DISTURBANCES OF THE TEMPORAL ORGANIZATION OF SPEECH FOLLOWING BILATERAL THALAMIC SURGERY IN A PATIENT WITH PARKINSON'S DISEASE

GERALD J. CANTER
Department of Communicative Disorders, Northwestern University

DIANA ROUPAS VAN LANCKER
Departments of Linguistics and Physiology, University of California at Los Angeles
UCLA

This report summarizes a detailed analysis of the speech of a 45-yr-old man who had become dysarthric following bilateral thalamic surgery for the relief of symptoms of Parkinson's disease. His speech was characterized by a rapid rate and a mild-to-moderate articulatory deficit. Intelligibility was markedly reduced. The rapid rate was found to be the result of decreased syllable durations rather than to changes in pause or phrase patterns. Decreased syllable durations resulted from abnormal shortening of vowels. Consonant releases were found to be prolonged. This distorted temporal relationship among speech segments was considered to be an important factor in the patient's poor intelligibility and partially explained why uniform electronic expansion of his speech resulted in only negligible increase in intelligibility. It is hypothesized that this speech disturbance results from the interaction of central "metronomic" abnormality with a peripheral neuromotor articulatory impairment.

INTRODUCTION

In contrast to the slow speech of most dysarthric speakers, speech is abnormally rapid in some parkinsonian patients. Canter (1963) reported that one of his 17 patients with Parkinson's disease spoke at the extraordinarily rapid rate of 250 words a minute. Darley, Aronson, and Brown (1975, p. 194) indicated that rapid rate, short rushes of speech, and progressive acceleration ("increase of rate within segments of contextual speech . . . and increase overall from the beginning to the end of the sample") characterized their patients with Parkinson's disease. Selby

Address correspondence to Diana Van Lancker, Ph.D., Department of Linguistics, University of California at Los Angeles, Los Angeles, CA 90024.

© 1985 by Elsevier Science Publishing Co., Inc.
52 Vanderbilt Ave., New York, NY 10017
(1968, p. 188) described his observations of rapid speech in those parkinsonian patients who "talk fast, running words towards the end of a sentence."

Netsell, Daniel, and Celesia (1975) found that within a group of patients with Parkinson's disease, there was a subgroup who showed, at least on occasion, very rapid short rushes of speech. This occurred not only in spontaneous speech but also on syllable repetition. During rapid syllable production, bursts of muscle action potentials as high as 13 per sec were observed. This rate is far beyond what even a well-practiced normal can do voluntarily, suggesting that these patients are no longer producing voluntary sequences of muscle contractions. Instead, some mode of neuromotor activity beyond the speaker's control seems to have been engaged.

Speech rate has been altered experimentally by electrical stimulation of the ventrolateral nucleus of the thalamus in patients undergoing neurosurgery for the relief of symptoms of Parkinson's disease. A slowing of speech was observed by Mateer (1978) during stimulation of the left ventrolateral thalamus, and by Hassler, et al. (1960) during pallidal stimulation. Schaltenbrand (1965) reported slowed speech during stimulation of these and adjacent sites. Rapid speech has also been reported frequently (Van Buren and Borke, 1969; Darley et al., 1975; Hassler et al., 1960). Patients of Guiot et al. (1961) reported an "impulse to go faster" and felt "forced . . . to hurry" during stimulation. Such observations have suggested a key role for certain subcortical nuclei in the regulation of speech rate (Botez and Barbeau, 1971; Krayenbuehl et al., 1965; Kent and Rosenbek, 1982; Samra et al. 1969). Indeed, Schaltenbrand (1975) has referred to the thalamus as "the main system of internal clocks or the nervous system," regulating "temporal patterns and configurations in time."

Clinical experience indicates that neurosurgical intervention for Parkinson's disease only occasionally produces improvement of speech. In fact, it is not uncommon—especially in patients who have undergone bilateral thalamic surgery—to see a worsening of the dysarthria. For example, Allan, Turner, and Gadea-Circia (1966) studied 53 patients with Parkinson's disease who underwent staged bilateral operations and reported that articulation improved in only one case, while it deteriorated in 35 cases.

The patient who is the subject of this paper is one whose dysarthria, characterized by an abnormally rapid rate of speech, developed subsequent to bilateral thalamic surgery. It was our purpose in this investigation to describe precisely the determinants of rapid rate in this individual and to determine, insofar as possible, how reduced intelligibility was related to the rate abnormality. We anticipated that this information might be useful in increasing our understanding of the neural mechanisms governing speech.
CASE DESCRIPTION

PD is a 45-yr-old white male. Symptoms of Parkinson's disease were first noted 17 yr ago. The initial symptoms were muscle rigidity and slowness of movement. The early age of onset and the symptom complex indicated a postencephalitic Parkinson's syndrome. Speech was reported to be mildly slurred, but normally intelligible. About 6 yr after onset, a tremor developed bilaterally in the upper extremities. Stereotaxic thalamotomies were performed bilaterally, the left side first and right 6 mo later. In both operations, the target was the ventrolateral thalamic nucleus. Following the surgery, PD's tremor was almost completely eliminated. Little change was observed in his rigidity and slowness of movement. The patient's speech showed a marked deterioration following the second operation, however. According to the speech pathologist who saw PD shortly after surgery, articulatory precision was reduced and rate of speaking became abnormally rapid.

PD was employed as a court bailiff and this impairment in communication was seen as a hazard to his employment. On the advice of friends and coworkers, who complained that they could not understand his speech, he came to the Speech Clinic at Northwestern University. At the time of the speech examination, he was under a drug regimen of Elatrin and Sinemet (recently substituted for L-Dopa). Clinical evaluation of PD's language comprehension and expression, including administration of the Boston Diagnostic Aphasia Examination, indicated no linguistic abnormalities. PD's major disturbance was his increased speaking rate, which he was often unable to modify to any great extent even when he made voluntary attempts to do so. It was particularly difficult for a listener to adjust to this, because PD was not consistent. In occasional utterances, speech was unhurried and relatively easy to understand, while in other utterances the rate was very rapid and speech was totally unintelligible. These observations are similar to those made by Samra et al. (1969) on their patients who had undergone thalamic surgery.

On single-word articulation tests, PD's performance was usually normal. Only in connected speech was a deficit apparent. During periods where speech was not produced rapidly, a mild impairment of articulation could be discerned. PD showed reduced precision in the production of stop consonants. The imprecision seemed to be based on inadequate articulatory valving, such that stop consonants were frequently produced in a fricative manner. During rapid runs of speech, PD's articulation became still less precise, so that some utterances were transmitted as unintelligible "blurs" in which the identity of speech sounds was lost and syllable boundaries were often not apparent to the listener.

METHODS

We used two basic types of speech samples for analyses: texts and paradigms. The texts were paragraphs of continuous speech, whether orally
read or spontaneously produced. The paradigms were lists of words and phrases selected from previous phonetic studies on temporal organization of normal speech which had been specially designed to reveal properties of timing (Gaitenby, 1965; Lehiste, 1972). The texts were used to establish PD's overall rate characteristics, while the paradigms were used to examine timing relationships among speech segments. Normal speech samples using all these same materials also were obtained for purposes of comparison.¹

**SPEECH INTELLIGIBILITY**

Because the patient’s problem was most evident during connected speech, we did not use standard word or sentence materials for the assessment of intelligibility. Instead, the material was drawn from two recorded speech texts: (a) oral reading of the Rainbow Passage, and (b) the patient’s spontaneous description of his job. A normal speaker (GJC) also was recorded reading the Rainbow Passage and a transcript of the patient’s job description.

From each of the two texts, 20 phrases (4–7 words long) were selected. In each phrase, individual words or short phrases were designated as "target" items. For example, one test phrase was "everybody is assessed the money that they owe"; the target items were "everybody" and "assessed"; from the oral reading passage, the first test phrase was "a boiling pot of gold at one end"; the target items were "boiling" and "pot." Each test phrase contained from one to three target items, and there were 40 key items in each text. The phrases containing the key items were randomly divided into two sets (A and B) for each text. The first tape of a pair had the patient’s production of set A and the control speaker’s production of set B. On the second tape, the patient produced set B and the control, set A. This was done to eliminate the effect of any possible difficulty bias of the two half-texts.

Two groups of college students listened to these recorded materials. The first group (n = 32) heard the Rainbow Passage. Half of the listeners heard the first tape (with PD producing set A and the control speaker producing set B), and the others heard the second tape (with the reverse arrangement). The same procedure was used with the second group of listeners (n = 26), who heard the recorded samples of spontaneous speech. All listening was done in a quiet classroom, with the playback equipment set at an easily audible level. The listeners were asked to write

¹ The normal speaker familiarized himself thoroughly with the text before reading aloud and attempted to approximate spontaneous speech as closely as possible. Though this procedure was not ideal, it was considered to provide a better sample for comparison with the patient’s spontaneous speech than a genuine spontaneous speech sample, which would not have contained comparable linguistic content.
down each phrase, and the intelligibility score for each speaker was the mean percentage of target items identified correctly out of the total of 40 items in each sample.

The obtained intelligibility scores showed that PD's ability to communicate verbal information was markedly impaired, as we had judged clinically. Whereas the control speaker achieved almost perfect intelligibility (95% for oral reading and 97.5% for spontaneous speech) PD's intelligibility scores were very poor (31% and 23%, respectively).

Overall Temporal Structure of Speech

A series of measurements was made to determine the overall temporal structure of our patient's speech pattern. The same measures were taken from the recorded samples of the control speaker. All of the measures were derived from amplitude–time tracings using a Bruel and Kjaer Graphic Level Recorder (Model 2305) equipped with a 50 dB potentiometer. Identical settings were used for all samples: chart speed was 30 mm/sec, writing speed was 200 mm/sec, and lower limiting frequency was 40 Hz. We measured overall rate, pause and phrase patterns, and syllable duration. Table 1 summarizes the findings from these analyses.

**Rate of Speech.** Overall rate of speech was determined by dividing the total time (including pauses) in the sample by the number of words uttered. Even though the data in Table 1 show an obvious difference in speaking rates between the patient and the control speaker, comparison with group normative data was highly desirable. Such data on oral reading of the Rainbow Passage were available from a previous study in which speaking

<table>
<thead>
<tr>
<th>Measure</th>
<th>Oral reading (98 words, 127 syll.)</th>
<th>Spontaneous speech (236 words, 325 syll.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patient (PD)</td>
<td>Control (GJC)</td>
</tr>
<tr>
<td>Total time (sec)</td>
<td>27.7</td>
<td>32.9</td>
</tr>
<tr>
<td>Total pause time (sec)</td>
<td>7.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Total phrase time (sec)</td>
<td>20.4</td>
<td>27.4</td>
</tr>
<tr>
<td>Percentage of total time occupied by pauses</td>
<td>26%</td>
<td>17%</td>
</tr>
<tr>
<td>Number of pauses</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Overall rate of speech (wpm)</td>
<td>212.27</td>
<td>178.72</td>
</tr>
<tr>
<td>Mean number of words per phrase</td>
<td>6.53</td>
<td>6.13</td>
</tr>
<tr>
<td>Mean syllable duration (msec)</td>
<td>161</td>
<td>216</td>
</tr>
</tbody>
</table>
rates were measured for 17 normal-speaking middle-aged and older adult males (Canter, 1963). These speakers had a mean rate of 178.8 words per minute (wpm), with a range from 153.6 to 205.2 wpm. The control speaker in the present study approximated this value almost exactly with a rate of 178.7 wpm, and the patient's rate of speech exceeded the normal range at 211.3 wpm. With regard to spontaneous speech, we compared our speakers' rates with the data from a group of 50 young adult males performing a similar speaking task ("The Job Task," Williams, Darley, and Spriestersbach, 1978). The median rate for this normative group was 136.2 wpm. The normal speaker in the present investigation was once again very close to the central value, with a rate of 139.0 wpm. PD's rate of 200.9 wpm was far in excess of the 90th percentile of normal males, reported as 160.0 wpm.

These data confirm the clinical impression that PD did indeed speak at an abnormally rapid rate. In addition, they show that the control speaker was quite representative of normal speakers in terms of overall rate of speech. This gave us increased confidence that we should be able to interpret differences between PD and the control speaker meaningfully on measures where there were no normative group data.

**Pause and Phrase Patterns.** In order to interpret more precisely our patient's rapid speech pattern, additional measurements were made from the graphic level recording. First we looked at pauses. Some individuals have an abnormally rapid speaking rate because they fail to pause often enough or long enough. This was not the case with PD, as is indicated by additional data in Table 1. In both oral reading and spontaneous speech, his pauses were nearly as numerous as the control speaker's. Both speakers contributed percentages of pause time roughly comparable to means for normal speakers cited by Goldman-Eisler (1964, 1968) and Huggins (1968). Thus, we cannot attribute any of the clinical impression of fast speech to deficient pausing. In addition, the two speakers were similar in average number of words per phrase. Perusal of the transcribed protocols, matched with the graphic level recordings, showed that both speakers typically produced their pauses at expected syntactic boundaries. These data strongly indicate that pause and phrase patterns were normal for PD, and thus that these parameters do not contribute to his rapid speech. Work of Goldman-Eisler (1967), Rochester (1973), and Boomer (1965) indicates that pauses reflect boundaries around units of linguistic planning (as contrasted with being arbitrary or merely meeting physiological needs). Our observations on PD's pauses and phrase structure, coupled with his normal performance on the Boston Diagnostic Aphasia Examination, indicate that PD's speech is not disturbed at the level of linguistic formulation, but rather at later stages of motor speech planning and/or execution.
Syllable Duration. Given that the patient’s pause and phrase patterns were not deviant, it appeared likely that his rapid speech must be due to a genuinely increased rate of articulation of the ongoing speech stream. We determined mean syllable duration by measuring the total phrase time (total speech time minus total pause time) and dividing this value by the number of dictionary syllables in the text.\(^2\) The data in Table 1 indicate that PD’s mean syllable durations for both text samples (read and spontaneous) were substantially shorter than those of the control speaker.

Progressive Acceleration of Speech and Short Rushes. Because clinical observers cited earlier (Darley et al., 1975, p. 194; Selby, 1968, p. 188) have reported that some patients with Parkinson’s disease tend to have short rushes of speech and may show a progressive increase in rate from the beginning to the end of an entire speech sample, we decided to determine if PD’s speech showed these characteristics. The first question, whether PD increased his rate of speech from the first portion of a text to the later portion, was answered by measuring mean syllable durations from the first- and second-halves of both the oral reading passage and the spontaneous speech sample.

In oral reading, the mean syllable duration for the first half-text was 159.9 msec (SD = 56.2) while the mean for the second half-text was 145.5 msec (SD = 40.4). Even though the mean syllable duration was shorter during the last half of the sample, the variability was considerable and the difference was not statistically significant \((t = 0.453, df = 10, p > .05)\). Similarly, in the spontaneous speech sample, the mean syllable duration was shorter in the second half (127.3 msec, SD = 22.19) than in the first half (143.8 msec, SD = 26.50). But again, the mean difference did not approach significance \((t = 1.10, df = 10, p > .05)\). In general, then, whether oral reading or spontaneous speech is considered, a significant reduction of syllable duration was not reliably seen during the latter halves of PD’s overall speech text.

We next turned our attention to possible tendencies for PD to accelerate progressively (that is, to decrease syllable duration) from the beginning half of a sentence to the final half. Each sentence was divided in half; the division was made at the nearest syntactic boundary. For both oral reading and spontaneous speech, mean syllable durations for the first halves of six sentences were compared with the second halves of the same six sentences. In oral reading, the initial halves of sentences actually had shorter syllable durations \((x = 136.8 \text{ msec}, SD = 56.6)\) than the second

\(^2\) This procedure introduced a possible source of error. As noted earlier, PD’s rapid utterances often were unintelligible to the point that syllable junctures could not be identified. It is possible that he may have omitted some syllables during these runs of rapid speech. If so, the obtained measures of mean syllable duration would be somewhat lower than they should be.
halves (X = 168.2 msec, SD = 33.4). The difference was not significant (t = 1.07; df = 10; p > .05). In spontaneous speech, the reverse trend was observed. Syllable durations were shorter for the second halves of sentences (X = 129.7, SD = 19.54) than for the initial halves (X = 141.5 msec, SD = 29.86). The difference once again failed to reach significance (t = 0.753 msec; df = 10; p > .05). The data thus fail to show that PD’s speech pattern is characterized by any reliable tendency to increase his rate of utterance from the beginning of his sentences to the ends. Again, variability was seen to be considerable.

These findings lead one to question the validity of clinical observations that patients like PD genuinely do show progressive speech acceleration. Perhaps careful measurement of other patients’ speech would also fail to reveal such differences. Clearly, it will be necessary to obtain objective data on several patients with rapid speech patterns to determine if progressive acceleration is a genuine phenomenon in some of them.

One previously reported clinical observation that we were able to confirm in PD was the occurrence of short rushes of speech. It was this phenomenon, in fact, that led to the large variability in PD’s syllable durations noted above. During some half-sentences, located variously in the first or the second half of the texts, we observed mean syllable durations as short as 64.5 msec. These segments of rapid speech constitute short rushes. Their occurrence is not at all systematic with regard to position within a sentence or within a sample.

Variability in rate of speech was also observed in measurements made of PD’s production of utterances based on a paradigm designed by Gaitenby (1965) to establish facts about (normal) rate of speech within the sentence unit. One aim of Gaitenby’s study was to investigate the temporal relationship between a phrase in utterance-final position, and that same phrase appearing in nonfinal position. A speaker produced repetitions of a sentence, then produced another sentence that included the first as an embedded phrase, and yet another that embedded these in a longer utterance, etc. Our measurements conform to the original study’s design, in that we obtained values for segment lengths and overall lengths for each portion of five progressively embedded sentential utterances, for both PD and the control (GJC). Spectrograms made of utterances from GJC and PD were measured and remeasured by two other phoneticians. Agreement was found in all cases. Phrasal boundaries from the spectrographic records could easily be identified despite the speech problem in the clinical patient, mainly because the utterance was known, and only phrasal boundaries were identified in this case. The same criteria for identifying phrasal boundaries were applied to both speakers. For example, the beginning of the closure for the voiced velar consonant in the word “get,” which begins the second phrasal unit of concern in this exercise, identified the boundary between the first and second unit. Average
Figure 1. The phrase “Why don’t you” in isolation (A) and embedded in utterances B–E. The ordinate shows the percentage of shortening for each speaker.

Syllable durations within phrases were obtained by dividing the total phrase duration by the number of syllables in that phrase. Syllable duration measurements made on this controlled speech paradigm also confirm findings from analyses of the text material: PD’s syllable durations are sometimes nearly half the length of mean syllable durations found for the normal control for the same phrase. In this sample, the range of values for PD occurs from 62 msec to 200 msec, while normal values range from 121 msec to 432 msec.
Table 2. Durations for Phrases Occurring in Final Position and Embedded in Longer Phrases

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GJC</td>
<td>580</td>
<td>580</td>
<td>100%</td>
<td>580</td>
<td>580</td>
<td>100%</td>
<td>580</td>
<td>580</td>
<td>100%</td>
<td>580</td>
<td>580</td>
<td>100%</td>
<td>580</td>
<td>580</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>PD</td>
<td>520</td>
<td>520</td>
<td>100%</td>
<td>520</td>
<td>520</td>
<td>100%</td>
<td>520</td>
<td>520</td>
<td>100%</td>
<td>520</td>
<td>520</td>
<td>100%</td>
<td>520</td>
<td>520</td>
<td>100%</td>
</tr>
<tr>
<td>B</td>
<td>GJC</td>
<td>450</td>
<td>450</td>
<td>100%</td>
<td>450</td>
<td>450</td>
<td>100%</td>
<td>450</td>
<td>450</td>
<td>100%</td>
<td>450</td>
<td>450</td>
<td>100%</td>
<td>450</td>
<td>450</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>PD</td>
<td>412</td>
<td>412</td>
<td>100%</td>
<td>412</td>
<td>412</td>
<td>100%</td>
<td>412</td>
<td>412</td>
<td>100%</td>
<td>412</td>
<td>412</td>
<td>100%</td>
<td>412</td>
<td>412</td>
<td>100%</td>
</tr>
<tr>
<td>C</td>
<td>GJC</td>
<td>422</td>
<td>422</td>
<td>100%</td>
<td>422</td>
<td>422</td>
<td>100%</td>
<td>422</td>
<td>422</td>
<td>100%</td>
<td>422</td>
<td>422</td>
<td>100%</td>
<td>422</td>
<td>422</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>PD</td>
<td>420</td>
<td>420</td>
<td>100%</td>
<td>420</td>
<td>420</td>
<td>100%</td>
<td>420</td>
<td>420</td>
<td>100%</td>
<td>420</td>
<td>420</td>
<td>100%</td>
<td>420</td>
<td>420</td>
<td>100%</td>
</tr>
<tr>
<td>D</td>
<td>GJC</td>
<td>435</td>
<td>435</td>
<td>100%</td>
<td>435</td>
<td>435</td>
<td>100%</td>
<td>435</td>
<td>435</td>
<td>100%</td>
<td>435</td>
<td>435</td>
<td>100%</td>
<td>435</td>
<td>435</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>PD</td>
<td>295</td>
<td>295</td>
<td>100%</td>
<td>295</td>
<td>295</td>
<td>100%</td>
<td>295</td>
<td>295</td>
<td>100%</td>
<td>295</td>
<td>295</td>
<td>100%</td>
<td>295</td>
<td>295</td>
<td>100%</td>
</tr>
<tr>
<td>E</td>
<td>GJC</td>
<td>363</td>
<td>363</td>
<td>100%</td>
<td>363</td>
<td>363</td>
<td>100%</td>
<td>363</td>
<td>363</td>
<td>100%</td>
<td>363</td>
<td>363</td>
<td>100%</td>
<td>363</td>
<td>363</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>PD</td>
<td>348</td>
<td>348</td>
<td>100%</td>
<td>348</td>
<td>348</td>
<td>100%</td>
<td>348</td>
<td>348</td>
<td>100%</td>
<td>348</td>
<td>348</td>
<td>100%</td>
<td>348</td>
<td>348</td>
<td>100%</td>
</tr>
</tbody>
</table>

The ratio of the length of each phrase, when embedded to its length in final position, is given as a percentage.

*Utterances*

A. Why don’t you
B. Why don’t you get tickets
C. Why don’t you get tickets for tomorrow
D. Why don’t you get tickets for tomorrow night
E. Why don’t you get tickets for tomorrow night’s performance.
(the duration of the phrase appearing in isolation). The values for the two normal controls (from our and from Gaitenby's study) and for PD are given. For the two normal controls, the duration values for utterances of the initial phrase decrease rapidly and then plateau as the phrase-type is embedded in progressively longer sentences. For PD, in contrast, the extent of shortening fluctuates markedly, suggesting, again, abnormal variability in the extent of shortening with respect to the original duration values. This observation constitutes further demonstration of short rushes occurring apparently randomly.

Progressive acceleration was not observed in these controlled speech samples, in agreement with our observations on connected texts. Instead, a normal pattern of prepausal lengthening was observed in the speech of the patient and the two normal speakers, in that all phrases in final position were subjected to nonfinal shortening when embedded into nonfinal position. In all cases, PD conformed to the normal pattern by shortening each phrase relative to the value of that phrase in final position. Note that only small reductions, most of which are similar to the normal values, appear in the phrase that remains in initial position ("Why don't you"), these values for PD being 79%, 81%, 51%, and 61% with each progressive embedding (compared with the control's values, 78%, 73%, 75%, and 63%, respectively). PD's most drastic rate increases occur internally in the phrase. (This fact conforms with Oller's (1973) observations in normal speakers that initial position, like final position, is also subject to lengthening effects.) This observation further supports our conclusion that overall linguistic planning is normal and intact in PD.

An Attempt to Restore Intelligibility Through Speech Expansion

Insofar as accelerated rate based on abnormally short syllable durations constituted the most obvious abnormality in PD's speech, we wondered if an electronic expansion of his speech would improve his intelligibility. This was accomplished using a computerized speech compressor/expander (Varispeech II, manufactured by Lexicon, Inc.). Since PD's syllable durations were shorter than mean normal durations by 25% in oral reading and by 27% in spontaneous speech, we expanded PD's speech samples by the closest estimations we could make to these percentages. If reduced durations of syllables were wholly responsible for his poor speech intelligibility, we should anticipate a marked improvement when listeners heard his speech expanded. Twenty listeners were used to obtain intelligibility measures of PD's expanded speech. In spontaneous speech, the change in intelligibility was from 23% (unexpanded) to 34% (expanded). Though in the expected direction, these changes were certainly not of a
magnitude to lead us to conclude that PD’s problem could be viewed simply as an overall speeding up of normal articulatory movements.4

Temporal Microstructure of Speech

The fact that electronic expansion of PD’s speech did not result in a marked improvement of intelligibility leads to the likelihood that PD’s rapid speech might be characterized by altered temporal relationships among speech sounds (rather than being a uniformly speeded-up version of normal speech). These relationships between segments are what we refer to here as the temporal microstructure of speech. We considered investigation of these relationships crucial, because of the high information load they carry (Klatt, 1976; Huggins, 1978).

In an adaptation of the procedure developed by Lehiste (1972), PD and the normal speaker read aloud the words “stick,” “sleep,” “shade,” and “speed” in isolation, and then embedded in progressively longer words and phrases. Spectrograms were made from these speech samples. For each word, there was a set of eight utterances of increasing length. Both PD and the control speaker produced each set 10 times. To reduce possible order effects, in half the trials, the utterances were produced in the order of shortest to longest; in the other half this sequence was reversed.

From Lehiste’s paper, we took some similarly obtained data from another normal speaker (LS), so that we were able to compare PD with two controls on certain measures. Tables 3 and 4 show results for the words “stick” and “sleep,” spoken in isolation and in the derived phrasal forms, as representative of measurements made on all four words and their derived phrases. The durations of the embedded base words and their vowel nuclei are given in milliseconds and in percentages relative to the word and vowel durations as produced in isolation. Each entry in the table represents the mean of ten trials.

For the base words and their nuclei, it is apparent that our patient and the two controls followed the expected pattern of decreasing durations as the base was embedded in progressively longer phrasal utterances. As expected, PD systematically reduced the duration of his base words to a greater degree than the controls. The data show, in agreement with the findings of Lehiste, that the vowel nucleus shortens more than other seg-

---

4 To consider this problem further, we took the intelligibility tapes of our control speaker, and we compressed them, so as to make his mean syllable durations equal to those of our patient’s natural speech. This required compression of 32%. The intelligibility of the control’s unaltered speech had been 97.5%. Even with speech accelerated by 32%, intelligibility was maintained, with very little degradation, at 91%. It is apparent that merely speeding up normal speech by 32% (or 1.3 times normal) had no serious effect. This is not surprising when we consider previous findings. Garvey (1953) showed that the intelligibility of normal speech was not reduced below 90% until it was accelerated to 150% (the original rate), a result consistent with data reported by Zemlin, Daniloff, and Shriner (1968).
Table 3. Ratios of Word "Stick" Said in Isolation to Word as "Stem" Embedded in Longer Phrases, Both for Entire Word Durations and for Vowel–Nucleus Durations

<table>
<thead>
<tr>
<th>Phrase</th>
<th>Word</th>
<th>Nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LS</td>
<td>GJC</td>
</tr>
<tr>
<td>stick</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>sticky</td>
<td>80</td>
<td>76</td>
</tr>
<tr>
<td>sticking</td>
<td>80</td>
<td>73</td>
</tr>
<tr>
<td>stickily</td>
<td>70</td>
<td>69</td>
</tr>
<tr>
<td>stickiness</td>
<td>62</td>
<td>67</td>
</tr>
<tr>
<td>the stick fell</td>
<td>72</td>
<td>68</td>
</tr>
<tr>
<td>the stick is broken</td>
<td>65</td>
<td>66</td>
</tr>
<tr>
<td>the stick was discarded</td>
<td>62</td>
<td>63</td>
</tr>
</tbody>
</table>

ments in progressive embeddings. And it has been observed that the vowels shorten relatively more than the consonants with increased rates of speech (Kozhevnikov and Chistovich, 1965; Huggins, 1978; Gaitenby, 1965). This normal tendency is greatly exaggerated in PD. In half of the utterances tested, his vowel durations showed proportional shortening of 33% to 41%, decrements beyond the values obtained from the two normal speakers.

These observations are of interest with regard to the formulations of Klatt (1973). His model predicts that "the minimum stressed vowel duration that one would expect to encounter in normal speech is 45% of the inherent vowel duration of that vowel." The reduced vowel durations of the control speakers shown in Tables 3 and 4 conform closely to Klatt’s prediction, with the greatest duration reductions at 43%. In PD, however, more than half of the 13 embedded words had the vowel nucleus shortened to 39% or less of the inherent duration (that is, of the duration of the word

Table 4. Ratios of Word "Sleep" Said in Isolation to Word as "Stem" Embedded in Longer Phrases, Both for Entire Word Durations and for Vowel–Nucleus Durations

<table>
<thead>
<tr>
<th>Phrase</th>
<th>Word</th>
<th>Nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LS</td>
<td>GJC</td>
</tr>
<tr>
<td>sleep</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>sleepy</td>
<td>82</td>
<td>75</td>
</tr>
<tr>
<td>sleeping</td>
<td>85</td>
<td>74</td>
</tr>
<tr>
<td>sleepily</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>sleepiness</td>
<td>70</td>
<td>66</td>
</tr>
<tr>
<td>sleep heals</td>
<td>74</td>
<td>73</td>
</tr>
<tr>
<td>sleep refreshes</td>
<td>64</td>
<td>68</td>
</tr>
<tr>
<td>my sleep was disturbed</td>
<td>61</td>
<td>67</td>
</tr>
</tbody>
</table>
spoken in isolation). Not only does this help us to understand why PD's connected speech was so much more defective than his production of single words, but it also suggests that he may have shortened vowels to a point where their identifiability was reduced.

PD's short-duration vowels, when combined with the (normal) tendency to undershoot vowel targets in rapid speech (Lindblom, 1963), may have

Figure 2. Spectrographic records of utterances produced by PD and GJC.
caused not only difficulty in vowel identification but also a degradation of the information concerning contiguous consonants, which is normally encoded into the vowel spectra. In fact, inspection of the spectrographic records reveal that the formant patterns typically are more discernible in the speech of the normal speaker. What is more, formant transitions indicating consonant loci are not distinct in this abnormally rapid speaker. From the spectrograms in Figure 2, it can be seen that the formants in the acoustic record for PD do not show the distinguishable and characteristic patterns seen in the record for the control speaker. Of course, further research on the question of vowel targets in both stressed and

Figure 3. Phonetic segment durations for target word in isolation and in embedded utterances, for PD and normal speaker (GJC).
reduced vowels is required to fully determine the effects of such under-
shooting on vowel and contiguous consonant identification in abnormally
rapid speech.

To look further for temporal alterations in PD's speech that might help
to explain the poor intelligibility of his speech, we measured durations of
each phonetic segment in all four words utilized in this part of our study,
comparing individual phonetic segments for both PD and the control (GJC)
in all the progressive embeddings of the paradigm. The measurements for
the base words are given schematically in Figures 3–6. Each schema
represents an average of measurements made from 10 spectrograms made
of the 10 repetitions of each phrase for PD and the control. As described
for the previous spectrographic analysis, determination of the phonetic
units of interest could be easily achieved because the utterances were
known. In this case, it was necessary only to identify the segments within

Figure 4.

a. **Speed**

b. **Speeder**

c. **Speeding**

d. **Speedily**

e. **Speediness**

f. **Speed kills**

g. The **speed** increased

h. The **speed** was controlled
Figure 5.

each of the four monosyllable words ("stick," "shade," "sleep," "speed") embedded in the longer utterances. In every case, amplitude in the high-frequency regions was clearly visible, indicating the initial sibilant (or "shibilant"); the absence of acoustic information was counted as the consonant closure, the presence of energy across a broad range of frequency was clearly seen as the release of the stop consonant, and formants constituted the vocalic portion of each word. These measurements were checked by two other phoneticians, and again, no discrepancies were observed. The same criteria for segmentation were applied to both PD and GLC. The measurements from each of 10 spectrograms for each target utterance were averaged; thus, each value represents a mean of 10 samples. Note that for PD, the consonant releases in almost every case constitute a longer percentage of the whole word than is seen for the control speaker. In some instances, PD's consonant releases are
markedly prolonged. This feature undoubtedly contributes considerably to the "slurred" nature of PD's speech. The closure periods themselves are equal to or longer than those of the control. Conversely, with the exception of the short vowel in stick, the vowel occupies a smaller proportion of the PD's production of the whole word than the control speaker's productions, as has been described above. These patterns can be seen to hold remarkably consistently in the target words as they are produced in increasing embedded derivations.

**DISCUSSION**

We are led to consider this speech disturbance as having two major components. First, we postulate impairment of a mechanism which serves as a speech metronome or pacemaker. In PD, the surgical thalamic lesions presumably upset a balance within this mechanism so that he was driven
to produce speech at an abnormally rapid rate. The direct result of this disturbance is hypothesized to be the reduced duration of syllables, seen mainly as a shortening of vowel length. However, we do not believe that all the abnormalities in segmental timing revealed by our analysis of the temporal microstructure of PD's speech can be explained by the same disturbed mechanism. The tendency for this patient to devote unusually high percentages of his word durations to the release of stop consonants, for example, is most likely based on his more peripheral neuromotor deficits, including muscle weakness and perhaps rigidity.

Taken individually, these two types of speech disturbance are not necessarily serious hazards to intelligibility. We know that speech can be produced at rates exceeding those of PD and remain understandable. And we observed that PD's speech was intermittently understandable despite dysarthric articulation. But when his defective neuromotor system was driven to produce speech with extraordinary speed, it is not surprising that intelligibility was seriously reduced. This proposed interaction of a "metronomic" abnormality with a neuromotor articulatory deficit becomes more compelling when we consider that for lip movements, for example, "an increase in the activity level of the muscle" is required for articulation when speech rate is increased (Gay, et al., 1974, p. 60).

We appreciate the help of Roger Colcord, Jean Wallace, Karen Emmorey, Paul Hardee, Edith Li, Ron Netsell, Richard Peach, Dale Terbeek, Kazuyoshi Fukuzawa, Daniel Kempler, and Susan Curtiss at various stages of data-gathering and preparation of this paper. The largest part of this study was done at the Department of Communicative Disorders at Northwestern University where DVL was a postdoctoral NRSA Fellow under NIH Training Grant 5T32NS 07100 and was completed under NIRA #4-443944-31117 at UCLA.

REFERENCES


