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We are submitting herewith a dissertation written by Linda Byrum Lilley entitled "Stress, Rate, and Phone Duration in Apraxia of Speech." We have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

Patrick J. Carney

Patrick J. Carney, Major Professor

Ellen I. Hamby

Ellen I. Hamby, Major Professor

We have read this dissertation and recommend its acceptance:

Stephen Handel

Harold L. Luper

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

STRESS, RATE, AND PHONE DURATION
IN APRAXIA OF SPEECH

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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Linda Byrum Lilley

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With God all things are possible.

Matthew 19:26

ABSTRACT

The purpose of this study was to assess, for subjects with apraxia of speech and for normal speakers, phone durations and trends of phone duration when syllabic stress, speaking rate, and meaning were varied. Subjects were ten apraxic and five normal speakers. The subjects produced a word (permit) and a nonsense syllable (perpit), both with two different syllabic stress patterns. Utterances were produced in the carrier phrase, "My ______ please" and were spoken at normal and at fast rates. Durational measurements were obtained from oscillographic displays for the following segments: both vowels and the medial consonant in the target word, the target word, and the entire phrase. Only utterances which were perceptually correct in terms of articulation and stress were analyzed.

The apraxic speakers had longer phrase, word, and phone durations than normal speakers. However, apraxics maintained the same relative phone/word durations as the normals. Therefore, apraxia does not appear to be a disorder of the durational relations among phones.

In talking at the faster rate, normal subjects proportionately decreased phone, word, and phrase durations. There was considerable durational overlap between apraxics' productions at the two rates. While it is unclear as to why apraxics did not change speaking rate, altering rate was aberrant in the apraxic speakers. Thus, the mechanism for changing speaking rate may be involved in apraxia.

Most durational findings applied to apraxic and normal speakers for meaningful and nonsense stimuli, although there was greater durational variability for both speaking groups for the nonsense syllables. Other than the increase in durational variability, there do not seem to be temporal differences between the production of meaningful and nonsense stimuli.

Insofar as perceptually correct utterances are representative of apraxics' speech, it can be inferred that apraxia is not a disorder of the durational relations among phones. It was hypothesized that apraxia is a disorder in the selection of the correct program for the target utterance. Implications for a theory of apraxia were discussed.

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CHAPTER I

INTRODUCTION

Apraxia of speech has been defined as:

> a sensorimotor speech disorder resulting from brain damage. Symptoms are impaired volitional production of normal articulation and prosody. The articulation and prosodic disturbances. . .result from inhibition or impairment of central nervous system programming of skilled oral movements (p. 63) (Rosenbek and Wertz, cited in Wertz, 1978).

Some of the articulatory behaviors characteristic of apraxic speakers include numerous substitutions of one phone for another (Johns and Darley, 1970; Trost and Canter, 1974), inconsistent, variable, and unpredictable errors (Shankweiler and Harris, 1966; Johns and Darley, 1970), more errors on consonant clusters than on consonant singletons or vowels, and more errors on affricates and fricatives than on plosives (Shankweiler and Harris, 1966; Johns and Darley, 1970; Deal and Darley, 1972; Trost and Canter, 1974; LaPointe and Johns, 1975). Most of the literature has emphasized articulation skills of apraxic speakers, but it appears that apraxia may not be simply a disorder of articulation. Perceptual and acoustic studies have produced evidence that temporal aspects of speech are impaired in apraxia. Perceptually, experimenters have observed that apraxic subjects reduce their speaking rate and stress syllables evenly (Johns and Darley, 1970; Darley, Aronson, and Brown, 1975; Kent and Rosenbek, in press). Acoustically, apraxic speakers have been reported to differ from normal speakers in segment duration, second formant transition, and voice onset time (Bauman, 1975; DiSimoni and Darley, 1977; Jaffe and

and Duffy, 1977; Freeman, Sands, and Harris, 1978; Colson, 1979; Fager and Deutsch, 1981; Gawle and Duffy, 1981; Kent and Rosenbek, in press).

Although data exist to support the premise that there are temporal differences in apraxic speech, little information exists as to the nature of the temporal impairments or temporal alterations of the apraxic speaker. Further, it is not known what types of control an apraxic speaker uses when temporal changes are required. This information is essential to understand and to define the nature of apraxia of speech, as well as to better treat those individuals suffering from the disorder. The purpose of this study was to investigate the performance of apraxic speakers in controlling temporal adjustments during speech.

Review of Literature

Perceptual and acoustic information exists to support the observation that temporal processes are affected in apraxic speech. Speaking rate, stress and rhythm patterns, duration, second formant transition, and voice onset time are measures of temporal processes of speech. Evidence that these temporal changes occur in apraxic speech are reviewed.

Perceptual Characteristics

Most of the perceptual information available about apraxia of speech is concerned with articulation and the nature of errors which occur. Included in those studies of articulation are observations which suggest that apraxia of speech affects the temporal organization of speech as well as the sequencing of articulatory events. Perceptual observations that temporal processes are impaired also are frequently contained in textbook descriptions of apraxia.

In an experiment investigating the articulation skills of apraxic speakers, Johns and Darley (1970) observed alterations in the temporal characteristics of their speech. The ten apraxic subjects were required to read the "My Grandfather" passage at their normal rate and as fast as possible. In order to elicit conversational speech, the subjects also described pictures. The responses were tape recorded and broad phonetic transcriptions were performed later.

The subjects made markedly fewer articulatory errors and were more intelligible in the "fast" reading of the passage as compared with the normal rate. Although there were fewer errors in the fast reading condition, no durational measures or speaking rates were reported. Therefore, the results are difficult to interpret. That is, it is not apparent whether the apraxic subjects did, in fact, increase their rate or by how much. However, if the results are accurate, it appears that apraxic speakers may indeed be capable of making temporal alterations and that the temporal changes and articulation may be related.

From the conversational speech samples, Johns and Darley reported that the apraxic speakers appeared to slow their rate and make careful articulatory movements as compared with normal speakers. The authors reported that the apraxic subjects acknowledged that they were attempting to slow down. Johns and Darley suggested that the speaking rate of apraxic speakers was "slow, even, and hesitant" because speaking in that manner was useful in compensating for anticipated articulatory difficulties. Thus, Johns and Darley hypothesized that the temporal disturbances which occur in apraxia of speech are compensatory.

Another perceptual reference to the temporal aberrations which occur in apraxic speech is contained within a text by Darley, Aronson, and Brown (1975). These authors defined apraxia of speech as:

> an articulatory disorder resulting from impairment, due to brain damage, of the capacity to program the positioning of speech musculature for the volitional production of phonemes and the sequencing of muscle movements for the production of words (p. 255).

They further reported that temporal abnormalities do occur in apraxic speech. In describing those abnormalities, they wrote that apraxic speakers "slow down, space their words and syllables evenly, and stress them equally" (p. 250). Like Johns and Darley (1970), they suggested that apraxic subjects make temporal changes in order to avoid articulatory errors. According to Darley, Aronson, and Brown, it is because of the "careful programming of muscle movements" that prosodic differences, which include speaking rate and stress changes, occur in apraxic speakers. They suggested that the aforementioned impairments are "probably compensatory."

In 1976, Rosenbek and Wertz (cited in Wertz, 1978) added to the definition of Darley, Aronson, and Brown (1975). They proposed that symptoms of apraxia of speech include the "impaired volitional production of normal articulation and prosody" (p. 63). According to the general observations of Rosenbek and Wertz, characteristics of apraxic speech include distortion of durational relationships of vowels and consonants, slowed speaking rate, and the use of equal and even stress patterns. These authors suggested that the temporal changes which occur in apraxia of speech are primary components of the disorder. That is, they proposed that timing is affected by the nature of the disorder and the temporal changes are not compensatory as Johns and Darley (1970) and Darley, Aronson, and Brown (1975) hypothesized.

Tonkovich, Asp, Shadden, and Mason (1977) further studied the temporal difficulties which occur in apraxic speech. Specifically, they investigated the ability of ten normal and ten apraxic speakers to imitate rhythm and intonation patterns on the Test of Rhythm and Intonation Patterns (TRIP) (Koike, 1977). The TRIP was designed to assess the abilities of children to imitate suprasegmental patterns. It consists of 25 tape recorded suprasegmental patterns of different combinations of the nonsense syllable /ma/ produced by a male speaker. The first 14 items (Rhythm) are systematically varied in tempo and the syllable which receives the stress (MA ma). The next three items (Tempo) are varied in tempo (ma ma ma) and the last eight items (Intonation) have different intonation patterns (ma). Not unexpectedly, normal speakers better imitated suprasegmental patterns than apraxic speakers. The apraxic speakers performed most poorly on the Tempo section of the TRIP. Most apraxic subjects also performed poorly on the Rhythm and Intonation sections. The authors suggested that the suprasegmental deficiencies might be attributed to faulty temporal patterning of rhythmic sequences, implying that impairments in timing may be inherent to apraxia of speech.

According to the previously reviewed perceptual information, it appears that temporal disturbances exist in apraxia of speech. Speaking rate appears slower than normal, stress patterns seem to be more equal, and apraxic speakers do not imitate rhythm and intonation patterns as well as normal speakers. These impairments have been interpreted as being compensatory or as being primary components of the disorder itself.

Acoustic Characteristics

Acoustic measures have been used to confirm perceptual reports and to investigate subtle aspects of apraxia of speech which may not be readily apparent to a listener. Several acoustic studies revealing temporal impairments which occur in apraxia of speech have been reported. Phone duration, voice onset time, voicing control, and second formant transition data are among the parameters that have been investigated acoustically.

In an unpublished master's thesis, Bauman (1975) investigated the duration of the vowels /i/, /ɑ/, and /u/ in a consonant-vowel-consonant (CVC) context. The initial consonant was /p/ and the final consonant varied among ten different phones. Subjects were six apraxic and six normal speakers. They read aloud the phrase, "I will repeat: ____." Responses were tape recorded and durational measures were made using an oscilloscope and a transpitch meter. Bauman reported that overall duration was shorter in apraxic than in normal subjects. For the apraxic group, /i/ was shortest, yet for the normal subjects, /u/ had the shortest duration. The vowel /ɑ/ generally was longer than /i/ and /u/ for both groups. It also was reported that apraxic speakers had shorter vowel durations before voiced consonants than before voiceless consonants while the normal speaker produced shorter vowels before voiceless consonants. Therefore, it appears as if phonetic context affects phone duration in apraxic (and in normal) speakers.

DiSimoni and Darley (1977) investigated the effects of increasing utterance length on phone duration in a single apraxic speaker. The subjects said the following: "/ipi/," "/ipi/ saw /ipi/," and "/ipi/ saw /ipi/ with /ipi/." They used a datagraph optical oscillograph and measured the duration of consonant /p/ in /ipi/. They observed that /p/ duration for the apraxic speaker generally was shorter than those for normal speakers. Moreover, results indicated that /p/ duration for the apraxic speaker did not decrease systematically as the length of utterance was increased, as is the case in normal speakers. Rather, the duration of /p/ decreased from the one word to the three word condition, but increased from the three word condition to the five word condition. Despite the fact that the apraxic speaker did not evidence the same pattern as did the normal speakers, she did follow a consistent pattern of consonant duration from day to day. That is, they reported there was considerable day to day variation in the absolute duration of /p/, but the pattern of /p/ duration remained the same.

Based on the results, DiSimoni and Darley suggested that programming durational control of speech segments is inefficient in apraxia of speech. They further hypothesized that apraxic speakers concentrate on smaller speech segments than normal speakers because the articulatory mechanism receives faulty information about the size of the unit to be programmed; therefore, phone duration does not decrease as utterance length increases. They also speculated that although speaking rate may be slower than normal, the fact that /p/ duration was shorter than normal suggested that the rate of movement of /p/ was more rapid in the apraxic speaker than in normal speakers.

Fager and Deutsch (1981) performed an experiment similar to that of DiSimoni and Darley (1977) in which the effect of utterance length on duration was measured in normal and apraxic speakers. Fifteen apraxic and fifteen normal subjects read words and phrases of increasing length from index cards. The stimuli in the Fager and Deutsch experiment included "zip, zipper, zippering" and the same "/ipi/" stimuli utilized by DiSimoni and Darley (1977). Responses were tape recorded. Wideband spectrographic analyses were performed and duration of initial consonants, vowels, CV segments, and words were determined. Fager and Deutsch reported that as word length increased, duration of prestressed vowels and initial CV segments decreased in the normal and the apraxic subjects. Ratios of consonant duration to CV unit duration also were observed to increase as word length increased in both groups of speakers. Thus, apraxic speakers followed normal duration patterns when word length increased. However, when phrase length increased, apraxic speakers differed from normal speakers in segment duration. Durations of all segments measured for the normal speakers decreased as phrase length increased, while they did not for the apraxic subjects. When all measurements were combined, apraxic consonant durations were shorter than normal and vowel duration and total word duration were longer than normal. Despite these differences between groups, the authors reported that speech segment duration of apraxics was close to that of normals. Thus, they concluded that programming of relative speech segment duration was intact. However, they also suggested that since apraxic speakers did not always follow normal "rules," then they do not consistently perform with maximum competence and efficiency. The consonant duration data are consistent with those of DiSimoni and Darley (1977).

In an experiment assessing the duration of phones, Colson (1979) investigated consonant and vowel duration in apraxic and normal speakers. The subjects imitated nonsense syllables embedded in a carrier phrase. The stimuli were $C_1V_1C_2V_2$ nonsense syllables where C was /p/, /t/, or /k/, V_1 was /ɑ/, and V_2 was /ə/. Phone duration was determined from measurements taken from a digital storage oscilloscope. Mean initial consonant durations of apraxic speakers were consistently greater by 125 ms than those of normal subjects. Medial consonants were longer in apraxic speakers, but only by approximately 30 ms. Vowel durations of apraxic speakers were also longer in duration than for the normal speakers. The results that phone durations are longer in apraxic than in normal speakers appear contradictory to those of Bauman (1975), DiSimoni and Darley (1977), and possibly to those of Fager and Deutsch (1981). It is not known what the reasons for the differences are.

Gawle and Duffy (1981) measured vowel durations of normal, aphasic, and apraxic speakers in CVC syllables in an attempt to study temporal aspects of speech through acoustic measures. Five apraxic subjects repeated six CVC word pairs (ie: beat/bead) twenty times each. The 120 stimuli were presented in random order. Vowel duration was measured from oscilloscopic displays or through spectrographic analysis. Four of the five apraxic speaker, vowel durations were within the normal range. These results were obtained irrespective of the voicing (voiced or voiceless) of the final consonant. Not only were vowel durations shorter than normal, but four of five apraxic subjects' vowel durations for voiced final consonants were short enough to be considered in the range of normal subjects' vowel durations for voiceless final consonants. In addition to these differences in duration between groups, for the apraxic speakers, variability of duration also was greater than normal in all consonant contexts. Based upon these results, Gawle and Duffy concluded that their apraxic subjects were not normal in durational control of vowels in CVC words. That is, a vowel in a voiced environment more closely resembled a normal speaker's production of that vowel in a voiceless environment. The finding that vowel durations in apraxics are shorter than normal is similar to the result of Bauman (1975). The results are inconsistent with the data of Colson (1979) and Fager and Deutsch (1981) who observed that vowel durations were longer than normal.

There is agreement in the literature that durational characteristics of apraxic speech differ from those of normal speech. However, the nature of that impairment remains unclear. Another durational measure which has been investigated is that of voice onset time (VOT).

Jaffe and Duffy (1977) compared the VOTs of alveolar stops produced by aphasic, apraxic, and normal subjects. Each subject repeated CV or CVC syllables in which the first consonant was /t/ or /d/. The normal subjects had consistent VOTs for each of the two sounds. The aphasics were less homogeneous than the normals, but not significantly. The apraxic subjects differed from the normal and aphasic groups and were also more variable. Three of five apraxic subjects overlapped the VOT for /t/ and /d/, one subject made no distinction between the voiced and voiceless phones relative to VOT, and one subject's responses appeared to be random in the VOT of /t/ and /d/. Therefore, the authors concluded that it appeared that apraxic speakers were impaired in their ability to produce discrete voicing changes. That is, apraxic speakers may not make the subtle temporal differences in VOT which distinguish /t/ from /d/, possibly indicating that temporal control is impaired.

In another VOT study, Freeman, Sands, and Harris (1978) measured the VOTs of a single apraxic speaker in the production of voiced and voiceless plosives. The subject read words beginning with plosives and VOTs were determined from wideband spectrograms. Freeman, Sands, and Harris reported that this apraxic subject's VOTs for /p/ and

/b/ were compressed (shorter) as compared with normal subjects and that there was overlap in VOT between the two phones. Similar results were obtained for /t/ and /d/ and /k/ and /g/. It is apparent that the temporal changes observable in apraxia of speech extend to voice onset time, which is an interarticulatory measurement.

In an extensive acoustic experiment, Kent and Rosenbek (in press) studied acoustic patterns of apraxia of speech in seven apraxic and seven normal subjects. The purpose of the study was to provide a segmental and prosodic description of apraxia of speech. Stimuli included 19 words, 4 sentences, and conversational speech samples. Wideband and narrowband spectrographic analyses were performed. Temporal measures included duration, second formant transition, and voice onset time.

An analysis of the durational measures indicated that speaking rate was slower in apraxic than in normal speakers for total sentence duration and for duration of polysyllabic words. In general, vowel durations were longer in apraxic subjects than in normal subjects. Excessive lengthening of vowels occurred in longer utterances spoken by apraxic speakers, which is contrary to the normal pattern that phone length decreases as utterance length increases (Lehiste, 1972). The observation that consonant durations were longer than normal is consistent with Colson (1979) and is in disagreement with DiSimoni and Darley (1977) and Fager and Deutsch (1981).

In studying second formant transition, Kent and Rosenbek measured the rate of change and duration of the second formant transitions for the /pli/ spoken in the sentence, "Please put the groceries in the refrigerator." The authors observed that apraxic speakers have a slower than normal rate of second formant increase and a longer second formant transition. They concluded that underlying articulation is slower for apraxic than for normal speakers.

In the same study, Kent and Rosenbek investigated voice onset times for four CVC words. Voice onset times for /p/, /t/, /k/, and /g/ were highly variable among apraxic speakers, but average VOTs were not significantly different from those of normal speakers. However, in other word stimuli beginning with fricatives or clusters, there was incoordination between onset of voicing and termination of frication. That is, the apraxic subjects exhibited a greater or lesser voicing lead when producing fricatives. These results appear consistent with those of Jaffe and Duffy (1977) and Freeman, Sands, and Harris (1978) who reported that the VOTs of apraxic speakers were more compressed, overlapping, and random as compared with those of normal speakers.

From the results of this study, Kent and Rosenbek (in press) formed a description of apraxia, which includes the following characteristics: slow speaking rate, prolongation of transitions and steady states of phones as well as intersyllabic pauses, slow and inaccurate movements of the articulators for consonants and vowels, and frequent mistiming and dyscoordination of voicing with other articulators. They suggested that the underlying articulation is slower for apraxic than for normal subjects. Kent and Rosenbek proposed a hypothesis to explain the speaking difficulties encountered by apraxic speakers. They speculated that for normal speakers, "1) temporal schemata (time plans of movement) help to control the sequencing of movements and 2) spatial targets are defined by a space coordinate system of the vocal tract" (p. 36). Kent and Rosenbek proposed that a breakdown occurs in the aforementioned areas in apraxia of speech. That is, they advanced a spatio-temporal hypothesis and further suggested that it is "perhaps unwise" to view apraxia as a purely phonological or motor disorder. The two areas may be independent, but are more likely not to be mutually exclusive. That is, apraxia of speech probably involves temporal and phonological impairments and one may not be independent of the other.

From the preceding review of the literature, it is apparent that temporal characteristics of apraxic speech differ from those of normal speakers. Durational changes have been documented acoustically, though there is conflicting evidence as to whether phone duration is longer or shorter than normal and as to what role context plays in durational control. Temporal adjustments which are within an apraxic speaker's control to make are not known.

Rationale

Apraxia of speech has been described as a motor speech disorder or a disorder of motor programming (Darley, Aronson, and Brown, 1975; Wertz, 1978). This disorder of motor programming results in disruptions of the normal articulatory (Johns and Darley, 1970; Darley, Aronson, and Brown, 1975; Wertz, 1978; Kent and Rosenbek, in press) and temporal (Johns and Darley, 1970; Darley, Aronson, and Brown, 1975; Bauman, 1975; DiSimoni and Darley, 1977; Tonkovich, Asp, Shadden, and Mason, 1977; Jaffe and Duffy, 1977; Wertz, 1978; Freeman, Sands, and Harris, 1978; Colson, 1979; Fager and Deutsch, 1981; Gawle and Duffy, 1981; Kent and Rosenbek, in press) processes of speech. Acoustic evidence is increasing which suggests that temporal variations may be more significant aspects of the disorder than was previously thought. Among the temporal variations that have been reported are shorter consonant duration (DiSimoni and Darley, 1977; Fager and Deutsch, 1981), longer consonant duration (Colson, 1979; Kent and Rosenbek, in press), shorter vowel duration (Bauman, 1975; Gawle and Duffy, 198;), longer vowel duration (Colson, 1979; Fager and Deutsch, 1981; Kent and Rosenbek, in press), longer second formant transition (Kent and Rosenbek, in press), and variable voice onset time (Jaffe and Duffy, 1977; Freeman, Sands, and Harris, 1978; Kent and Rosenbek, in press).

From these reports it is apparent that some of the temporal processes of apraxic and normal speech differ. However, there is conflicting evidence as to the nature of those differences. Controversy also exists as to the reasons why those differences occur. Johns and Darley (1970) and Darley, Aronson, and Brown (1975) suggested that the temporal alterations are compensatory or that the apraxic speaker changes the temporal patterns of his speech to avoid errors of articulation. Conversely, DiSimoni and Darley (1977), Tonkovich, Asp, Shadden, and Mason (1977), Rosenbek and Wertz (cited in Wertz, 1978), Fager and Deutsch (1981), Jaffe and Duffy (1981), and Kent and Rosenbek (in press) speculated that the temporal impairments may be a primary feature of the disorder. That is, there is a lack of or impairment of temporal control in apraxia.

Based upon this information, it appears that more data are needed about temporal differences between apraxic and normal speakers. Specifically, phone duration is of interest since much of the research seems to conflict. Additionally, the ability of apraxic speakers, as compared with normal speakers, to control phone duration or timing needs to be assessed. Information about the temporal control of apraxic speech will contribute to an understanding of the nature of apraxia and will aid in the development of more efficient treatment techniques.

To assess temporal control, a task in which there is as little variation as possible of parameters other than duration would be preferable. One such task would be to produce a phonetic context with a different stress pattern. Changing a syllable of stress requires adjustments in segment duration. In normal English speakers, vowel duration is an acoustic measure which is closely associated with changes in perceptions of syllable stress (Fry, 1955; Gay, 1978; Nakatani and Aston, 1978). By imposing specific stress conditions, the ability of apraxic speakers to make durational adjustments can be observed. Vowel duration in different stress conditions should be measured because this is where differences in stress are apparent in normal speakers (Fry, 1955; Gay, 1978; Nakatani and Aston, 1978). Additionally consonant durations are also of interest because consonant duration is affected in apraxia. Researchers have reported that consonant duration is longer (Colson, 1979; Fager and Deutsch, 1981) than normal. In normal speakers, consonant duration is relatively constant in different stress conditions of a phonetic context (Fry, 1955). It is not know if this "rule" is affected by the neurological impairment which causes apraxia of speech.

It seems necessary to investigate stress in different conditions. Recall that different contexts appear to affect the acoustic measurement obtained (Bauman, 1975; DiSimoni and Darley, 1977; Colson, 1979; Fager and Deutsch, 1981; Gawle and Duffy, 1981). It is essential to use words because a different stress pattern in some words results in a difference in meaning (permit). However, if words were the only stimuli, similarities or differences in results might be attributed to the subjects programming of different words and not different stress patterns. Therefore, it then appears important to use nonsense syllables as stimuli, also. Pilot data revealed that there may be different patterns in the way apraxic speakers perform temporally on words and on nonsense syllables.

Another way in which durational control in different stress conditions can be investigated is by imposing rate constraints. A logical task to assess durational control through different rate measures would include requiring speakers to say an utterance at normal rate, then to say the same utterance as quickly as possible. Thus, the speech mechanism is forced to perform optimally. The important information to be gained from this task is to determine whether apraxic speakers control rate, to determine what kind of temporal changes they make when asked to change the rate of an utterance, and to compare the differences in stress between normal and fast speaking rates. When speaking rate is increased in normal speakers, duration of vowels and consonants decreases (Gay, 1978). The durational rules that apraxic speakers follow are not known at this time.

Statement of Purpose

The purpose of this study was to assess, for apraxic and for normal speakers, phone duration and trends of phone duration when syllabic stress, speaking rate, and meaning were varied. Specifically, the primary topics of investigation were:

1. comparisons between apraxic and normal speakers in phone duration when the syllable of stress is altered from the first to the second syllable of two syllable contexts.

2. comparisons between apraxic and normal speakers in phone duration when speaking rate is increased.

3. comparisons between apraxic and normal speakers in phone duration patterns of meaningful and nonsense stimuli.

CHAPTER II

PROCEDURES

The experimental procedure consisted of ten apraxic and five normal speakers producing four words, ten times each, at normal and fast speaking rates. The four stimuli were a word pair in which the syllable of stress was altered and a similar pair of nonsense syllables also differing in syllabic stress.

Subjects

Subjects were ten apraxic (Ss 1-10) and five normal speakers (Ss 11-15) between 23 and 75 years of age. The mean age of the apraxic subjects was 54.8 years, while the mean for the normal speakers was 61.0 years (Appendix A, Table A-1). All subjects passed a hearing screening at 30 dB (ANSI) in the better ear at 500, 1000, and 2000 Hz and all were native English speakers. The following additional criteria were used in the selection of the apraxic subjects:

1. Left hemisphere brain trauma of at least eight weeks duration;
2. The presence of apraxia of speech and no discernible dysarthria as determined by performance on an oral mechanism examination;
3. Moderate to no detectable comprehension impairment as determined by a z-score of 0 or better on the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass and Kaplan, 1972);
4. No reported premorbid communication impairment.

The normal speakers had no reported history of speech impairment nor any discernible speech impairment as judged by the examiner.

Stimuli

The stimuli for the two stress conditions consisted of one pair of nonsense syllables with different stress patterns and one pair of words in which a change in the syllable stressed resulted in a change in meaning. The nonsense syllables were /pɝpIt/ and /pɚpIt/ and the words were /pɝmIt/ and /pɚmIt/. Each stimulus was placed in the carrier phrase, "My ____________ please." Meaningful and nonsense stimuli were selected because apraxic speakers may make different temporal changes based upon the context (pilot study).

The stimulus "permit" was chosen because a change in syllable of stress results in a change of meaning and because the pilot data showed that apraxic speakers produced the different contexts successfully. "Perpit" was selected because the phonetic context closely resembles that of "permit." The word pairs were selected because the difference between the two utterances of the same context spoken in different stress conditions is primarily temporal rather than phonemic.

Equipment

The subjects' responses were recorded on a Panasonic Model RQ-323As cassette tape recorder. Utterances were later analyzed using a Nicolet Model 206 Oscilloscope.

Procedures

Each subject was tested individually in a quiet, well lighted room. He was seated facing the examiner. Verbal instructions were given prior to the task. Each subject was allowed as much practice as was necessary to elicit correct productions. Each context was practiced immediately prior to the recording of the context. Test stimuli were used as practice items.

The four stimulus phrases were prerecorded and the examiner practiced saying each utterance immediately prior to presenting that set of stimuli. Consistency of phone duration was assessed by arbitrarily selecting one examiner presentation for each of the four stimuli for ten subjects and determining the standard error. The standard error was between 5.4 and 14.8 ms for all phones. See Appendix A, Table A-2, for specific measures for each context for each subject.

The subjects repeated after the examiner the four stimuli in the carrier phrase. The phrases were produced ten times each at both normal and fast speaking rates. Thus, each speaker was asked to produce a total of 80 utterances, 40 at a normal rate and 40 at a fast rate.

The order of presentation of the four stimuli was random and each of the apraxic subjects was presented the stimuli in a different order. The normal subjects received the stimuli in the same order as five randomly selected apraxic subjects. The subjects were presented with a phrase (ie; "My /pɝmIt/ please") and asked to repeat that phrase. Rate was not mentioned and the utterance was considered as being spoken at normal rate. Then the subjects were told, "Say 'My /pɝmIt/ please' as fast as you can." The procedure was repeated ten times for that utterance, alternating normal and fast speaking rates. There was approximately a three minute rest period between each set of stimuli during which the examiner conversed with the subject, the subject had refreshments, or the subject was silent. The examiner then practiced the next context followed by the subject's practicing of that context. The same procedure was implemented for the remaining contexts: ten utterances at normal rate alternated with ten utterances at rapid rate.

When incorrect articulatory responses of the target word occurred, the examiner allowed the subject to self correct if he did so of his own initiative. If not, the examiner proceeded with the task. Only three attempts to self correct were permitted. The first five articulatory correct utterances of the target context for each of the four stimuli were used for analysis purposes. In the event that five correct utterances were not obtained during testing, five more trials of the deficient utterance(s) were attempted. If five articulatory correct utterances were not produced after the additional trials, then the available correct responses were used for listener analysis and the insufficiency was noted.

To determine if the stress and articulation were correct, a panel of ten listeners rated each utterance. The listeners were graduate students in speech pathology. They were told what the four target contexts were and were asked to judge independently what response the subject made. If a subject's response was not one of four target words, the listeners were asked to indicate an error response. Criterion for further analysis was 90% listener agreement. Utterances not receiving 90% listener agreement were noted but not analyzed in this study.

Measurements

For the pilot study, phone, word, and phrase durations were determined from wideband spectrograms and from oscillograms. Spectrographically, vowel duration was defined as the portion from the first vertical striation following the consonantal burst to the last vertical striation preceding the consonant. The medial consonant was indicated by a decreased amplitude and a change in periodicity of the vertical striations. Consonant duration was defined as the portion of decreased amplitude between the last vertical striation of the first vowel and the first vertical striation of the second vowel. Oscillographically, determination of phone boundaries was based upon changes in waveform. Specifically, changes in frequency and amplitude over time were used to aid in determining phone boundaries. Vowels were defined as the portion of increased frequency and amplitude, while the medial consonant was defined as that portion betwen the two vowels (Figure 1).

Reliability between measures obtained from wideband spectrograms and oscillograms was computed using the following formula for computing standard error: $SE = \sqrt{\frac{(X_1 - X_2)^2}{2N}}$. The standard errors obtained for the two measurement techniques for three randomly selected contexts of /pɚmIt/ were 3.1 ms for /ɚ/, 5.4 ms for /m/, and

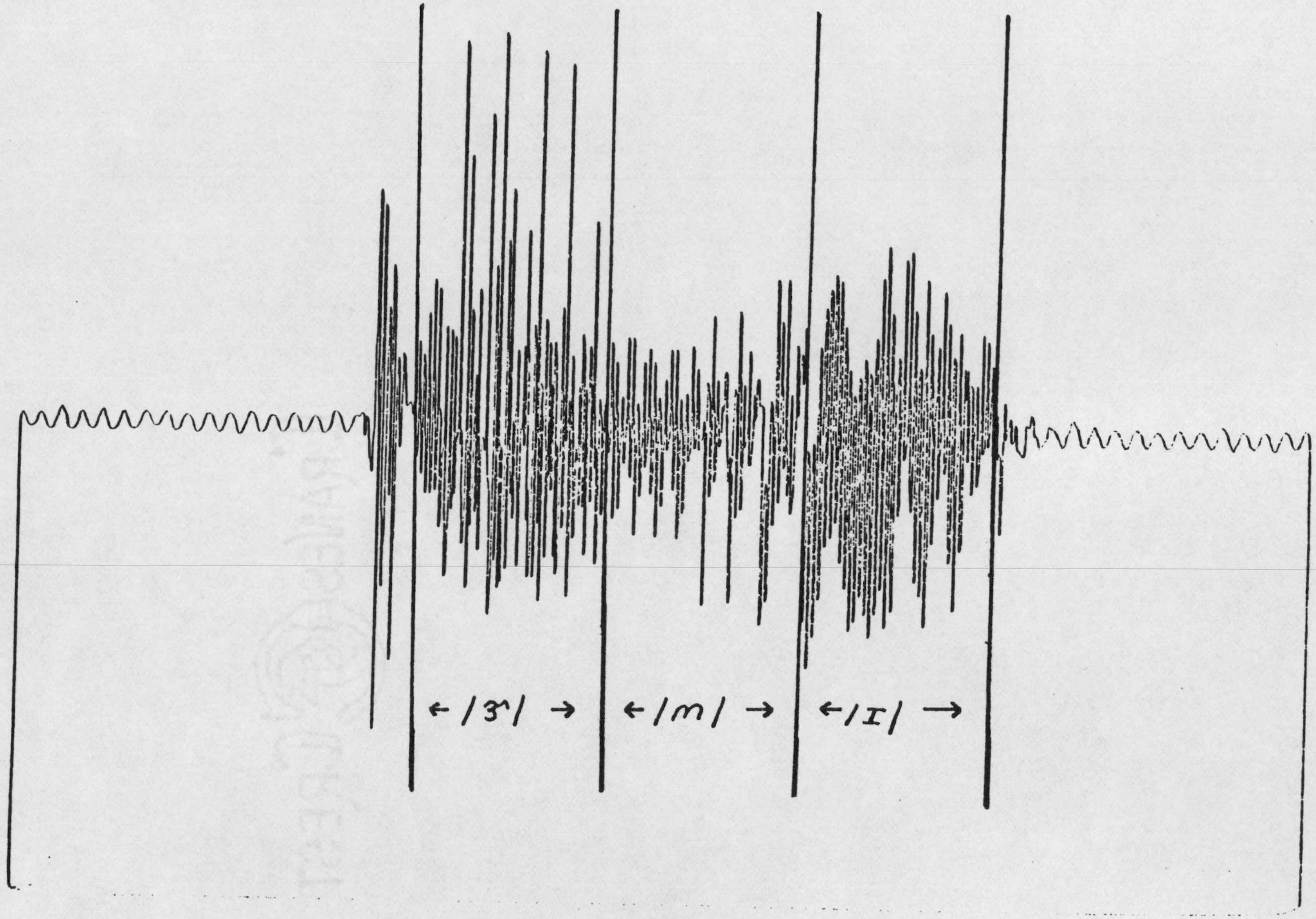

Figure 1. Sample oscillogram showing how measurements were obtained.

and 3.5 ms for /I/. The small values for the standard error of the measurement indicate that the differences in phone duration between the two measurement techniques were minimal for the examiner. The oscilloscope was used for the present study.

Oscillograms were obtained for the first five articulatory correct utterances for each stress context at both normal and fast rates. Articulation and stress of each utterance was judged as perceptually correct by a panel of listeners. Duration, in milliseconds, of the phrase, word, initial vowel, medial consonant, and second vowel were determined from the oscillographic displays for the first five correct utterances for each stress context at both rates. Segment boundaries were determined and durations were read from the face of the oscilloscope.

CHAPTER III

RESULTS

Ten apraxic and five normal subjects produced ten utterances of each of the following stimuli at normal and at fast rates in the carrier phrase, "My ______ please:" /pɝmIt/, /pɚmIt/, /pɝpIt/, and /pɚpIt/. Duration, in milliseconds, was measured from oscillographic displays of the first five articulatorily correct productions of each target word. Durational measures obtained included phrase duration, word duration, duration of the first vowel in the target word, duration of the medial consonant, and duration of the second vowel.

Reliability

Intrajudge reliability of phone duration was determined by randomly selecting three utterances for three subjects, making new oscillograms, and determining the standard error of the measurements from the first measures of the phones analyzed. Word and phrase durational measures were not included because those measures include phone duration and because phone durations were the primary interest in this investigation. Test-retest reliability was computed using the following formula for computing standard error: $SE = \sqrt{\frac{(X_1 - X_2)^2}{2N}}$. The standard error obtained for the remeasurement of the nine phones was 4.88 ms. This value is comparable to those reported in similar experiments (Gay, 1978; Burns, 1979; Colson, 1979).

Standard deviations were computed for each subject for the durational measures obtained for each segment. The standard deviations for each subject serve as an index of intrasubject variability. Individual subject means and standard deviations for all segments of all utterances are located in Appendix B. The apraxic subjects had the least and the most variation in phone duration. The range of standard deviations for phones was from 2.6 ms by apraxic speaker 1 (S 1) for the /ɝ/ in /pɝmIt/ to 135.6 ms by S 8 for the /p/ in /pɚpIt/ spoken at a fast rate. For the normal subjects, the range of standard deviations was from 4.7 ms by S 14 for the /I/ in /pɚmIt/ to 69.4 ms by S 11 for the /p/ in /pɚpIt/. For all speakers, 70% or 164 of 233 standard deviations for each individual phone assessed were less than 40 ms. This indicates that most phones were produced with similar durations for a given speaker.

Durational Measures

Permit

Normal Rate

Normal speakers. Group means and standard deviations are reported in Table 1. Overall mean durations for the five normal speakers for /ɝ/, /m/, and /I/ in the phrase "My /pɝmIt/ please" were 118.9 ms, 60.2 ms, and 76.3 ms, respectively. The mean duration of /pɝmIt/ was 315.0 ms while total phrase duration was 952.2 ms. Durational ranges (ms) were as follows: phrase: 815.6-1034.4, word: 276.2-368.0, /ɝ/: 100.6-145.2, /m/: 43.6-76.6, and /I/: 65.0-93.8. The mean durational measures for /pɚmIt/ were 70.7 ms, 62.3 ms, and 114.2 ms for /ɚ/, /m/ and /I/, respectively, 303.0 ms for the word /pɚmIt/

TABLE 1. Mean duration (ms) and standard deviation of "My permit please" spoken with different stress patterns at normal and fast rates by normal and apraxic speakers.

	Normal Rate										Fast Rate									
	/pɝmIt/					/pɚmIt/					/pɝmIt/					/pɚmIt/				
Normal N=5	phrase	word	/ɝ/	/m/	/I/	phrase	word	/ɚ/	/m/	/I/	phrase	word	/ɝ/	/m/	/I/	phrase	word	/ɚ/	/m/	/I/
$\bar{X}$	952.5	315.0	118.9	60.2	76.3	1061.4	303.0	70.7	62.3	114.2	889.3	285.0	103.2	58.7	67.2	939.0	267.9	59.4	58.1	110.1
SD	93.0	34.2	23.0	11.7	11.6	114.5	41.9	9.2	9.1	17.7	113.2	19.0	7.2	17.3	7.6	115.8	37.4	13.0	13.6	24.9
Apraxic N=10	phrase	word	/ɝ/	/m/	/I/	phrase	word	/ɚ/	/m/	/I/	phrase	word	/ɝ/	/m/	/I/	phrase	word	/ɚ/	/m/	/I/
$\bar{X}$	1288.4	568.3	199.3	123.3	125.3	1775.2	557.9	129.8	124.5	196.7	1269.2	504.4	182.6	117.2	127.2	1566.1	563.4	117.4	121.6	196.3
SD	207.4	127.5	68.1	37.2	28.1	584.5	156.5	39.9	43.3	58.8	204.0	109.6	40.6	43.0	26.4	644.4	234.2	50.4	31.8	52.8

and 1061.4 ms for the entire phrase. Durational ranges (ms) were: phrase: 919.6-1197.0, word: 257.4-371.0, /ɚ/: 62.2-83.6, /m/: 53.8-73.6, and /I/: 94.2-142.6. Fry (1955) reported similar phone durations for the two words; however, word durations obtained in this study were more than 200 ms shorter than those obtained by Fry.

All of the normal subjects had similar mean durational patterns for both words. That is, for each speaker, /ɝ/ was the longest phone and /m/ was the shortest phone in the word /pɝmIt/. In the context /pɚmIt/, /I/ was the longest phone and /ɚ/ and /m/ were approximately the same length.

Comparing the two stress conditions, Figure 2 demonstrates that /ɝ/ was longer than /ɚ/, /m/ was approximately the same length for both stress conditions, and the /I/ in /pɚmIt/ was longer than /I/ in /pɝmIt/. These results are not surprising since stressed vowels are longer than unstressed vowels (Fry, 1955; Gay, 1978; Nakatani and Aston, 1978). Analysis of Figure 3 shows that the total word durations for both contexts were approximately the same length. The phrase "My /pɚmIt/ please" was longer than "My /pɝmIt/ please" (Figure 4).

<u>Apraxic speakers</u>. Phrase, word, and phone durations were obtained for the apraxic speakers and those data are also contained in Table 1. Mean durations (ms) of /pɚmIt/ were: phrase: 1288.4, word: 568.3, /ɝ/: 199.3, /m/: 123.3, and /I/: 125.3. Durational ranges were as follows: phrase: 1110.7-1588.0, word: 408.4-890.4, /ɝ/: 116.0-342.8, /m/: 61.2-186.0, and /I/: 94.8-186.0. Although

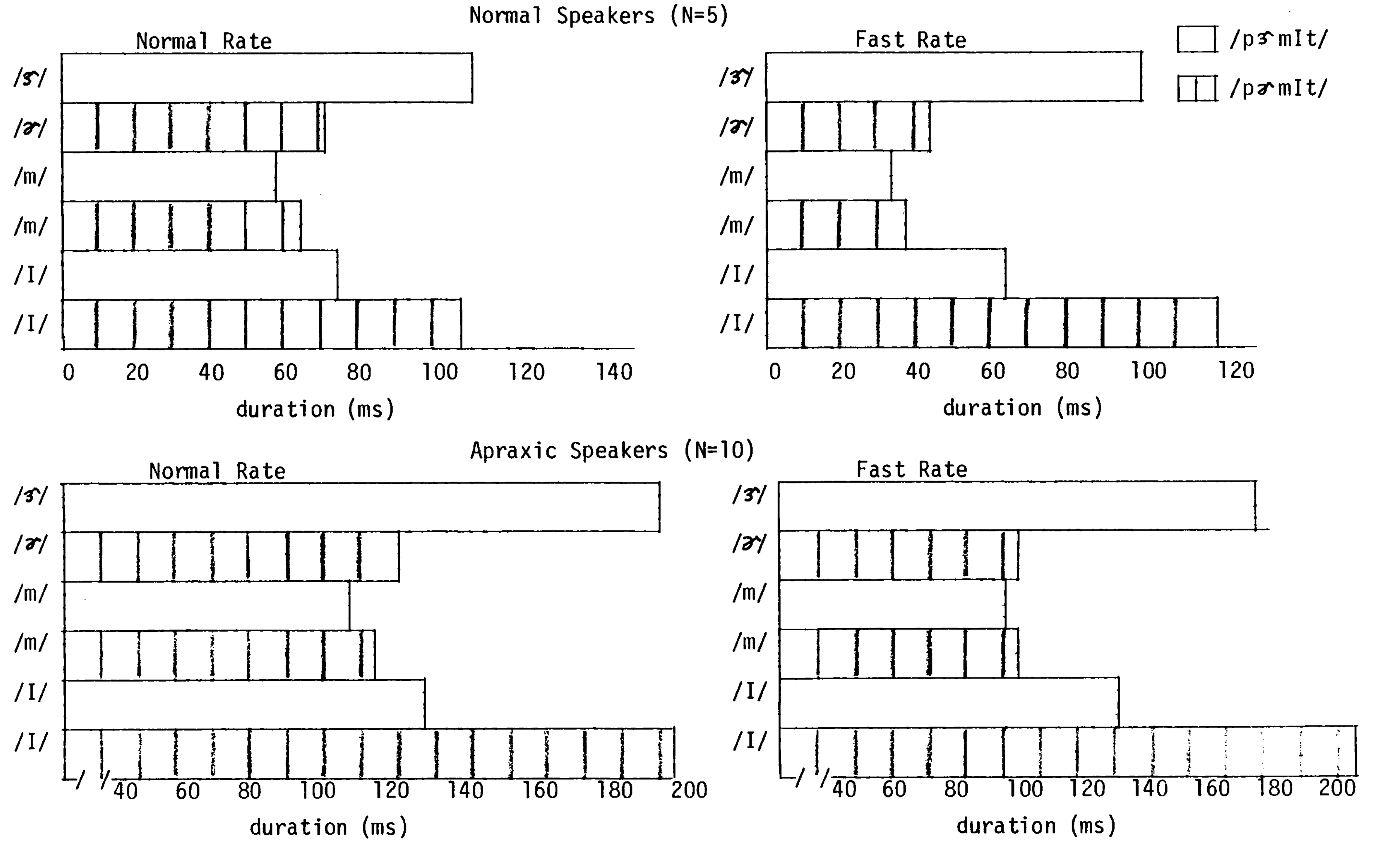

Figure 2. Mean phone duration of the two stress conditions of "permit" for normal and apraxic speakers at normal and fast rates.

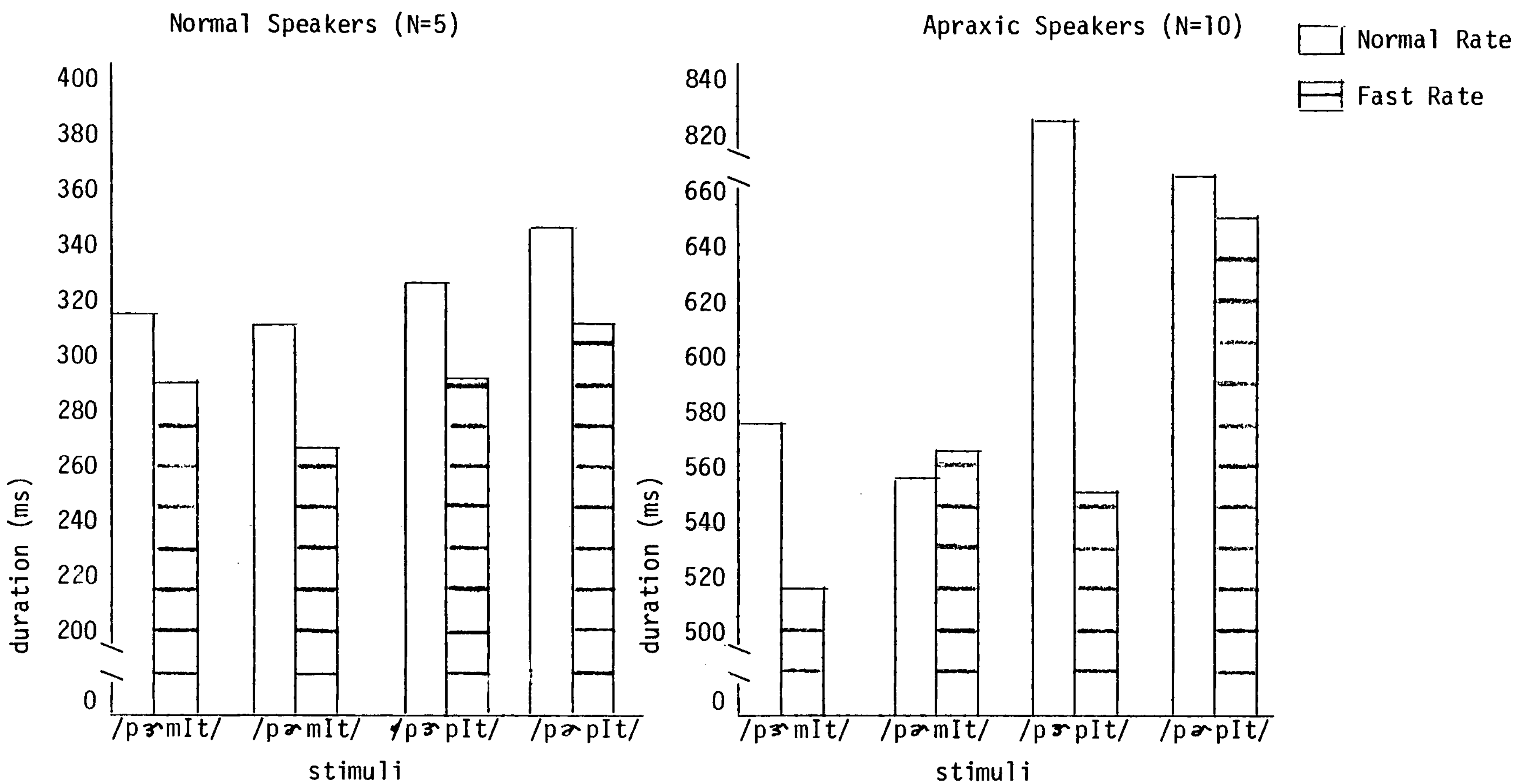

Figure 3. Mean word duration of both stress conditions of "permit" and "perpit" for normal and apraxic speakers at normal and fast rates.

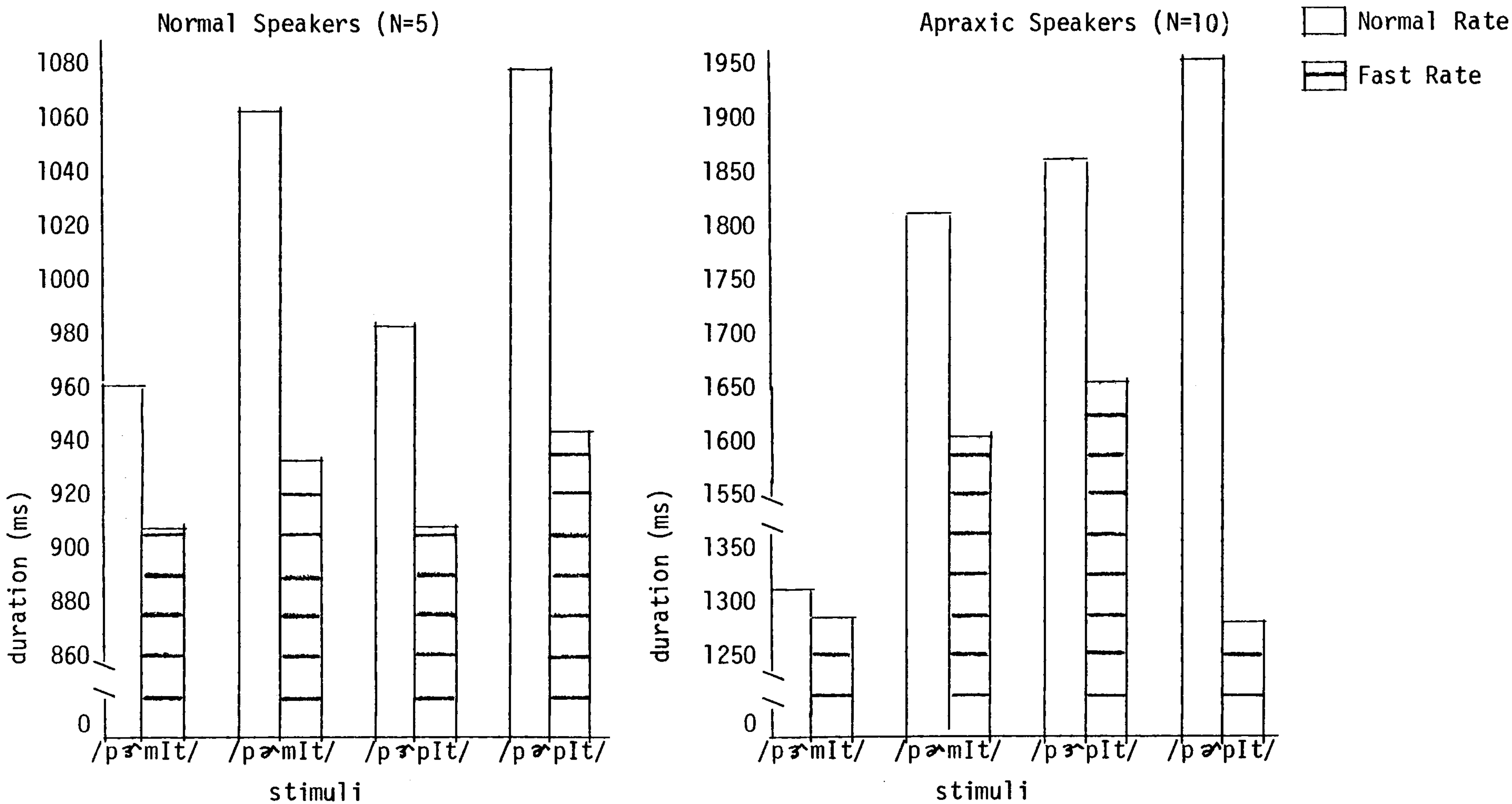

Figure 4. Mean phrase duration of "My ______ please" for normal and apraxic speakers at normal and fast rates.

Ss 4, 6, 8, 9, and 10 produced the target word /pɝmIt/ correctly, they did not produce the entire phrase without error. Therefore, phrase durations for these subjects were not reported and mean phrase duration was based on the values of the five apraxic speakers who produced the entire phrase correctly.

The mean durational measures for /pɚmIt/ were 129.8 (/ɚ/), 124.5 (/m/), 196.7 (/I/), 557.9 (word), and 1775.2 ms (phrase). Durational ranges (ms) were: phrase: 1287.6-2851.3, word: 434.6-974.0, /ɚ/: 78.5-220.0, /m/: 77.2-213.0, and /I/: 140.4-334.0. Ss 4, 6, and 10 did not produce the entire phrase correctly, so phrase durations were not reported and phrase means were from the seven speakers who produced the phrase correctly.

An analysis of Table 1 indicates that apraxic subjects had longer durations than normal subjects for all phrases, words, and phones. However, most of the apraxic speakers had similar durational trends to those of the normal subjects. Figure 2 shows that for the apraxic speakers, the longest phone in /pɝmIt/ was /ɝ/, followed by /I/ and /m/, respectively. For the context /pɚmIt/, /I/ was longer than either /ɚ/ or /m/, both of which had similar durations. Mean word durations for both contexts were similar with values of 568.3 ms for /pɝmIt/ and 557.9 ms for /pɚmIt/ (Figure 3). An analysis of Figure 4 illustrates that mean phrase duration for /pɚmIt/ (1775.2 ms) was longer than that for /pɝmIt/ (1288.4 ms).

Two subjects, S 4 and S 8, did not have the same durational patterns as the other 13 speakers for /pɝmIt/, while both did for /pɚmIt/ (Appendix, Table B-1). For S 4, /m/ (178.0 ms) was the longest phone, while /ɝ/ (116.0 ms) and /I/ (124.0 ms) had approximately the same durations. As was true of the other speakers, /ɝ/ (149.2 ms) was the longest phone in /pɝmIt/ for S 8, but /I/ (94.8 ms) was approximately 30 ms shorter than /m/ (126.4 ms). Although S 3 and S 9 had similar durational patterns as the other subjects for /pɝmIt/, they deviated from this pattern for /pɚmIt/. Values for S 3 were 109.2 (/ɚ/), 145.8 (/m/), and 140.4 (/I/). The same measures for S 9 were 122.0, 162.3, and 174.3 for /ɚ/, /m/, and /I/, respectively. Both speakers had similar durations for /m/ and /I/, while /ɚ/ was the shortest phone.

Comparing phone durations for /pɝmIt/ and /pɚmIt/, the apraxic subjects had durations similar to those of the normal subjects. The mean duration of /ɝ/ (199.3 ms) was longer than /ɚ/ (129.8 ms), stressed /I/ (196.7 ms) was longer than unstressed /I/ (125.3 ms), and duration of /m/ (123.3 ms) in /pɝmIt/ and 124.5 ms in (/pɚmIt/) remained approximately the same in both contexts (Figure 2).

Some individual exceptions to the trends were noted. There was an isolated instance by S 4 when the unstressed phone /I/ (124 ms) was longer than /ɝ/ (116 ms) in the word /pɝmIt/. There were two occasions (by S 2 and S 6) in which the differences in duration between stressed and unstressed vowels were only ten ms. For one production of /pɝmIt/ by S 2, the duration of /ɝ/ and /I/ were 122 and 120 ms, respectively. S 2 also had a single production of /pɚmIt/ in which /ɚ/ (196 ms) and /I/ (202 ms) had similar durations. S 6 produced /ɝ/ (156 ms) and /I/ (150 ms) in /pɝmIt/ with similar durations. However, it appears that apraxic speakers generally made the same durational changes that the normal subjects made.

To compare further the apraxic and normal durational proportions, word/phrase and phone/word ratios were computed. The durational ratios are reported in Table 2. An analysis of these data indicates that the word/phrase durational proportion for /pɝmIt/ was .33 for the normal speakers and was .44 for the apraxic subjects. The apraxics took proportionately longer than the normal speakers to produce the target word in the phrase for the context /pɝmIt/. However, word/phrase durations were .29 and .31 for the normal and apraxic speakers, respectively, for /pɚmIt/.

Phone/word ratios for /ɝ/, /m/ and /I/ for the normal speakers were .38, .19, and .24, respectively. The same measures for apraxic speakers were .35, .22, and .22. The proportions .38 and .35, .19 and .22, and .24 and .22 for /ɝ/, /m/, and /I/, respectively, are approximately equal for the two groups. Similarly, phone//pɚmIt/ measures were .23, .21, and .38 for /ɚ/, /m/, and /I/ for the normal speakers and .23, .22, and .35 for the apraxic speakers. The proportions .23 and .23, .21 and .22, and .38 and .35 are comparable for normal and apraxic subjects for /ɚ/, /m/, and /I/, respectively.

Although apraxic speakers had longer segment durations than normal speakers, they did not appear to have different relative durations from normal speakers. However, apraxic speakers took proportionately more time than normals to produce /pɝmIt/ in the phrase "My /pɝmIt/ please."

TABLE 2. Durational ratios for normal and apraxic subjects for "permit" at normal and at fast rates.

Proportion	Normal Speakers (N=5)	Apraxic Speakers (N=10)
Normal Rate		
/pɝmIt//phrase	.33	.44
/ɝ//word	.38	.35
/m//word	.19	.22
/I//word	.24	.22
/pɚmIt//phrase	.29	.31
/ɚ//word	.23	.23
/m//word	.21	.22
/I//word	.38	.35
Fast Rate		
/pɝmIt//phrase	.32	.40
/ɝ//word	.36	.36
/m//word	.21	.23
/I//word	.24	.25
/pɚmIt//phrase	.29	.36
/ɚ//word	.22	.21
/m//word	.22	.22
/I//word	.41	.35

Fast Rate

Normal speakers. Group means and standard deviations are reported in Table 1. The overall mean durations (ms) for the five normal speakers for /pɝmIt/ were 103.2 (/ɝ/), 58.7 (/m/), 67.2 (/I/), 285.0 (word), and 889.3 (phrase). Durational ranges (ms) were phrase: 732.4-1029.2, word: 270.4-313.0, /ɝ/: 95.8-113.6, /m/: 39.8-78.6, and /I/: 55.2-75.6. Durations for /pɚmIt/ for the phrase and word were 939.0 and 267.9 ms, respectively, and were 59.4, 58.1, and 110.0 ms for /ɚ/, /m/, and /I/, respectively. Ranges (ms) were: phrase: 811.4-1076.6, word: 210.6-307.2, /ɚ/: 45.0-75.8, /m/: 38.6-71.4, and /I/: 80.2-140.2.

An analysis of Figure 3 demonstrates that, as a group, normal subjects did indeed produce all words at the fast rate in less time than those produced at the normal rate. Similarly, Figure 4 illustrates that phrases at the fast rate were shorter than at normal rate, and Figure 5 shows that the individual phones were shorter at the faster than at the normal rate. On the average, normal adult speakers did indeed spend less time on each phrase, word, and phone when asked to produce the sequences at a faster rate.

Inspection of Appendix B indicates that there were some individual durational differences for all segments. For example, S 15 took longer to say both phrases at the faster rate and S 12 took more time to say "My /pɝmIt/ please" at the faster rate than at the normal rate.

Durational ratios were computed for the fast rate condition (Table 2). An analysis of these data indicates that the word/phrase duration for /p3^mIt/ was .32 for the fast rate condition and .33 at the normal rate. Phone/word ratios for /p3^mIt/ were .36, .21, and .24 for /3^/, /m/ and /I/, respectively at the fast rate. Recall that the same proportions were .38, .19, and .24 at the normal rate. Every proportion was approximately equal at both rates. The same was true for /pə^mIt/. Word/phrase duration was .29 at both rates. Phone/word ratios were .22 (/ə^/), .22 (/m/), and .41 (/I/) at the fast rate and .23, .21, and .38 for the same proportions at the normal rate.

Since the proportions were similar at both rates, it appears that all segments were shortened similarly. Not only did most normal subjects produce these sequences at a faster rate upon request, they talked proportionately faster. That is, they spent a similar relative amount of time on each segment, regardless of speaking rate. The subjects made similar durational changes for the two stress conditions spoken at normal and at fast rates.

Apraxic speakers. Group means and standard deviations for the apraxic speakers are reported in Table 1 (p. 28). The mean durations (ms) for /p3^mIt/ were 182.6 (/3^/), 117.2 (/m/), 127.2 (/I/), 504.4 (word), and 1269.2 (phrase). Durational ranges were: phrase: 1056.0-1560.0, word: 408.8-770.0, /3^/: 135.0-262.0, /m/: 62.8-176.0, and /I/: 88.4-186.0. S 4 did not produce the target word correctly and Ss 6, 8, 9, and 10 did not produce the entire phrase without error. Thus, mean word and phone durations were based on nine measures and mean phrase duration was obtained from five measures.

Mean durational measures (ms) for /pə^mIt/ were 117.4, 121.6, and 196.3 for /ə^/, /m/, and /I/ respectively. Word duration was

563.4 ms and phrase duration was 1566.1 ms. Durational ranges (ms) were: phrase: 876.0-2519.3, word: 444.8-1214.5, /ɚ/: 70.8-239.0, /m/: 82.8-176.0, and /I/: 152.4-338.0. Ss 4, 6, and 10 did not produce the target phrase correctly; therefore, mean phrase duration was based on the values of the other seven apraxic speakers.

From Table 1 (p. 28) it can be seen that apraxic speakers had longer mean durations than normal subjects for all phrases, words, and phones. Recall that /ɝ/ was the longest phone in /pɝmIt/ for normal subjects, followed by /I/ and /m/, respectively. Figure 2 (p. 30) illustrates the same was true for the apraxic subjects as a group. For the context /pɚmIt/, /I/ was the longest phone while /ɚ/ and /m/ had similar durations for both groups of speakers except that apraxics' durations were longer.

As might be expected, there was greater individual subject variation in the apraxic speakers during the production of the fast sequences. Although six of the ten apraxic subjects had similar durational patterns as the normal speakers when asked to increase speaking rate, four subjects did not. S 4 never did produce /pɝmIt/ at a fast rate and her durations for /pɚmIt/ did not parallel those of the majority of apraxic speakers. The longest phone was /I/ (198.0 ms), but /ɚ/ (112.0 ms) was approximately 30 ms shorter than /m/ (146.7 ms). S 8 and S 9 did not follow the general durational trends of the other eleven apraxic and normal subjects for either utterance spoken at a rapid rate. For both subjects, /m/ in /pɝmIt/ was longest, followed by /ɝ/ and /I/. For /pɚmIt/, /I/ was the longest, followed by /ɚ/ and /I/ again for both speakers. The phone durations of S 3 paralleled those of the six apraxic and five normal subjects for /pɚmIt/ spoken at the fast rate; however, they diverged from that pattern when saying /pɝmIt/ at the fast rate. While /ɝ/ (186.0 ms) was the longest phone, /m/ (150.7 ms) was almost 40 ms longer than /I/ (114.0 ms). Despite these individual subject variations six of the apraxic subjects had similar, though longer, durational patterns as the normal subjects.

Overall means for the ten apraxic speakers are reported and discussed because individual phone, word, and phrase durations did not differ and because including the data of the four subjects who did not consistently follow the normal trend did not skew the results. An analysis of Figure 3 (p. 31) reveals that the overall mean duration of /pɝmIt/ decreased at the faster rate (504.4 ms) from 568.3 ms at the normal rate. However, the duration of /pɚmIt/ (563.4 ms) increased slightly at the faster rate. The value at the normal rate was 557.9 ms.

Mean duration of both phrases decreased at the faster rate (Figure 4, p. 32). Duration of "My /pɝmIt/ please" was 1288.4 ms at the normal rate and decreased slightly at the faster rate (1269.2 ms). Phrase duration for /pɚmIt/ was 1775.2 at the normal rate and was 1566.1 ms at the faster rate.

An analysis of Figure 5 reveals that mean phone duration decreased slightly for some contexts produced at the faster rate. Mean duration of /ɝ/ (199.3 ms--normal, 182.6 ms--fast) and /m/ (123.3 ms--normal, 117.2 ms--fast) decreased at the fast rate. However, mean duration

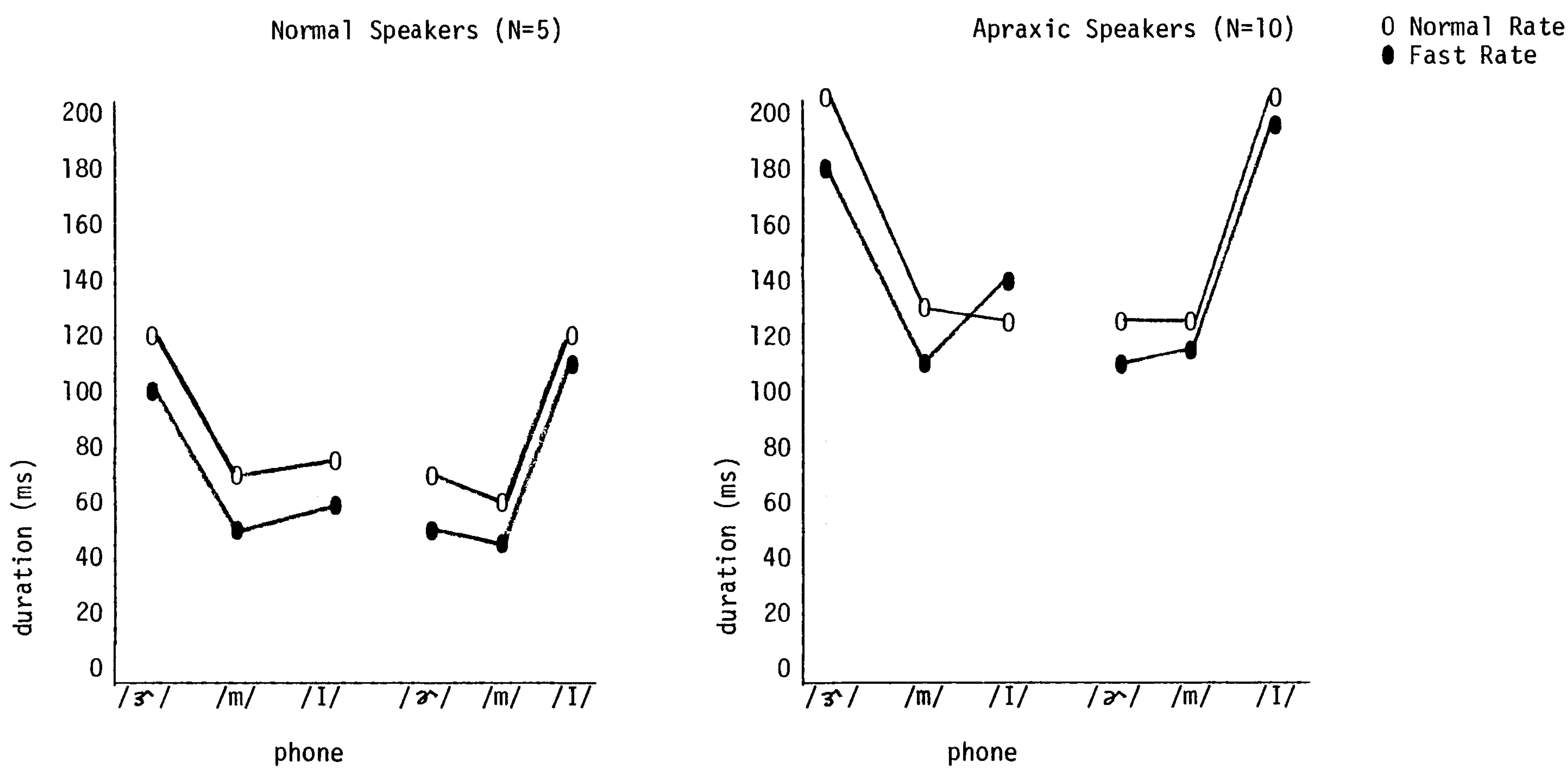

Figure 5. Mean phone duration of both stress and rate conditions of "permit" for apraxic and normal speakers.

of /I/ (125.3 ms--normal, 172.2 ms--fast) slightly increased at the faster rate. For /pɚmIt/, overall duration of /ɚ/ decreased from 129.8 to 117.4 ms and duration of /m/ decreased slightly from 124.5 to 121.6 ms for the normal and fast rates. The length of /I/ remained approximately the same (normal--196.7 ms, fast--196.3 ms). Many of the phone durations were approximately equal at the normal and fast rates.

Not only did apraxic speakers as a group have difficulty producing a faster speaking rate, there was considerable individual overlap among phrase, word, and phone duration for the two rates for individual apraxic speakers. For example, an analysis of Appendix B, Tables B-1 and B-2 indicates that S 2's phrase duration of /pɝmIt/ was longer at the faster (1313.2 ms) than at the normal (1194.4 ms) rate. The same was true for all other apraxic speakers for different phrases, words, and phones and for both stress conditions of "permit."

Recall that the values in Appendix B are means and most are based on five measures of the same utterances (exceptions are noted). For all apraxic speakers, individual (as opposed to mean) segment durations at the faster rate often were longer than at the normal rate. Productions at the normal rate frequently took less time than those at the faster rate. Some overall mean segment durations were longer at the faster rate. The same was true for individual productions by individual speakers. There was considerable durational overlap between the two rate conditions produced by apraxic speakers.

To further compare segment durations, durational proportions were computed for the fast rate condition and are reported in Table 2. Word/

phrase duration for /pɝmIt/ was .40 for the fast rate condition and .44 at the normal rate. At the fast rate, phone/word ratios for /pɝmIt/ were .36, .23, and .25 for /ɝ/, /m/, and /I/, respectively. The same proportions at the normal rate were .35, .22, and .22. For /pɚmIt/, word/phrase duration was .36 at the faster rate and .31 at the normal rate. Phone/word ratios were .21, .22, and .35 for /ɚ/, /m/, and /I/, respectively, at the fast rate and were .23, .22, and .35 for the same phones at the normal rate. All of the proportions were approximately equal at both rates, although the apraxic speakers had considerable durational overlap between rate conditions. Thus, this division between different rates may be meaningless. However, as a group, the apraxic subjects made similar durational changes for the two stress conditions spoken at normal and at fast rates.

Perpit

Normal Rate

Normal speakers. Group means and standard deviations for the normal speakers are reported in Table 3. The mean durations for the normal speakers for /ɝ/, /p/, and /I/ in the phrase "My /pɝpIt/ please" were 127.8, 75.1, and 67.9, respectively. Durations were 323.9 ms for the word and 983.6 ms for the entire phrase. Durational ranges (ms) were: phrase: 841.4-1087.8, word: 253.6-455.8, /ɝ/: 106.6.-171.0, /p/: 51.0-106.6, and /I/: 34.0-102.2. The mean durational measures (ms) for /pɚpIt/ were 76.2, 102.1, and 104.8 for /ɚ/, /p/, and /I/, respectively, and 342.2 for the word and

TABLE 3. Mean duration (ms) and standard deviation of "My perpit please" spoken with different stress patterns at normal and fast rates by normal and apraxic speakers.

	Normal Rate										Fast Rate									
	/pɝpɪt/					/pɚpɪt/					/pɝpɪt/					/pɚpɪt/				
Normal N=5	phrase	word	/ɝ/	/p/	/ɪ/	phrase	word	/ɚ/	/p/	/ɪ/	phrase	word	/ɝ/	/p/	/ɪ/	phrase	word	/ɚ/	/p/	/ɪ/
$\bar{X}$	983.6	323.9	127.8	75.1	67.9	1067.8	342.2	76.2	102.1	104.8	901.5	295.6	120.3	65.7	63.1	956.9	305.7	67.5	79.0	109.5
SD	101.7	81.2	26.7	22.9	28.2	153.4	47.2	13.3	29.9	31.3	133.5	86.9	20.1	23.6	18.2	178.5	59.5	15.2	25.5	22.4
Apraxic N=10	phrase	word	/ɝ/	/p/	/ɪ/	phrase	word	/ɚ/	/p/	/ɪ/	phrase	word	/ɝ/	/p/	/ɪ/	phrase	word	/ɚ/	/p/	/ɪ/
$\bar{X}$	1839.6	835.5	236.3	340.1	143.8	1968.1	653.4	151.6	202.2	181.7	1670.5	557.4	205.9	122.1	124.6	1273.6	647.3	141.1	190.4	184.6
SD	883.1	747.0	129.1	537.4	51.2	941.6	231.4	54.3	106.3	49.4	764.5	140.1	32.9	47.7	29.6	211.3	307.4	64.9	131.8	48.6

1067.8 for the phrase. Ranges (ms) were: phrase: 871.0-1245.6, word: 289.4-392.0, /ɚ/: 61.0-90.0, /p/: 54.0-131.6, and /I/: 53.4-134.4.

As expected, /ɝ/ (127.8 ms) was longer than /ɚ/ (76.2 ms) and stressed /I/ (104.8 ms) was longer than unstressed /I/ (67.9 ms) (Figure 6). Duration of /p/ was approximately 25 ms longer when the second syllable was stressed. Individual subject variation and standard deviations were greater for the nonsense syllables than with the "permit" contexts. Figure 3 (p. 31) shows that /pɚpIt/ was longer than /pɝpIt/ and Figure 4 (p. 32) illustrates that the phrase containing /pɚpIt/ was longer than that of /pɝpIt/.

Apraxic speakers. A general observation of apraxics' utterances revealed that the speakers sometimes substituted words (i.e., perfect, paper, paper dolls) when asked to repeat the nonsense syllables. Recall that utterances with incorrect articulation or stress were not analyzed in this investigation.

For the ten apraxic speakers, average durations (ms) of /ɝ/, /p/, and /I/ were 236.3, 340.1, and 143.8, respectively, and were 835.5 and 1839.6 for the word and phrase, respectively (Table 3). Ranges (ms) were: phrase: 1134.4-3586.8, word: 380.4-2866.0, /ɝ/: 160.0-578.0, /p/: 69.2-1836.0, and /I/: 79.6-239.2. Durations (ms) for comparable measures of /pɚpIt/ were 151.6, 202.2, and 181.7 for /ɚ/, /p/, and /I/, respectively. Word duration was 653.4 ms and phrase duration was 1968.1 ms. Ranges (ms) were phrase: 1068.4-3425.0, word: 432.0-1127.0, /ɚ/: 77.0-246.5, /p/: 93.6-350.0, and /I/: 108.5-285.5. Subjects 4, 6, and 10

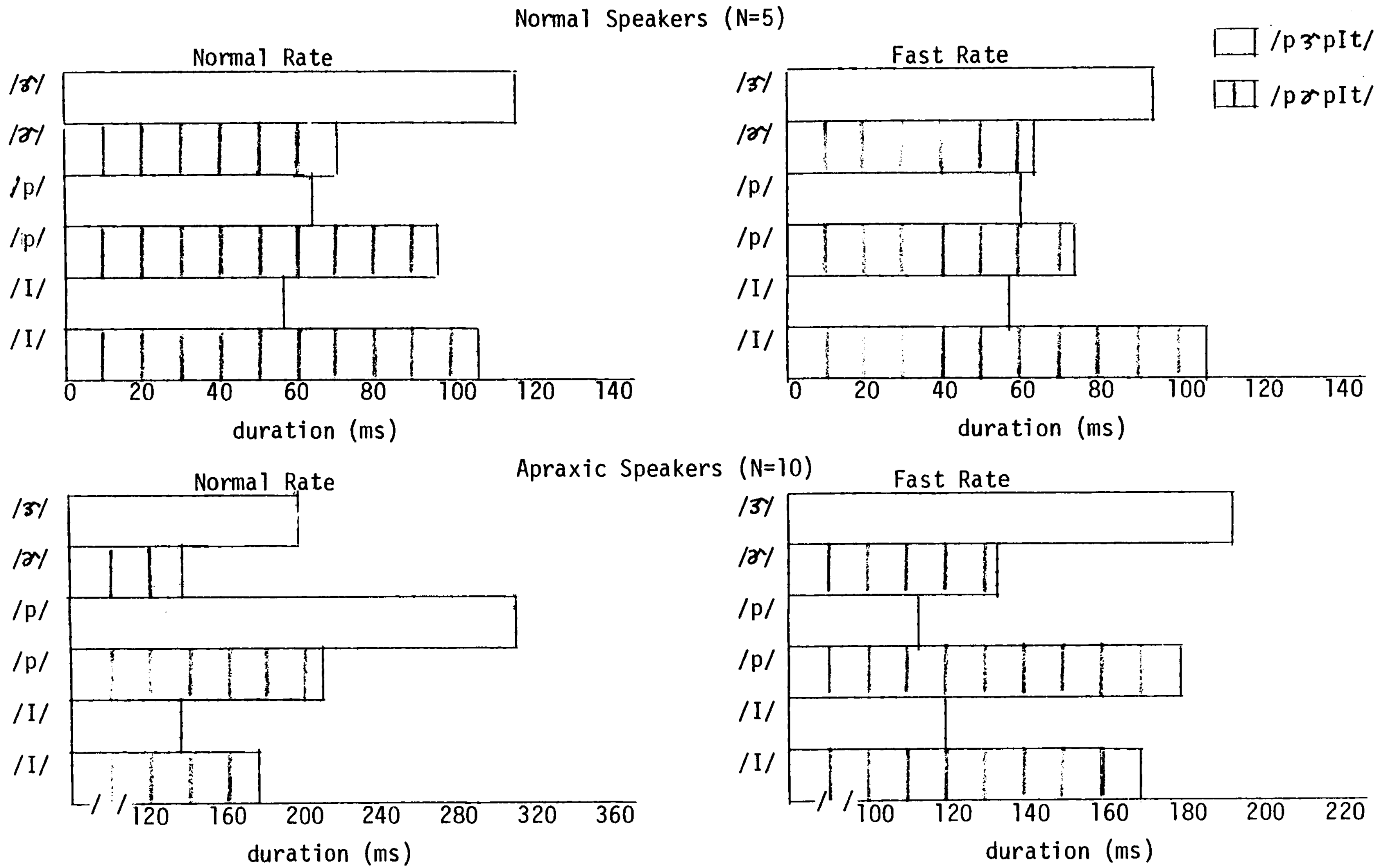

Figure 6. Mean phone duration of the two stress conditions of "perpit" for normal and apraxic speakers at normal and fast rates.

did not correctly produce either phrase. Thus, mean phrase duration was based upon the other seven apraxic subjects.

As was true for the normal subjects, /ɝ/ (236.3 ms) was longer than /ɚ/ (151.6 ms) and stressed /I/ (181.7 ms) was longer than unstressed /I/ (143.8 ms) (Figure 6). Duration of /p/ was over 125 ms longer when the first syllable was stressed, which is opposite of what occurs in normal speakers. The long duration of /p/ in /pɝpIt/, which is illustrated in Figure 7, is at least partially attributable to a lengthy pause between /ɝ/ and /p/ For the apraxic, as with the normal speakers, the standard deviations generally were greater during the production of the nonsense syllables than of the words.

As in the production of the words, apraxic segment durations for the nonsense syllables were longer than those of the normal speakers. Analysis of Table 3 and Figure 3 (p. 31), Figure 4 (p. 32) and Figure 7 indicates that phrase, word, and phone durations for the apraxic subjects were longer than those of normal subjects.

Furthermore, the proportional segment to segment durations were not similar for the normal and apraxic subjects for the production of /pɝpIt/ at the normal rate (Table 4). The word/phrase duration ratios were .33 for the normal and .45 for the apraxic subjects. Phone/word ratios for /ɝ/, /p/, and /I/ were .39, .23, and .21, respectively for the normal and .28, .41, and .17, respectively, for the apraxic speakers. The apraxic speakers spent proportionately less time on the stressed vowel and more time on the consonant for

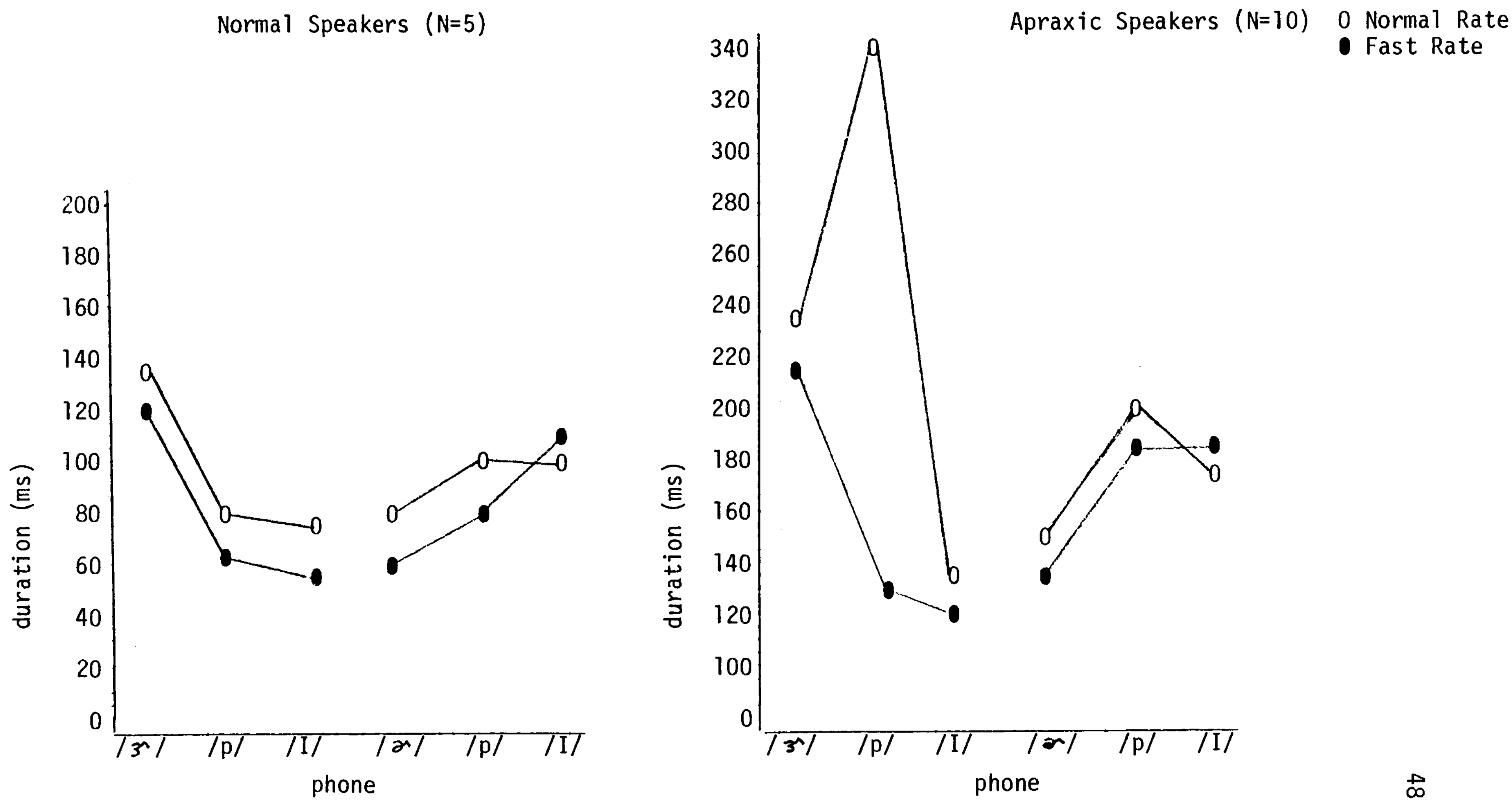

Figure 7. Mean phone duration of both stress and rate conditions of "perpit."

TABLE 4. Durational ratios for normal and apraxic subjects for "perpit" at normal and at fast rates.

Proportion	Normal Subjects (N=5)	Apraxic Subjects (N=10)
Normal Rate		
/pɝpIt//phrase	.33	.45
/ɝ//word	.39	.28
/p//word	.23	.41
/I//word	.21	.17
/pɚpIt//phrase	.32	.33
/ɚ//word	.22	.23
/p//word	.30	.31
/I//word	.31	.28
Fast Rate		
/pɝpIt//phrase	.33	.33
/ɝ//word	.41	.37
/p//word	.22	.22
/I//word	.21	.22
/pɚpIt//phrase	.32	.51
/ɚ//word	.22	.22
/p//word	.26	.29
/I//word	.36	.29

/pɝpIt/. However, the proportions for /pɚpIt/ were very similar for the normal and apraxic speakers. Phone/word durations for the normal subjects for /ɚ/, /p/, and /I/ were .22, .30, and .31, respectively and were .23, .31, and .28, respectively, for the apraxic speakers.

Fast Rate

Normal speakers. Group means and standard deviations are reported in Table 3. The mean durations (ms) of /pɝpIt/ were 901.5 (phrase), 295.6 (word), 120.3 (/ɝ/), 65.7 (/p/), and 63.1 (/I/). Durational ranges (ms) were: phrase: 782.6-1101.8, word: 224.2-444.2, /ɝ/: 95.6-148.6, /p/: 48.4-106.0, /I/: 43.4-89.4. Durations (ms) for /pɚpIt/ were 956.9 for the phrase, 305.7 for the word, and 67.5, 79.0, and 109.5 for /ɚ/, /p/, and /I/, respectively. Ranges (ms) were: phrase: 665.2-1134.8, word: 229.8-390.6, /ɚ/: 52.2-87.0, /p/: 42.0-103.2, and /I/: 74.4-129.6.

Analysis of Figure 3 (p. 31) and Figure 4 (p. 32) reveals that /pɝpIt/ duration at the faster rate was shorter than at the normal rate in both phrases and words. The same was true for /pɚpIt/. Figure 7 contains a graphic comparison of phone duration between rates. With the exception of /I/ in /pɚpIt/, the normal subjects had similar relative durations for phones, but segment durations were shorter in the fast rate condition. That is, /ɝ/ (120.3 ms) was the longest phone while /p/ (65.7 ms) and /I/ (63.1 ms) were approximately the same length. For /pɚpIt/, /I/ (109.5 ms) was the longest, followed by /p/ (79.0 ms) and /ɚ/ (67.5 ms). The mean duration of /I/ in /pɚpIt/ was 5 ms longer in the fast rate

(109.5 ms) than in the normal rate (104.8 ms) conditions.

A single normal subject did not follow the durational patterns of the group. On the average, S 12 took longer to say both contexts at the fast rate than at the slow rate. Recall that S 12 also took more time to say "My /pɝmIt/ please" at the faster rate. In four of the five normal subjects, it appears that normal speakers made rate changes upon request. As was true for the normal rate condition, individual subject variation was greater for "perpit" than for "permit."

Durational proportions are reported in Table 4. The word/phrase durations for /pɝpIt/ were .33 for both the normal and fast rates. Phone/word ratios for /pɝpIt/ were .41 (/ɝ/), .22 (/p/), and .21 (/I/) at the fast rate. The same proportions at the normal rate were .39, .23, and .21. Word/phrase durations were .32 for /pɚpIt/ at both rates. Phone/word ratios were .22, .26, and .36 for /ɚ/, /p/, and /I/, respectively, at the fast rate. The proportions were approximately equal at both rates.

Comparing duration ratios for normal and fast rates, for most phones the rate changes were proportional. The normal subjects seemed to make similar changes in duration for both stress conditions at both rates. As with the meaningful contexts, it appears that normal subjects made similar durational changes for the stress conditions at both rates. An analysis of Figure 3 (p. 31) and Figure 4 (p. 32) indicates the word and phrase durations of /pɚpIt/ were longer than for /pɝpIt/, which is comparable to /pɚmIt/ being longer than /pɝmIt/.

Apraxic speakers. Durational data are presented in Table 3 (p. 44). The mean durations (ms) for /pɝpIt/ were 205.9 (/ɝ/), 122.1 (/p/), 124.6 (/I/), 557.4 (word), and 1670.5 (phrase). Ranges of duration were: phrase: 945.2-2863.3, word: 395.6-762.0, /ɝ/: 176.8-267.6, /p/: 56.4-201.0, and /I/: 85.2-189.5. Ss 4 and 6 did not produce the word correctly and Ss 7 and 9 did not produce the phrase correctly. Therefore, mean word and phone durations were based on eight measures and mean phrase duration was computed with six values.

Mean durational measures (ms) for /pɚpIt/ were 141.1, 190.4, and 184.6 for /ɚ/, /p/, and /I/, respectively. Word duration was 647.3 and total phrase duration was 1273.6. Durational ranges (ms) were: phrase: 1007.2-1518.5, word: 413.6-1240.0, /ɚ/: 84.8-171.6, /p/: 86.0-442.5, and /I/: 113.6-268.0. S 8 did not produce /pɚpIt/ correctly and Ss 4, 9, and 10 did not produce the phrase without error. Thus word mean duration was computed with nine values and mean phrase duration was based on six values.

As with normal subjects, individual subject variation increased with an increase in speaking rate. However, Figure 4 (p. 32) illustrates that when apraxic subjects were asked to increase their speaking rate, there was a decrease in overall mean phrase duration for all speakers who produced the phrases correctly. Phrase durations of /pɝpIt/ and /pɚpIt/ were 1839.6 and 1968.1 ms, respectively at the normal rate and 1670.5 and 1273.6, respectively, at the fast rate.

Similarly, there was a decrease in word duration at the faster rate for /p3˞pIt/. Duration of /p3˞pIt/ was 835.5 ms at the normal and 557.4 ms at the fast rate. However, duration of /pə˞pIt/ remained approximately equal for both rate conditions. Duration of /pə˞pIt/ was 653.4 ms at the normal and 647.3 at the faster rate.

Analysis of Figure 7 demonstrates that the decrease in speaking rate extended to phones, and applied to all phones except the /I/ in /pə˞pIt/. This exception also was true for the normal speakers. Phone durations for apraxic speakers for /p3˞pIt/ at the faster rate for /3˞/, /p/, and /I/ were 205.9, 122.1, and 124.6 ms, respectively. The same measures at the normal rate were 236.3, 340.1, and 143.8 ms, respectively. Fast rate measures for /pə˞pIt/ were 141.1, 190.4, and 184.6 ms for /ə˞/, /p/, and /I/, respectively. Normal rate durations for the same phones were 151.6, 202.2, and 181.7 ms, respectively.

However, closer inspection of mean durations of individual utterances (Appendix B,Tables B-3 and B-4) reveals that apraxic speakers may not change speaking rate upon request. S 2's phrase duration of /pə˞pIt/ was longer at the faster (1492.4 ms) than at the normal (1487.6 ms) rate. The same is true for other apraxic speakers for words and phones and for both stress conditions for "perpit." For all apraxic speakers, segment durations at the fast rate often were longer than at the normal rate. Productions at the normal rate frequently took less time than the same segments at the faster rate.

Durational proportions are located in Table 4. Word/phrase duration for /pɝpIt/ was .33 at the fast rate and .45 at the normal rate. At the fast rate, phone/word ratios for /pɝpIt/ were .37, .22, and .22 for /ɝ/, /p/, and /I/, respectively. The same proportions at the normal rate were .28, .41, and .17. None of these proportions are similar. Word/phrase duration of /pɚpIt/ was .51 at the fast rate and .33 at the normal rate. These measures are not similar, yet the phone/word durations for /pɚpIt/ are approximately equal. Ratios were .22, .29, and .29 for /ɚ/, /p/, and /I/, respectively at the fast rate and were .23, .31, and .28 for the same measures at the fast rate. The context /pɝpIt/ was the only target stimulus for which the subjects did not have similar durations. Yet for permit and for /pɚpIt/, apraxic subjects had similar durational changes at normal and at fast rates.

Summary of Results

Permit

1. For normal and apraxic speakers, mean duration of stressed vowels was longer than their unstressed counterparts.

2. Phone duration in apraxic speakers was longer than in normal subjects.

3. Phone/word durational ratios were similar for apraxic and for normal speakers.

4. Normal subjects decreased phrase, word, and phone duration when asked to speak at a faster rate.

5. Individual apraxic speakers did not consistently decrease

phrase, word, or phone duration when asked to speak at a faster rate.

Perpit

6. For both groups of speakers, there was greater durational variability in the production of nonsense syllables than in words.

7. For both groups of speakers, mean duration of stressed vowels was longer than their unstressed counterparts.

8. Phone duration in apraxic speakers was longer than in normal subjects.

9. Phone//pɝpIt/ durational ratios differed for apraxic and for normal speakers.

10. Phone//pɚpIt/ durational ratios were similar for apraxic and for normal speakers.

11. Normal speakers decreased phrase, word, and phone durations when asked to speak at a faster rate.

12. Individual apraxic speakers did not consistently decrease phrase, word, and phone durations when asked to speak at a faster rate.

CHAPTER IV

DISCUSSION

Duration

Normal Speakers

Normal Rate

Mean phrase, word, and phone durations were obtained for the five normal speakers for "My permit please" and "My perpit please." Although there are no previous data to which the durations for "perpit" can be compared, the phrase, word, and phone durational measures for "perpit" were similar to the measures for "permit." The phone durations (ms) obtained in this study for /pɝmIt/ for /ɝ/ (118.9 ms), /m/(60.2 ms), and /I/ (76.3 ms) were comparable to those obtained by Fry (1955) who reported the following durations for /ɝ/, /m/ and /I/: 120, 80 and 90 ms, respectively. Similarly, the measures for /pɚmIt/ in this study were 70.7, 62.3, and 114.2 for /ɚ/, /m/, and /I/, respectively, while the same measures reported by Fry were 60, 80, and 120 ms, respectively. Thus, phone durations for the two studies also were comparable for /pɚmIt/. However, the total word durations obtained in this study were more than 200 ms shorter than those of Fry. Fry reported that mean word durations of both stress conditions were 580 ms. Recall that word durations in this study were 315 and 303 ms for /pɝmIt/ and /pɚmIt/, respectively.

The most logical explanation for the difference in word duration between the two studies is that different acoustic definitions of word boundaries were used. The measurement techniques in this study were defined in the procedures and a representative sample is shown in Figure 1 (p. 24). Definitions of phone boundaries were not reported by Fry. Since /p/ and /t/ are plosives and have a build up of intraoral pressure and a burst of energy that follows, acoustic definitions of when the phones begin and end are crucial for accurate and reliable measurements.

Another possible explanation for the differences in word duration between the two studies is that different utterances were used. Specific phrases produced in the Fry study were not reported, but longer utterances have shorter phone durations than shorter utterances (Lehiste, 1972). However, if Fry's utterances were longer than those used in the present study, then this explanation would not apply. It seems likely that the different stimuli influenced the durational measures because phrase lengths may have differed.

A third possible explanation for the differences in word duration is that the manner of eliciting responses differed between the two studies. Subjects read sentences in the Fry study while stimuli in this study were repeated in a carrier phrase. It is possible that reading proficiency negatively influenced speaking rate in the Fry study by causing subjects to speak more slowly. It is also possible that the speaking rate of the examiner in this investigation affected the subject's rate of speaking. Perhaps the subjects attempted to imitate the examiner's speaking rate, thus speaking more rapidly. This explanation seems unlikely because durations of /ɝ/, /ɚ/, and both contexts of /m/ and /I/ were comparable between the two studies.

A less likely explanation for why word durations were different is that measurement techniques also differed between the two studies. Fry's measurements were obtained from spectrograms while durational measures in this study were made from oscillograms. It appears doubtful that the different measurement techniques accounted for differing word durations because duration can be measured directly using either method and because phone durations were comparable between the two studies.

Comparing the two stress conditions of "permit" and "perpit," the normal speakers in this study had longer vowel durations during the productions of "permit" and "perpit," the phone /ɝ/ was longer than /ɚ/, /m/ and /p/ were approximately the same length for both stress conditions in their respective contexts, and /I/ in /pɚmIt/ or /pɚpIt/ was longer than /I/ in /pɝmIt/ or /pɝpIt/. These results are not unexpected since stressed vowels are longer than unstressed vowels and vowel duration is the acoustic correlate most closely associated with syllabic stress (Fry, 1955; Gay, 1978; Nakatani and Aston, 1978).

Fast Rate

The normal subjects produced all segments more quickly at the fast rate than at the normal rate. The speakers spent less time on each phone, word, and phrase when asked to produce the sequence at the faster rate. These results are consistent with those of Gay (1978) who reported that consonants and vowels and shorter durations when speaking rate was increased. Mean vowel duration in this study was decreased by 4.2 and 15.7 ms, depending on the context.

Gay reported that stressed vowels in the context /p_p/ decreased 20 to 30 ms at the fast rate.

Durational ratios were computed for the normal and fast rate conditions. For "permit" and "perpit." every phone/word ratio at the fast rate was within .04 of the same ratio obtained at the normal speaking rate. Thus, the normal speakers systematically and proportionately decreased all segments when speaking at the faster rate.

Apraxic Speakers

Normal Rate

Phone, word, and phrase durations of apraxic speakers were longer than those of normal speakers. This finding is consistent with perceptual reports that apraxics have a slower than normal speaking rate (Johns and Darley, 1970; Darley, Aronson, and Brown, 1975). The finding that apraxic speakers have longer phone durations than normal also is consistent with acoustic data from Colson (1979) and Kent and Rosenbek (in press) who reported that vowel and consonant durations of apraxic subjects were longer than those of normals. However, this observation is inconsistent with acoustic findings of Bauman (1975), DiSimoni and Darley (1977), and Gawle and Duffy (1981). Bauman and Gawle and Duffy reported that apraxics' vowel durations were shorter than those of normals. DiSimoni and Darley observed that consonants produced by apraxic speakers were shorter than consonants produced by normal speakers.

Several possible explanations for the conflicting results among studies may be advanced. The subject criteria, sample sizes, stimuli, and measurement techniques differed among studies. Differences in subject criteria may have a profound effect on the outcome of a study. All of the researchers used traditional criteria to diagnose apraxia (Johns and Darley, 1970; LaPointe and Johns, 1975; Darley, Aronson, and Brown, 1975). However, the concomitant aphasia varied among studies. For example, Kent and Rosenbek (in press) included in their criteria that the subjects did not have Broca's aphasia. Other researchers described varying degrees of aphasia in their subjects (Colson, 1979; Gawle and Duffy, 1981). Colson's subject criteria included mild expressive aphasia and no significant comprehension impairments. The subjects in the Gawle and Duffy study were aphasic patients who showed "clear evidence of apraxia." Fager and Deutsch (1981) did not report the type and severity of coexisting aphasia. In the present study, aphasia was limited to moderate to no detectable comprehension impairment. Thus, there were differences among studies as to the presence, type, and extent of concomitant aphasia. It may be that the apraxic speakers were not homogeneous in all studies because the concomitant aphasia differed in those studies.

Etiology was another subject criterion which varied among studies. The single apraxic subject in the DiSimoni and Darley (1977) study had multiple sclerosis. Subjects in the other studies had suffered cerebrovascular accidents, head injuries, or brain tumors. Subjects in the present study had left hemisphere brain trauma, which included stroke, head injury, and brain tumor. This explanation appears likely to account for some differences among studies because different types of cortical lesions may have similar symptoms (ie: articulation errors, abnormal prosody) and also have different symptoms (ie: unpredictable phone substitutions, shorter or longer phone durations than normal). The differences in subject criteria have an effect on task performance; however, differences in results among studies were not caused by a single difference in subject criteria.

Another possible explanation for differing results among studies is that the sample sizes were extremely small in all of the studies. DiSimoni and Darley reported a case study, Colson (1979) and Gawle and Duffy (1981) had five subjects, Bauman (1975) had six subjects, and Kent and Rosenbek (in press) has seven subjects in their studies. The conflicting durational information is based on a total of 24 speakers whose results were reported previously and on the performance of the ten apraxic speakers in this study. A smaller sample size reduces the chances of obtaining a representative sample. The small sample sizes probably have a significant effect on the results obtained from each investigation, but probably do not entirely explain the differing results among studies.

Another possible explanation for different results among studies is the stimuli. The phonetic environments differed among studies, as did context, meaning, and length of utterance. Subjects in the Bauman (1975) study said, "I will repeat CVC" (a consonant-vowel-consonant syllable), in which the CVC context was a word or a nonsense syllable. The stimuli in the Gawle and Duffy study were six CVC words not embedded within a carrier phrase. Bauman and Gawle and Duffy observed that vowel durations were shorter than normal. Colson's (1979) stimuli were "You will say CVCV," where the CVCV utterance was one of several nonsense syllables. She reported that apraxics had longer vowel and consonant duration than normals. Kent and Rosenbek (in press) used words and phrases and reported that phone durations of apraxic speakers were longer than those of normals. While it is not apparent how each of the differing variables specifically affect the results of an experiment, phonetic environment, context, meaning, and utterance length affect the speaker's production of an utterance. However, it does not appear that these variables systematically affected the results. That is, similar durational results were obtained when stimuli were different and different results were obtained when stimuli were similar. Thus, it is not likely that stimuli alone account for the differences in results among studies.

A less likely explanation of the differing reports of phone duration in apraxic speakers is the use of different measurement techniques. Measurements were obtained primarily from oscillograms for all but the Kent and Rosenbek (in press) study. Kent and Rosenbek performed spectrographic analyses of the utterances obtained in their study. Duration can be measured directly from oscillograms and spectrograms, so it is doubtful that the measurement techniques significantly altered the duration in the studies reported.

Fast Rate

As a group, apraxic speakers did not consistently decrease segment duration at the faster rate. Although overall group means show decreases in segment duration, an examination of individual subject data reveals that individual apraxic subjects may not change speaking rate (Appendix B). For all apraxic speakers, segment durations at the faster rate were often longer than the productions at the normal rate. This finding applied to both the nonsense and the meaningful tasks. The apraxic speakers did not appear to alter consistently and appreciably the durations of phones upon request. Furthermore, all individual apraxic speakers had considerable overlap among segment durations between productions at normal and at fast speaking rates.

Durational ratios were computed for the normal and fast rate conditions. For both contexts of "permit" and for /pɚpIt/, every phone/word ratio at the fast rate was with in .05 of the same ratio at the apraxic's normal speaking rate. If there were no differences between the normal and fast rate conditions, it would be expected that the duration ratios would be similar for both speaking rates.

Maximum speaking rate is at least partially determined by the physiological capacity of the speech mechanism. The speech mechanism includes the articulators and the neural prerequisities for speech. Since one of the subject criteria was "no discernible dysarthria," it may be assumed within the limitations of the assessment that the articulators of the subjects were not themselves deficient.

Since structure and function of the articulators were intact, since the subjects had experienced brain damage, and since the apraxic speakers did not increase their speaking rate when asked, the apraxic subjects may not have been able to increase speaking rate. Since the articulators were intact, it seems that articulatory programming was involved rather than the articulators themselves. The apraxic subjects may not have increased their speaking rate because they already were talking as fast as possible. This speculation seems probable and parallels that of DiSimoni and Darley (1977) who suggested that speaking rate is slower in apraxic speakers because "the articulatory mechanism is driven near its limit of speed of articulation" (p. 263). If apraxic speakers are talking as fast as they can, then acceleration of speaking rate would be impossible.

Another reason why the apraxic subjects did not increase their speaking rate might be that they were attempting to maintain the durational ratios necessary for correct production. That is, the apraxic speakers may have been attempting to control their rate of speaking because an increase in speaking rate might result in an increase in articulation or stress errors. They may not have spoken at a faster rate so the relationship among phones would remain constant. The apraxic speakers may have voluntarily maintained their normal speaking rate to reduce the possibility of articulation errors. It is also possible that if the apraxic speakers did increase their speaking rate, then errors of stress and/or articulation occurred, and, thus were not analyzed in this study.

Another possible, but less probable, contributing factor to the lack of apparent reduction in duration when asked to speak more rapidly is an impairment in comprehension. The subject criterion for auditory comprehension was a z-score of 0 or better on the <u>Boston Diagnostic Aphasia Examination</u>. It may be that the apraxic speakers did not differentiate their rate of production for the two rate conditions because they did not understand the difference between normal and fast speaking rates. This seems to be an unlikely explanation because of the relatively stringent comprehension criterion which was included to minimize the possibility that the subjects would not understand the task. Nonetheless, comprehension is a factor which may contribute to the overlap of segment duration between speaking rates.

Comparisons Between Normal and Apraxic Speakers

<u>Stress</u>

Although absolute segment durations were longer in apraxic than in normal speakers, most apraxic speakers had similar durational trends as the normal subjects. Comparing the two stress conditions of "permit" for both groups of speakers, /ɝ/ was longer than /ɚ/, /m/ was approximately the same length for both stress conditions, and the /I/ in /pɚmIt/ was longer than the /I/ in /p mIt/. The apraxic speakers changed duration, and, thus syllabic stress in utterances perceived to have correct stress patterns and articulation.

Moreover, the apraxic and the normal speakers did not appear to have different relative phone to word durations. The most significant finding of this study was that vowel and consonant to word ratios were within ± .03 of being equal for both subject groups for phone/word durations for productions of "permit" at the normal rate. Although segment durations were longer in apraxic than in normal speakers, durational proportions were similar for the two groups of speakers. Fager and Deutsch (1981) studied phone/syllable duration for apraxic speakers and reported that, based upon C/CV and V/VC proportions, apraxic speakers had durational trends that were similar to those of the normal subjects for most contexts. Actual proportions were not reported so it is not apparent whether the ratios were the same for apraxic and for normal subjects or whether the two groups followed similar trends.

Although ratios of phone/word duration generally were comparable for apraxic and normal speakers, this was not consistently true for word/phrase duration. The word/phrase duration for /pɝmIt/ for the normal speakers was .33, while the same proportion for the apraxic speakers was .44. The ratio for /pɚmIt/ was .29 for the normal and .31 for the apraxic speakers. The apraxics took proportionately longer than the normals to produce the target word within the phrase for /pɝmIt/ and about the same proportional amount of time to produce /pɚmIt/.

Relative speech segment durations were similar between apraxic and normal speakers. The apraxic speakers changed vowel duration relative to word duration for words with different stress patterns.

Furthermore, they maintained the same proportionate medial consonant duration for both stress conditions, just as normal speakers did. Because the apraxic speakers maintained the same phone/word ratios as the normal subjects for both contexts, apraxia may not involve the durational relations among phones. The results of this study indicate that apraxic speakers can systematically change vowel duration with variations in stress. Apraxic speakers seem to have some type of durational control of stress, at least for utterances with perceptually correct articulation and stress.

The literature suggests that apraxic speakers stress syllables evenly (Johns and Darley, 1970; Darley, Aronson, and Brown, 1975; Kent and Rosenbek, in press). However, the apraxic speakers in this study changed stress and proportionately changed phone duration. It may be that the results of this study do not conflict with the perceptual reports of Johns and Darley (1970) and Darley, Aronson, and Brown (1975). It is possible that listeners may or may not perceive stress differences in the speech of apraxics because their phone durations are longer than normal. That is, listeners expect to hear approximately five syllables/second. When one or even less than one syllable is heard in one second, the listener's perception of stress may be disrupted. It is possible that a listener hears stress equalizations, when in fact the speaker produces durational proportions necessary for correct stress perception. Stress equalizations may be heard because the length of the segment is longer than what the listener is accustomed to hearing from normal speakers.

Another possible reason why the duration measures and the perceptual reports appear to conflict is that duration is not the only acoustic correlate of stress. Although duration is the acoustic measure which is most closely associated with stress, amplitude and fundamental frequency also change when stress changes (Fry, 1955; Gay, 1978; Nakatani and Aston, 1978). Apraxic speakers may not change intensity for fundamental frequency when syllabic stress varies. Therefore, durational programming may be intact in verbal apraxia, but intensity and/or frequency may be aberrant, possibly contributing to the perception that stress is equalized in apraxics' speech.

Although the previous explanations for why duration measures and perceptual reports conflict are probable, a more likely possibility is that only correct utterances were analyzed in this study. Utterances with inappropriate stress or articulation were not included in the analysis, so duration was not measured for utterances with equal syllabic stress. Thus, possible instances of equalization of phone duration were excluded from the analysis.

Rate

The apraxic speakers in this study had longer phrase, word, and phone durations than normal speakers at normal and at fast speaking rates. The brain damaged subjects performed the experimental task more slowly than the normal subjects. The apraxic speakers had incurred cortical damage which is the probable cause of the slower speaking rate which affected phone, word, and phrase duration.

Brain damage may result in slower neural processing, and, thus slower task performance. It is likely that the impairment in cortical functioning is responsible for the increase in segment duration which occurred at both speaking rates.

The normal subjects proportionately decrease segment duration when asked to talk at a faster rate, while the apraxic speakers did not. Again, it seems logical that the cortical damage was the probable cause for the apparent lack of change in the speaking rate of the apraxics. Explanations for why apraxic speakers did not appear to change speaking rate were discussed previously.

Meaning

Most durational findings applied to both groups of speakers for the meaningful and nonsense stimuli. There was greater durational variability in the production of nonsense syllables than in words for both apraxic and normal speakers. Fewer apraxic speakers produced the syllables correctly and when the productions of "perpit" were correct in terms of articulation and stress, segment durations were more variable than in the production of words. Apraxic speakers sometimes substituted words for nonsense syllables. They required more trials to produce the nonsense syllables and had fewer correct productions of the nonsense syllables.

It is not surprising that apraxic speakers had more errors and greater durational variation in the production of nonsense syllables than of words. This finding is consistent with that of Wertz (1978) who reported that apraxic speakers have more articulation errors during the production of meaningful than of nonsense stimuli. Like normals, the apraxic speakers simply were less familiar with the nonsense task.

The only exception to the similar durational trends between meaningful and nonsense stimuli was the apraxic group's production of /pɝpIt/ at the normal rate. Since there was a difference in relative durations between apraxic and normal speakers for /pɝpIt/ and not for /pɚpIt/, it may be that apraxic speakers have different durational rules for nonsense syllables than for words. Recall that in both stress conditions of "permit," the apraxic and the normal speakers had similar relative durations. If there is a difference in duration of words and of nonsense syllables, then it appears that the two types of stimuli should not be placed in the same category. That is, the /ɝ/ in /pɝmIt/ may not be comparable to the /ɝ/ in /pɝpIt/ because one stimulus is meaningful and one is not.

However, it is more likely that there is little difference between the production of words and of nonsense syllables for either subject group. It is possible that using different nonsense syllables would provide different results. Although /m/ and /p/ require the same articulators, manner of production is different. One phone is a voiced nasal and the other is a voiceless plosive. The difference in results might be a function of the phonetic sequence. Thus, it may be that the difference between the production of words and of nonsense syllables may be a function of the stimuli. This possibility seems unlikely because the phonetic sequences were the same for both groups of speakers.

It is also possible that the values of /pɝpIt/ for the apraxic speakers were not representative. Since apraxic speakers had greater durational variability than normal subjects, it may be that the durational measures were from a sample which was not representative of the group. This possibility seems likely because the duration ratios for /pɝpIt/ at the fast rate were similar for apraxic and for normal speakers. While it is probable that the values of /pɝpIt/ for the apraxic speakers were not representative, there may be other reasons why the two subject groups differed on that context.

Individual Subject Variation

Apraxic speakers, as a group and as individuals, had similar durational ratios as the normal subjects. Every apraxic speaker produced at least one context and six of the ten apraxic speakers produced both contexts at both speaking rates with similar relative phone durations as the normal speakers. Since six of the ten apraxic speakers had similar phone/word durations for both stress conditions of both contexts at both rates and ten subjects had similar ratios as the normal subjects for at least one context, it is conceivable that there were at least two groups of apraxics in this study.

All of the speakers met the subject criteria, yet the subjects may not have been a homogeneous group. As an attempt to identify possible sources of individual subject variation, several possible differences among subjects were explored. Possible differences among subjects which were investigated further included severity of apraxia, number of articulation errors, severity of the comprehension impairment, etiology, site and extent of lesion, time elapsed since onset, amount of treatment received, degree or severity of concomitant paresis, and age. The comparisons among subject performance and these variables were inconclusive.

The severity of apraxia and the number of articulation errors did not seem to account for individual subject differences. Some speakers with severe apraxia had similar durations as the normal subjects, while others did not. The severity of the comprehension impairment did not appear to distinguish among apraxic speakers. Subjects with the same BDAE auditory comprehension z-scores did not have similar durations. The etiology, site and extent of lesion and time elapsed since the onset of apraxia did not appear to differentiate among the task performances of apraxic speakers.

Other possible factors which might affect subject performance are the amount of treatment received, the degree of severity of concomitant paresis, and the age of the patient. None of these variables appeared to differentiate among task performances. For example, subjects who had different degrees and severities of concomitant paresis had similar durations, while those with similar symptoms of paresis performed differently.

Diadochokinetic rates were obtained at the same time as the tasks for this investigation were performed. These measures are reported in Appendix B, Table B-5. Mean number of syllable repetitions in five seconds for the ten apraxic subjects were 15.67, 17.04, 14.52, and 2.9 for /pʌ/, /tʌ/, /kʌ/, and /pʌtʌkʌ/, respectively. Means for the four subjects (Ss 3, 4, 8, and 9) were 14.5, 16.2, 15.0, and 2.8 for /pʌ/, /tʌ/, /kʌ/, and /pʌtʌkʌ/, respectively. These measures were very similar. Diadochokinetic rates did not appear to differentiate among the possible groups of apraxic subjects.

Finger tapping skills were obtained as a measure of nonspeech motor control. These data are reported in Appendix B, Table B-5. All apraxic speakers except S 7 performed the finger tapping task with their left hands. The mean number of taps in five seconds was 21.43 for all apraxic speakers. The mean number of finger taps for the four subjects who may have differed from the remaining subjects on performance of the experimental task was 23.33 and was 20.17 for the other six apraxic subjects. Analysis of the data in Appendix B, Table B-5 reveals that there was not a systematic change in finger tapping skills with changes in task performance.

Implications for Theory of Apraxia

Kent and Rosenbek (in press) hypothesized that in apraxia of speech, a breakdown occurs in the temporal schemata (time plans of movement) which help to control the sequencing of movements and in the space coordinate system which defines the spatial targets. Assuming temporal schemata can be assessed by measuring proportionate segment durations, the "time plans of movement" for apraxic speakers for phones were produced similar to those of the normal speakers for utterances which were produced correctly. In this study, overall temporal schemata were slower in apraxic than in normal speakers, but relationships among segments were preserved.

The apraxic speakers seemed to program relative speech segment duration in a manner similar to the normal speakers. Yet the mechanism did not seem to perform optimally because there were frequent articulation errors and stress aberrations in the utterances of apraxic speakers which were not analzyed in this study. A revision of the Kent and Rosenbek hypothesis might include a statement that apraxic speakers have a breakdown in the selection of "temporal schemata" which help to control the sequencing of movements. Theoretically, when the appropriate stress pattern is produced, the overall temporal schemata are slower than normal, but the temporal schemata among segments (phones) are preserved. Once the target utterance was "selected" correctly, the apraxic speakers appeared to have little difficulty in producing the normal duration relations among phones.

The finding that apraxic speakers maintain relative durations among phones is in opposition to the speculations of Rosenbek and Wertz (1976; cited in Wertz, 1978). These authors proposed that one characteristic of apraxia of speech was the distortion of durational relationships of vowels and consonants. The results of this experiment support exactly the opposite. In this study the durational relationships among vowels and consonants in two different stress conditions were produced similar to those of the

the normal subjects. It may be that durational ratios were not produced similar to normal in correct utterances. If there is a problem in durational relationships among phones, it seems that those differences might have been apparent in this study because duration was the primary factor which changed between conditions, unless there was durational differences in the incorrect utterances.

It appears that apraxia of speech is not a disorder of the temporal relations among phones. Once the apraxic speakers selects or retrieves the correct temporal and spatial program for a target utternace, it appears that he produces that utterance correctly, at least in terms of stress and articulation. Errors probably occur in the selection or retrieval of the appropriate program for that utterance. Incorrect utterances might occur when the speaker searches for the program for the target utterance. Therefore, apraxia of speech might be a disorder of the selection of the temporal and spatial program for the target utterance.

Limitations of the Study

The findings of this study apply to apraxic speakers within the following constraints of the experiment. First, the results of this study were obtained from subject's repetition of two words and two nonsense syllables which were embedded in a carrier phrase. Durations produced in the experimental task may not be similar to those produced in conversational speech because context, meaning, and utterance length are different in conversation. A second limitation of the study was that only utterances which were perceptually correct were analyzed. Analysis of incorrect utterances would provide different results. Additionally, there were only two contexts produced with two different stress patterns. Other stress contexts (ie: object, contract) might produce different results. A final limitation of this experiment was the small number of apraxic subjects, which decreased the likelihood of obtaining a representative sample.

Suggestions for Future Research

Additional research is needed to investigate more thoroughly the durational characteristics of the speech of apraxic speakers. Discussion of some areas which merit further research follow.

1. In this study, only utterances with correct articulation and stress were analyzed. However, there may be differences in the durational characteristics of utterances perceived to have incorrect stress. It is possible that the durations of incorrect utterances were aberrant, causing perception of stress to be incorrect. Utterances with incorrect stress should be assessed to determine durational relationships among speech segments, especially the phone/word proportions.

2. Although duration is the acoustic correlate most closely associated with stress, intensity and fundamental frequency often change as stress changes. Duration was the only component measured in this investigation. A comparison between apraxic and normal speakers among duration, amplitude, and fundamental frequency will contribute to the understanding of how apraxic speakers change

stress. That is, what acoustic features change when apraxic speakers change stress and do apraxic subjects change the acoustic correlates of stress in the same manner as normal speakers?

3. Additional information about speaking rate and altering speaking rate should be investigated to better understand the ability of apraxic speakers to control stress. It may be beneficial to obtain normal, fast, and slow speaking samples of the same utterances to force the speaking mechanism to perform optimally in order to further assess apraxic speakers' skills in rate control.

4. The apraxic speakers in this study were selected on the basis of relatively stringent subject criteria. Yet is is possible that they may not have been a homogenous group because six of the ten apraxic subjects responded similarly to normal subjects on all tasks, while each of the four remaining apraxic speakers had similar durations for some, but not all tasks. It is possible that there may be more than one group of speakers with verbal apraxia. If there is more than one type of apraxia, then the criteria in this study were not sensitive enough to differentiate between groups. If there is more than one group of apraxic speakers, it is necessary to define factors which distinguish between groups in order to better understand the nature of apraxia and to implement more efficient treatment strategies.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to assess, for subjects with apraxia of speech and for normal speakers, phone durations and patterns of phone duration when syllabic stress, speaking rate, and meaning were varied. Subjects were ten apraxic and five normal speakers. The subjects produced a word (permit) and a nonsense syllable (perpit), both with two different syllabic stress patterns. Utterances were produced in the carrier phrase, "My ______ please" and were spoken at normal and at fast rates. Durational measurements were obtained from oscillographic displays for the following segments: both vowels and the medial consonant in the target word, the target word, and the entire phrase. Only utterances which were perceptually correct in terms of articulations and stress were analyzed.

The apraxic speakers had longer phrase, word, and phone durations than the normal speakers. However, the apraxic speakers maintained the same relative phone/word durations as the normals. These similar durational proportions were observed in consonants and vowels produced in words and in nonsense syllables. Thus, apraxia of speech does not appear to be a disorder of the durational relations among phones. It was hypothesized that apraxia is a disorder in the selection of the correct program for the target utterance.

In comparing the normal and fast speaking rates, the normal speakers proportionately decreased phone, word, and phrase durations at the faster speaking rate. However, there was considerable durational overlap between the normal and the fast rate conditions among apraxic speakers. While it is unclear as to whether the apraxic subjects were speaking at the capacity of their speaking mechanisms, or whether an increase in speaking rate resulted in production errors, it was observed that changing speaking rate was aberrant in apraxic speakers, and, thus is a component of apraxia. Further information is necessary to examine apraxic speakers' skills in rate control.

Most durational findings of the meaningful and nonsense stimuli applied to both apraxic and normal speakers. There was greater durational variability of phones, words, and phrases in the production of nonsense syllables than in words for both speaking groups. The subjects were more familiar with and proficient in the articulation of the meaningful stimuli. Within the limitations of the stimuli, it appears that apraxic and normal speakers have similar durational proportions for meaningful and nonsense stimuli. That is, other than the increase in durational variability, there do not seem to be temporal differences between the production of meaningful and nonsense stimuli.

On the basis of these results, for a similar group of subjects and for perceptually correct utterances, the following conclusions can be made:

1. Phone, word, and phrase durations are longer in apraxic than in normal speakers; relative phone/word durations are preserved

in apraxia of speech; thus, apraxia is not a disorder involving the temporal relations among phones;

2. Apraxic speakers do not consistently alter speaking rate when instructed;

3. Meaningfulness of the stimulus does not affect durational trends; however, durational and articulatory variability is greater for nonsense, than for meaningful stimuli.

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APPENDICES

APPENDIX A

TABLE A-1. Summary of age, sex, BDAE z-score, and time post onset of brain damage for apraxic speakers and age and sex for normal speakers.

Subject	Age	Sex	BDAE z-score	time post onset
Apraxic				
1	66	M	1	20 months
2	58	M	1	18 months
3	59	F	1	14 months
4	67	F	0	14 months
5	70	F	1	9.3 years
6	23	M	.5	8 weeks
7	62	F	1	8 months
8	56	F	1	17 months
9	53	M	1	2.7 years
10	34	F	.5	25 months
Normal				
11	65	F		
12	57	F		
13	53	F		
14	55	M		
15	75	M		

TABLE A-2. Phone duration, mean phone duration, and standard error (ms) for examiner presentations of the target phones for ten subjects.

S	/ɝ/	/m/	/I/	/ɚ/	/m/	/I/	/ɝ/	/p/	/I/	/ɚ/	/p/	/I/
1	118	78	80	69	90	135	122	86	60	59	124	128
3	116	83	69	70	88	119	116	102	84	53	110	132
4	102	75	74	72	87	129	117	120	88	53	123	132
5	114	59	68	72	81	95	125	101	70	56	108	131
6	118	81	82	70	85	114	127	100	71	53	124	120
7	122	73	88	65	82	131	124	78	62	60	109	141
11	119	81	82	62	80	127	118	91	70	65	103	121
13	118	61	81	74	76	115	112	119	68	54	103	121
14	115	67	95	81	70	102	115	86	70	45	103	125
15	113	79	85	61	83	95	136	108	72	47	101	130
$\overline{X}$	115.5	73.7	80.4	69.6	82.2	116.2	121.2	99.1	71.5	54.5	110.8	128.1
SE	5.4	8.6	8.3	5.9	6.0	14.8	7.1	14.1	8.6	5.9	9.4	6.5

APPENDIX B

TABLE B-1. Mean duration and standard deviations (ms) of phrases, words, and phones for five repetitions of "permit" at the normal rate by apraxic speakers.

			Subject 1	2	3	4	5	6	7	8	9	10
Normal Rate												
/pɝmIt/	phrase	$\overline{X}$	1130.4	1194.4	1110.7[b]	-[e]	1418.4	-[e]	1588.0[c]	-[e]	-[e]	-[e]
		SD	114.8	111.7	110.0	-	88.9	-	138.6	-	-	-
	word	$\overline{X}$	408.4	457.2	588.7	570[d]	523.2	547.0[b]	596.0	534.4	568.0[a]	890.4
		SD	27.7	51.3	108.5	-	68.0	24.0	11.3	63.8	105.8	86.7
	/ɝ/	$\overline{X}$	191.6	136.4	282.7	116	175.4	191.3	203.0	149.2	204.5	342.8
		SD	2.6	15.6	17.2	-	24.2	31.4	21.2	30.0	47.6	29.6
	/m/	$\overline{X}$	61.2	92.8	109.3	178	118.4	138.0	112.0	126.4	111.0	186.0
		SD	20.3	26.6	67.0	-	31.4	51.9	31.1	33.9	40.5	16.3
	/I/	$\overline{X}$	133.2	118.0	99.3	124	127.6	155.3	109.0	94.8	104.5	186.8
		SD	34.3	10.3	50.8	-	27.7	6.1	18.4	32.2	23.6	42.9

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-1 (continued)

			Subject 1	2	3	4	5	6	7	8	9	10
Normal Rate												
/pɚmIt/	phrase	$\overline{X}$	1361.0[a]	1442.8	1287.6	-[e]	1629.0	-[e]	1537.5[a]	2317.3[a]	2851.3[b]	-[e]
		SD	50.9	145.8	99.1	-	32.3	-	164.5	132.1	617.4	-
	word	$\overline{X}$	465.0	487.2	524.0	596.7[b]	434.6	437.5[a]	547.5	531.8	580.7	974.0[b]
		SD	23.7	60.8	31.3	18.6	24.3	78.8	59.6	66.0	112.2	90.3
	/ɚ/	$\overline{X}$	135.5	161.6	109.2	132.0	87.8	78.5	137.0	114.5	122.0	220.0
		SD	15.1	26.2	13.3	20.3	21.9	5.7	15.2	45.8	25.2	84.0
	/m/	$\overline{X}$	84.0	77.2	145.8	151.3	111.8	80.5	110.5	108.8	162.3	213.0
		SD	28.6	22.7	35.9	53.1	43.5	25.8	42.5	44.0	11.2	43.2
	/I/	$\overline{X}$	199.5	183.6	140.4	264.0	161.6	157.0	166.5	186.5	174.3	334.0
		SD	16.8	26.9	16.1	15.6	37.0	46.7	12.0	70.7	26.6	43.3

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-2. Mean durations and standard deviations (ms) of phrases, words, and phones for five repetitions of "permit" at the fast rate for apraxic speakers.

			Subject 1	2	3	4	5	6	7	8	9	10
Fast Rate												
/pɝmIt/	phrase	$\overline{X}$	1092.0	1313.2	1056.0[b]	-[e]	1325.0[a]	-[e]	1560.0[d]	-[e]	-[e]	-[e]
		SD	92.0	65.5	142.7	-	132.7	-	-	-	-	-
	word	$\overline{X}$	408.8	429.6	502.7	-[e]	470.8	506.7[b]	424.0	495.8	547.0[a]	770.0[a]
		SD	40.5	48.7	65.0	-	55.3	51.4	-	74.1	120.9	90.7
	/ɝ/	$\overline{X}$	166.0	151.6	186.0	-[e]	178.3	202.0	220.0	142.8	135.0	262.0
		SD	28.5	22.8	74.3	-	35.9	18.3	-	33.8	57.0	15.4
	/m/	$\overline{X}$	62.8	76.4	150.7	-[e]	108.0	101.3	70.0	164.4	145.5	176.0
		SD	21.1	12.6	29.3	-	22.9	28.6	-	34.8	34.3	55.9
	/I/	$\overline{X}$	123.6	135.6	114.0	-[e]	119.8	139.3	118.0	88.4	120.0	186.0
		SD	36.6	45.6	20.3	-	26.9	66.9	-	20.1	22.3	15.9

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-2 (continued)

			Subject 1	2	3	4	5	6	7	8	9	10
Fast Rate												
/pɚmIt/	phrase	$\overline{X}$	1134.7	1323.6	876.0	-[e]	1368.2	-[e]	1306.0	2435.0[b]	2519.3[a]	-[e]
		SD	125.5	64.6	30.9	-	80.4	-	76.6	65.0	263.0	-
	word	$\overline{X}$	481.3	482.4	444.8	510.7[b]	429.0	446.0	457.2	618.3	508.0	1214.5[a]
		SD	35.3	68.4	46.4	59.1	19.1	153.8	27.9	162.4	58.3	65.3
	/ɚ/	$\overline{X}$	138.0	155.2	100.4	112.0	78.2	70.8	76.0	108.3	96.5	239.0
		SD	26.2	29.6	14.8	19.1	14.4	11.8	14.4	25.7	27.5	41.6
	/m/	$\overline{X}$	101.3	90.4	111.2	146.7	82.8	113.2	101.6	166.7	125.8	176.0
		SD	31.9	22.4	28.6	40.4	21.6	40.9	17.4	17.6	34.5	76.8
	/I/	$\overline{X}$	161.3	192.0	152.4	198.0	190.4	166.8	177.6	210.0	176.5	338.0
		SD	13.3	21.8	14.5	34.7	45.5	42.4	47.6	40.9	70.7	62.1

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-3. Mean durations and standard deviations (ms) of five repetitions of phrases, words, and phones for "perpit" at the normal rate for apraxic speakers.

			Subject 1	2	3	4	5	6	7	8	9	10
<u>Normal Rate</u>												
/pɝpIt/	phrase	$\overline{X}$	1255.2	1656.8	1134.4	-[e]	1318.6	-[e]	1487.0[c]	3586.8	2438.3[b]	-[e]
		SD	101.3	46.0	145.5	-	37.1	-	1.4	514.8	149.0	-
	word	$\overline{X}$	427.6	612.8	481.6	2886.0[d]	380.4	564.4	543.0	1044.4	472.7	962.0[c]
		SD	38.4	35.2	17.7	-	28.5	79.1	24.0	334.2	44.6	2.8
	/ɝ/	$\overline{X}$	162.4	250.8	138.8	578.0	160.0	191.2	189.0	249.8	161.3	282.0
		SD	36.6	30.8	21.2	-	24.1	42.4	1.4	70.3	3.1	31.4
	/p/	$\overline{X}$	69.2	110.8	121.6	1836.0	95.4	204.0	172.0	445.6	89.3	257.0
		SD	36.9	38.8	31.0	-	28.0	61.4	84.9	323.8	9.9	9.9
	/I/	$\overline{X}$	122.4	158.8	103.6	148.0	79.6	122.0	131.0	239.2	110.0	223.0
		SD	13.7	25.2	21.7	-	17.3	31.2	55.2	69.7	28.8	75.0

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-3 (continued)

			Subject 1	2	3	4	5	6	7	8	9	10
Normal Rate												
/pɚpIt/	phrase	$\overline{X}$	1312.0[a]	1487.6	1849.3[b]	-[e]	1460.5[a]	-[e]	1068.4	3425.0[d]	3174.0[b]	-[e]
		SD	80.1	102.7	112.2	-	60.7	-	59.6	-	392.6	-
	word	$\overline{X}$	432.0	501.2	592.7	760.5[a]	442.5	534.5[a]	456.4	825.0	862.0	1127.0[a]
		SD	19.9	32.6	22.7	80.3	32.5	50.5	59.2	-	5.2	157.7
	/ɚ/	$\overline{X}$	138.0	169.6	166.7	130.0	77.0	92.5	101.6	215.0	179.3	246.5
		SD	20.8	19.4	20.2	36.5	14.3	41.4	13.6	-	95.5	90.2
	/p/	$\overline{X}$	107.0	93.6	158.0	252.0	121.0	160.0	105.2	350.0	344.0	331.5
		SD	14.3	33.6	6.0	31.5	15.1	50.4	21.7	-	35.0	98.5
	/I/	$\overline{X}$	145.5	189.2	178.7	108.5	184.0	176.0	130.0	220.0	199.3	285.5
		SD	15.0	12.6	21.2	27.0	19.5	27.2	29.8	-	44.1	63.8

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-4. Mean durations and standard deviations (ms) of five repetitions of phrases, words, and phones for "perpit" at the fast rate for apraxic speakers.

			Subject 1	2	3	4	5	6	7	8	9	10
Fast Rate												
/pɝpIt/	phrase	$\overline{X}$	1107.6	1564.8	945.2	-[e]	1212.0	-[e]	-[e]	2863.3[a]	2330.0[a]	-[e]
		SD	56.8	130.0	111.7	-	55.3	-	-	369.9	137.4	-
	word	$\overline{X}$	408.4	554.8	416.4	-[e]	395.6	583.6	-[e]	696.8	641.8	762.0[d]
		SD	30.3	117.9	87.6	-	33.7	78.9	-	170.4	189.1	-
	/ɝ/	$\overline{X}$	176.8	267.6	156.8	-[e]	211.8	202.4	-[e]	219.8	193.8	218.0
		SD	16.8	36.9	36.1	-	95.7	23.9	-	27.5	81.4	-
	/p/	$\overline{X}$	56.4	79.6	98.0	-[e]	113.0	175.6	-[e]	201.0	127.0	126.0
		SD	14.6	53.9	54.3	-	69.3	59.4	-	135.6	70.3	-
	/I/	$\overline{X}$	120.0	122.4	85.2	-[e]	122.2	130.8	-[e]	189.5	118.5	180.0
		SD	12.2	36.9	37.6	-	83.2	35.0	-	45.9	23.1	-

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-4 (continued)

			Subject 1	2	3	4	5	6	7	8	9	10
Fast Rate												
/pɚpIt/	phrase	$\overline{X}$	1196.0	1492.4	1088.8	-[e]	1338.8	1518.5[a]	1007.2	-[e]	-[e]	-[e]
		SD	149.2	86.6	204.0	-	49.8	128.4	125.5	-	-	-
	word	$\overline{X}$	426.0	527.6	477.2	643.6	413.6	578.5	422.0	-[e]	1240.0[c]	1097.2
		SD	32.2	42.2	93.9	102.4	44.6	79.1	64.3	-	247.5	148.7
	/ɚ/	$\overline{X}$	125.3	176.4	93.2	109.6	84.8	127.5	91.6	-[e]	290.0	171.6
		SD	20.4	12.8	28.1	28.6	23.6	39.6	17.5	-	7.1	38.0
	/p/	$\overline{X}$	86.0	98.8	132.4	171.2	121.6	168.5	103.2	-[e]	442.5	389.6
		SD	19.1	30.0	35.4	25.2	12.8	51.5	25.9	-	159.1	61.1
	/I/	$\overline{X}$	170.7	182.8	172.8	113.6	180.8	191.0	134.0	-[e]	247.5	268.0
		SD	24.2	29.4	39.3	20.5	26.8	11.6	41.6	-	81.3	45.2

a-based on 4 measures
b-based on 3 measures
c-based on 2 measures
d-based on 1 measure
e-no correct utterances were obtained

TABLE B-5. Mean duration and standard deviations (ms) of phrases, words, and phones for five repetitions of "permit" at the normal rate by normal speakers.

		Subject	11	12	13	14	15
Normal Rate							
/pɝ^mIt/	phrase	$\bar{X}$	1034.4	1025.8	985.6	815.6	901.0
		SD	99.2	67.9	106.1	56.9	62.6
	word	$\bar{X}$	312.4	368.0	297.4	321.4	276.2
		SD	41.6	54.2	50.3	42.8	34.4
	/ɝ^/	$\bar{X}$	142.8	145.2	105.0	100.8	100.6
		SD	52.8	29.3	11.9	6.4	19.7
	/m/	$\bar{X}$	58.8	62.0	76.6	43.6	60.2
		SD	10.2	8.5	12.1	6.7	6.5
	/I/	$\bar{X}$	65.0	93.8	76.4	79.6	66.6
		SD	15.1	24.1	19.9	4.9	14.1
/pɚ^mIt/	phrase	$\bar{X}$	1197.0	1113.2	1110.0	919.6	967.2
		SD	133.8	80.3	43.6	15.1	94.9
	word	$\bar{X}$	371.0	302.4	257.4	285.8	298.4
		SD	42.4	25.9	40.5	10.1	22.5
	/ɚ^/	$\bar{X}$	77.2	66.4	62.2	64.2	83.6
		SD	9.6	7.5	7.8	8.9	11.7
	/m/	$\bar{X}$	53.8	60.0	70.0	54.2	73.6
		SD	18.2	11.7	24.6	6.6	8.4
	/I/	$\bar{X}$	142.6	115.0	108.4	94.2	110.8
		SD	11.6	10.8	26.2	4.7	15.4

TABLE B-6. Mean durations and standard deviations (ms) of phrases, words, and phones for five repetitions of "permit" at the fast rate for normal speakers.

		Subject	11	12	13	14	15
Fast Rate							
/pɝ^mIt/	phrase	$\bar{X}$	842.8	1029.2	883.2	732.4	595.0
		SD	348.0	102.2	46.1	26.4	57.3
	word	$\bar{X}$	270.4	313.0	265.4	292.6	283.8
		SD	104.4	47.1	17.1	39.9	39.6
	/ɝ^/	$\bar{X}$	113.6	96.8	95.8	104.4	105.4
		SD	41.6	54.2	9.4	13.0	14.8
	/m/	$\bar{X}$	41.2	68.6	78.6	39.8	65.2
		SD	21.8	15.1	20.0	9.8	12.2
	/I/	$\bar{X}$	55.2	75.6	68.0	71.0	66.2
		SD	14.8	13.3	7.5	10.6	15.5
/pɚ^mIt/	phrase	$\bar{X}$	1046.4	1076.6	878.8	811.4	882.0
		SD	81.7	14.0	26.5	42.1	65.5
	word	$\bar{X}$	307.2	282.2	210.6	253.0	286.6
		SD	53.2	28.4	32.4	15.7	26.9
	/ɚ^/	$\bar{X}$	75.8	47.8	45.0	61.2	67.0
		SD	17.8	12.1	7.8	5.7	17.4
	/m/	$\bar{X}$	38.6	71.4	59.6	51.2	69.8
		SD	5.3	8.7	8.7	18.3	14.8
	/I/	$\bar{X}$	140.2	129.0	80.2	92.4	108.2
		SD	20.2	51.8	16.0	28.7	16.3

TABLE B-7. Mean durations and standard deviations (ms) of five repetitions of phrases, words, and phones for "perpit" at the normal rate for normal speakers.

		Subject	11	12	13	14	15
Normal Rate							
/pɝpIt/	phrase	$\overline{X}$	1011.6	1087.8	1057.2	841.4	919.8
		SD	117.1	147.9	27.1	35.8	52.6
	word	$\overline{X}$	345.2	455.8	253.6	275.0	289.8
		SD	25.4	64.8	17.4	22.1	30.9
	/ɝ/	$\overline{X}$	135.4	171.0	106.6	108.6	117.4
		SD	12.7	34.8	17.8	9.2	23.3
	/p/	$\overline{X}$	51.0	106.6	88.6	57.0	72.4
		SD	19.0	60.3	9.2	9.8	7.6
	/I/	$\overline{X}$	90.8	102.2	34.0	62.0	50.4
		SD	20.2	12.9	10.7	7.7	8.0
/pɚpIt/	phrase	$\overline{X}$	1245.6	1056.6	1190.6	871.0	975.4
		SD	126.3	68.8	65.2	85.3	52.2
	word	$\overline{X}$	391.4	392.0	328.2	289.4	310.2
		SD	63.2	35.0	35.2	48.7	10.5
	/ɚ/	$\overline{X}$	90.0	87.6	63.8	61.0	78.4
		SD	28.0	35.2	5.4	10.8	15.2
	/p/	$\overline{X}$	114.2	116.0	131.6	54.0	94.6
		SD	69.4	38.8	30.5	19.1	8.7
	/I/	$\overline{X}$	134.4	124.4	107.2	53.4	104.6
		SD	7.1	25.8	9.5	40.7	7.1

TABLE B-8. Mean duration and standard deviations (ms) of five repetitions of phrases, words, and phones for "perpit" at the fast rate for normal speakers.

		Subject	11	12	13	14	15
Fast Rate							
/pɝpIt/	phrase	$\bar{X}$	899.6	1101.8	910.6	728.6	866.8
		SD	64.0	100.5	32.0	57.5	58.2
	word	$\bar{X}$	295.0	444.2	224.2	250.2	264.6
		SD	27.1	35.2	23.1	24.5	20.4
	/ɝ/	$\bar{X}$	130.8	148.6	95.6	112.5	114.0
		SD	23.1	15.1	7.9	10.7	8.7
	/p/	$\bar{X}$	50.0	106.0	66.2	48.4	57.8
		SD	21.1	20.0	7.9	15.8	16.3
	/I/	$\bar{X}$	73.2	89.4	43.4	55.0	54.4
		SD	20.0	18.4	12.1	27.0	16.2
/pɚpIt/	phrase	$\bar{X}$	1060.0	1134.8	968.6	665.2	955.8
		SD	70.8	30.1	45.4	44.6	18.8
	word	$\bar{X}$	310.0	390.6	275.8	229.8	322.2
		SD	26.4	54.1	18.0	31.0	17.3
	/ɚ/	$\bar{X}$	78.4	87.0	52.2	53.8	66.0
		SD	18.6	35.9	14.2	9.0	11.5
	/p/	$\bar{X}$	63.4	103.2	93.8	42.0	92.6
		SD	19.8	51.9	17.4	13.9	8.7
	/I/	$\bar{X}$	126.2	129.6	102.0	74.4	115.4
		SD	16.3	25.9	13.5	25.0	11.0

TABLE B-9. Mean number of times in three trials that subjects repeated syllables or tapped their index fingers in five seconds.

Subjects	/pʌ/	/tʌ/	/kʌ/	/pʌtʌkʌ/	Finger Tapping
Apraxic					
1	16.7	15.7	13.7	6.0	21.67
2	16.7	26.3	19.3	2.0	24.0
3	25.7	24.7	20.3	7.0	23.67
4	10.3	8.7	8.3	1.3	21.33
5	19.3	17.3	15.3	2.7	20.33
6	18.3	16.7	13.7	2.7*	17.33
7	16.7	18.3	18.0	3.3	18.67
8	12.7	18.7	22.3	1.7*	19.0
9	9.3	12.7	9.0	1.3*	29.33
10	11.0	11.3	5.3	3.0*	19.0
$\overline{X}$	15.67	17.04	14.52	2.9	21.43
Normal					
11	21.3	22.0	21.0	5.7	20.33
12	20.3	21.3	21.3	6.3	24.33
13	27.0	23.0	19.0	7.0	23.0
14	28.7	25.7	23.7	11.0	24.33
15	29.3	28.7	27.3	11.0	26.33
$\overline{X}$	25.3	24.1	22.5	8.2	23.66

*articulation error of consonant, vowel was produced correctly

VITA

Linda Byrum Lilley was born on February 22, 1958 in Heidelberg, Germany. She attended numerous schools throughout the United States and Germany and graduated from high school in May 1976. She entered East Carolina University the following September and received her Bachelor of Science degree in Speech, Language, and Auditory Pathology in May 1979. In the fall of 1979 the author accepted a graduate assistantship at the University of Tennessee, Knoxville and was awareded a Master's degree in Speech Pathology in August 1980. The author entered the doctoral program at the University of Tennessee in September 1980. She received the Doctor of Philosophy degree in Speech and Hearing Science in December 1982. She was employed as the Assistant Clinical Director in Speech Pathology at the University of Arizona, Tucson upon graduation.