such a characterization implies that various elements of B's speech prosody suffer mutual deterioration as the result

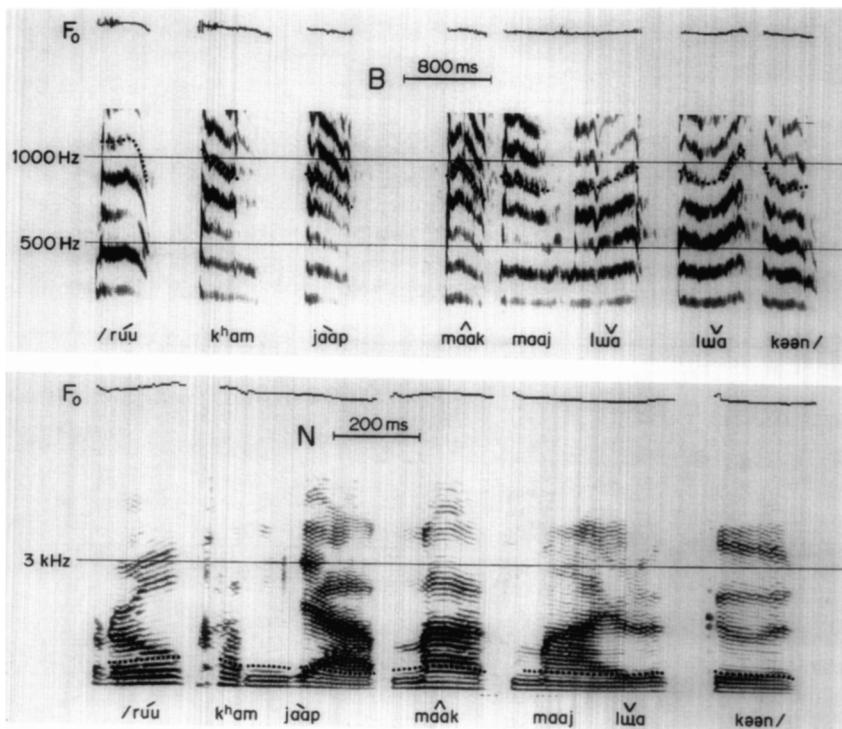


FIG. 10. F_0 contours of the sentence /ruu kʰamjaap māakmaaj l̄uakkeən/ 'He knew a lot of dirty words' produced by a Thai Broca's aphasic (B; top panel) and a normal male adult speaker (N; bottom panel). A dotted line is drawn through the fifth harmonic in the narrowband spectrograms (B: 2 kHz frequency range, 37.5 Hz analysis filter; N: 8 kHz frequency range, 45 Hz analysis filter).

of damage to Broca's area. To the contrary, some elements of B's speech prosody remain intact, while others are clearly impaired. Despite the fact that sentence timing and intensity were abnormal in her connected speech, B retained an ability to produce F_0 patterns associated with the five Thai tones. In particular, the findings from this case study reinforce the view that dysprosody in Broca's aphasia is more applicable to speech timing than to F_0 (Cooper & Klouda, 1987, Danly & Shapiro, 1982). Moreover, it is because differences in F_0 patterns are linguistically significant at the word level in a tone language that the data of B provide unequivocal evidence in support of Danly and Shapiro's hypothesis that dysprosody in the speech of Broca's aphasics stems primarily from their smaller units of speech programming.

With this different conceptualization of dysprosody in Broca's aphasia, it may be inappropriate to speak of a tone or intonation deficit per se. It is not the control of F_0 for tone or intonation specifically that is in question, but rather the control of F_0 over variable-sized temporal domains. The critical variable is the size of the domain over which the F_0

patterns extend. By definition, F_0 patterns associated with intonation extend over larger sized temporal domains than those associated with tone. If dysprosody in Broca's aphasia is primarily due to a narrower-than-normal scope for speech programming, it is predicted that tones will be more resistant to disruption than intonation. To produce intonation successfully, one must be able to control timing over phrase- or sentence-sized units; to produce tone successfully, one must be able to control timing over syllable-sized units of speech programming. Timing disturbances at the sentence level necessarily disrupts F_0 contours associated with intonation patterns. As exemplified in this case study of a Thai-speaking Broca's aphasic, F_0 contours associated with tone are not disrupted as a consequence of deviant timing at the sentence level.

APPENDIX

*Thai Phonemic Transcription and English Translation
of the Story of a Myna Bird*

ʔee n̄ȳg duu k̄ɔ̄n r̄ȳaŋ th̄i k̄h̄ēj l̄aw ʔā n̄ȳg ʔɔ̄g l̄ēw ʔaw r̄ȳaŋ
n̄og?laŋ dii kwāa nā mii n̄og?laŋ tua n̄ȳg man dāa k̄ēn pen faj l̄ēo
rūu khamjāab māagmaaj l̄yak̄ēn l̄ēw k̄ɔ̄ w̄ithii diaw th̄i c̄a? hāj
man q̄iaj dāaj nān k̄ɔ̄ khyy t̄h̄ŋ ʔaw phāa khlum kroŋ s̄ia man c̄a?
dāaj kh̄it wāa m̄yyd l̄ēw dāaj weelaa n̄ōn s̄ia thii ʔiitaa n̄i nā
r̄uŋchāaw wan n̄ȳg jaajsāawkēe cāwkh̄ɔ̄ŋ n̄og nān k̄ɔ̄ p̄ōd ʔaw
phāa th̄i khlum kroŋ ʔɔ̄g jāaŋ k̄h̄ēj rūu m̄aj khraj d̄ēōn phāan
maa ph̄ōodii bāadl̄uaŋ c̄a? jaajcāwkh̄ɔ̄ŋ k̄ee r̄iib w̄iŋ kl̄ab maa
khlum kroŋ cāwnōg jāaŋ rew waj l̄ēw k̄ɔ̄ w̄iŋ paj th̄i pratuu ch̄ēōn
bāadl̄uaŋ khāw maa naj bāan n̄og man k̄ɔ̄ n̄iŋ chiaw l̄ē ʔēw
jaajsāawkēe k̄ɔ̄ thāam ph̄ōbāadl̄uaŋ wāa hāj s̄aj nāmtaan k̄i
ch̄ōn naj kaafēe ʔāj cāwnōg man k̄takoon ph̄l̄dōŋ ʔɔ̄g maa wāa
m̄ēc hāj taaj th̄ā? n̄ā? ʔāj k̄laaŋ wan n̄i man s̄ān pen bāa l̄ēj wāēj

Hm . . . let me think . . . a story that I have told before. Ah! I remember now . . . the story of a myna bird. There was a myna bird who was very keen in using bad language. He knew a lot of dirty words. The only way that one could make him quiet was to cover his cage with a piece of cloth. This would make him think that it was dark and that it was the time to go to bed. Well, one early morning, the spinster who was the bird's owner came to uncover the cage as usual. Do you know what was passing by? A Roman Catholic priest! The owner of the bird rushed back to cover the cage as quickly as she could. Then, she ran to the door and invited the priest to come in. The bird was quiet. Finally, the spinster asked the priest, "How much sugar do you want in your coffee?" The bird, then, shouted out loudly, "Damn it! How come the day is so short!"

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