This is to certify that the

dissertation entitled

Constraints on Foot-Level Shortening

presented by

William F. Sennett

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Audiology and Speech Sciences

Major professor

Date 1/24/92

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE
OCT 2 3 1995 54		

MSU Is An Affirmative Action/Equal Opportunity Institution
c:\circ\datedue.pm3-p.1

CONSTRAINTS ON FOOT-LEVEL SHORTENING

By

William Fitzgerald Sennett

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Audiology and Speech Sciences

1992

ABSTRACT

CONSTRAINTS ON FOOT-LEVEL SHORTENING

By

William Fitzgerald Sennett

Foot-level shortening is a phenomenon in speech whereby the stressed syllable that heads a metric foot shrinks in duration as one or more unstressed syllables follow it within the same foot. Previous research provides conflicting evidence about the influence that syntactic boundaries may have on this phenomenon. The present study examined two possible constraints, one syntactic in nature and the other articulatory.

The first experiment made a new test of the hypothesis that a noun-phrase/verb-phrase boundary blocks foot-level shortening. Ten speakers produced pairs of sentences in which the foot structure was varied so that a stressed target syllable was followed by a word boundary and then either a stressed syllable or an unstressed syllable. Syntax was varied such that the target and the following syllables either occurred within the same phrase or were separated from each other by a noun-phrase/verb-phrase boundary. In a second experiment, the speakers again produced sentence pairs that contrasted according to their foot structure. The full set of sentence pairs exhibited a broad range of pauses separating the target and following words. This allowed for a test of the hypothesis that a

reduction in foot-level shortening is related to an increase in pause duration.

Waveform measurements of the target words in the first experiment indicated that a noun-phrase/verb-phrase boundary does indeed constrain foot-level shortening. The extent of the syntactic constraint is uncertain, however. One analysis indicated that it completely blocks foot-level shortening whereas another analysis indicated that it only reduces the magnitude of shortening. Results of the second experiment showed no relationship between the magnitude of the pause duration separating a stressed target syllable and the word that followed, on the one hand, and the degree of foot-level shortening present, on the other. Together, the experiments point more toward syntactic than articulatory constraints on foot-level shortening, but a complete account of the phenomenon cannot yet be put forth.

To my wife, Paulina,
and my daughter, Maria Elizabeth.

ACKNOWLEDGEMENTS

Many individuals influenced the successful completion of this dissertation, and I wish to acknowledge their contributions. My deepest appreciation goes to Brad Rakerd, the chairman of the guidance committee, for his support on this dissertation as well as for the opportunity to collaborate with him on earlier research. He has always been unfailing in his guidance and patience, and this project owes much to his efforts. I wish to thank Paul Cooke, who served as co-chairman of the committee, for his many valuable contributions throughout the different stages of the dissertation, not the least of which was to keep this project in its proper perspective. I also wish to thank the other members of the committee, Leo Deal and Hiram Fitzgerald, for their valuable observations, criticisms, and editorial work. It is certainly a better piece of work for the contributions of all involved.

My special appreciation goes to various members of my family: to my mother who always showed an interest in the dissertation prior to the onset of Alzheimer's disease; to my daughter, Maria, who was born during the duration of the project, and who competed for my interest; and especially to my wife, Paulina, who did everything she could to encourage

me in those moments when my interest in the project flagged.

Finally, I wish to thank others who have contributed in various ways to this effort. I thank Paul and Jane Wei for providing shelter and sustenance on my trips back to East Lansing from Chicago. I thank JoAnne Fleming, my departmental chair at Saint Xavier University, for providing me with the time to complete the dissertation. And I thank Joan Kaminski for her help in the preparation of many of the figures in the dissertation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

A. Précis

This dissertation concerns (a) durational interactions that take place between adjacent words in spoken English and (b) constraints that are imposed upon these interactions. It is a part of the large literature on prosodic effects in speech (Borden & Harris, 1984; Fry, 1958; Klatt, 1976; Ladd & Cutler, 1983; Lehiste, 1970, 1976; Lieberman, 1967; Netsell, 1973) which have taken on increasing importance in the field of speech-language pathology in recent years (Barnes, 1983; Beukelman & Yorkston, 1977; Kent & Rosenbek, 1982; Linebaugh & Wolfe, 1984; Murry, 1983; Robin, Klouda, & Hug, 1991; Rosenbek & LaPointe, 1985; Wingate, 1984; Yorkston & Beukelman, 1981).

To place the questions of the dissertation within their larger context, Section B of the Introduction provides a brief introduction to prosody. Section C highlights some general concerns of the research community regarding prosody, particularly with respect to temporal effects. The dissertation itself is concerned with two potential constraints on between-word durational interactions involving a phenomenon known as foot-level shortening. To place the questions of the dissertation in a historical context, Section D provides a review of the literature concerning foot-level shortening. Sections E and F give the specific motivations for, and implications of, the two studies that comprise the dissertation. Finally, Section G summarizes the purpose of each study.

B. Prosody

Prosody has been identified as an integrated process that incorporates aspects from the speech subprocesses of respiration, phonation, resonation, and articulation (Nation & Aram, 1984). Pitch, frequency, loudness, intensity, duration, silence, juncture, intonation, breath group, pitch accent, prominence, force, emphasis, stress, accent-up, accent-down, rhythm, tempo, tone, and voice quality have all been characterized as components of prosody (Barnes, 1983; Crystal, 1969; Netsell, 1973).

It is apparent that different levels of speech analysis are included here. Some terms refer to physical articulation events (e.g., force), some to acoustic parameters (e.g., intensity), some to perceptual effects (e.g., loudness), and some (e.g., stress) to more than one of these. Some authors have limited their definitions of prosody to one level, but others have been more inclusive in their use of prosody. One traditional perspective on prosody is that it consists of mental abstractions of speech patterns perceived by a listener. Specific prosodic features--such as intonation, stress, and rhythm--are perceptual events abstracted from the acoustic features of fundamental voice frequency, intensity, and duration (Freeman, 1982; Netsell, 1973). However, prosody is often treated as encompassing two or three levels of speech. For example, prosody has been defined as both an acoustic and a perceptual event (Nicolosi, Harryman, & Kresheck, 1978) and as both an articulatory and a perceptual event (Fry, 1958). Regarding the latter, the perception of intonation, stress, rhythm, and other prosodic features is conceived of as depending upon actual patterns that occur in the speech production mechanism. Thus, a close, though not a one-to-one, connection is seen between production and perception.

There are different objective means that can be used to study these patterns including the analysis of acoustic parameters of speech (Fry, 1955; Kent & Rosenbek, 1983; Klatt, 1976) and articulatory kinematics (Barlow, Cole, & Abbs, 1983; Forrest, Adams, McNeil, & Southwood, 1991; McNeil, Caligiuri, & Rosenbek, 1989). The focus of the experiments in the present study is acoustic in nature, investigating durational interactions among adjacent words in spoken English. Specifically, the current study involves acoustic measurements of word and pause durations. Prosodic features of interest include <u>stress</u>, <u>rhythm</u>, and <u>juncture</u>.

Stress, from a speech production perspective, refers to the force of production of one syllable relative to another (Nicolosi et al., 1978). Among other things, varying the syllable stress of a multisyllabic word may determine its word type, as with the utterance object. OBject, with the stress on the initial syllable, indicates a noun; obJECT indicates a verb. Perceptually, stressed syllables are longer, louder, and higher in pitch than unstressed syllables produced in a comparable context. The acoustic correlates of stress are, in turn, duration, intensity, and frequency, with stressed syllables being greater in all three parameters when compared to unstressed syllables (Fry, 1955, 1958; Lehiste, 1970; Lieberman, 1960). Significantly for this study, vowels located in stressed syllables are approximately twice the duration of the same vowels in unstressed syllables (Klatt, 1976).

Rhythm, in a general sense, involves "any kind of movement characterized by the regular recurrence of strong and weak elements" (Morris, 1976). Speech rhythm is "that aspect of oral language concerned with the periodic recurrence in time of similar patterns of pitch, loudness, duration, and quality" (Nicolosi et al., 1978). English is classified as a stress-timed language in which the rhythm is based upon the pattern of recurrence of stressed syllables (Classe, 1939; Pike, 1945). It has been speculated that this rhythm includes an overall tendency toward isochrony in the intervals between stressed syllables (Huggins, 1975; Lehiste, 1977; Pike, 1945), though there is extensive variation in the durations of the individual syllables.

In languages, such as Spanish, the rhythm is centered around the individual syllables, which are thought to be equal in duration, and not on the stressed syllables, which are thought to be unevenly spaced. Interestingly, in a study that measured interstress intervals in five different languages, the variability was the same for both stress-timed and syllable-timed languages (Dauer, 1983), with the mean interstress interval falling between 400 and 500 msec for all five languages.

Juncture pertains to the phonetic marking of boundaries between words, phrases, and sentences (Morris, 1988). Variations in juncture are signalled by differences in the durations of segments, syllables, and pauses. An example (from Handel, 1989) demonstrates some of these factors. The difference between "light housekeeper" and "lighthouse keeper" depends, in part, upon a slight delay between "light" and "house" and upon a longer duration for "light" in the first phrase.

A large body of literature demonstrates that durational interactions occur among the syllables of a word. (See Section D below.) The same is true for syllables separated from each other by a word juncture and, apparently, in syllables separated by some syntactic junctures as well.

C. Temporal Organization of Speech

A landmark study of the temporal organization of speech (Kozhevnikov & Chistovich, 1965) looked at durational interactions among speech segments at several linguistic levels. It was found that changes in speaking rate produced different kinds of changes at the syllable, word, phrase, and sentence levels. At the syllable level, minor changes occurred in consonant duration; relatively large changes occurred in vowel duration. However, the relative durations of the syllables within words remained constant as rate varied. From this, Kozhevnikov and Chistovich concluded that articulatory timing control is organized at the level of the syllable and not that of the phonetic segment. Within a sentence, it was found that the duration of a phrase showed less variability than the pauses between phrases. From this, the conclusion was drawn that, overall, timing is organized at the phrase level, not the sentence level.

Temporal regularities of speech are currently attracting the interest of researchers seeking to understand and treat speech disorders (e.g., Barnes, 1983; Osberger & Levitt, 1979; Rosenbek & LaPointe, 1985; Wingate, 1984: Yorkston & Beukelman, 1981; Yorkston, Beukelman, Minifie, & Sapir, 1984). They are also of interest to researchers from a number of other fields, including the following: (1) those seeking a formal description of the phonetic regularities of speech (e.g., Beckman & Edwards, 1987; Kiparsky, 1979; Liberman & Prince, 1977; Selkirk, 1980a, 1980b); (2) those with more pragmatic interests in characterizing linguistic performance (e.g., Cooper & Paccia-Cooper, 1980; Gee & Grosjean, 1983); and (3) those working to improve synthesized speech (e.g., Klatt, 1987).

Linguistics

A longstanding linguistic concern has been the development of formal descriptions for linguistic structure. There are, for example, comprehensive descriptions of syntax, morphology, and phonology. Recently, emphasis has been placed on expanding the formal descriptions to account for the prosodic characteristics of speech as well (Cooper & Eady, 1986; Kelly & Bock, 1988; Liberman & Prince, 1977; Nespor & Vogel, 1986; Selkirk, 1980a, 1984). Several recent models of rhythm postulate the existence of metrical units that are compatible with, but distinct from, grammatical units. To cite an example used by Fowler (1985), the name _Omaha Nebraska_ can be described linguistically as consisting of six syllables grouped into the two meaningful units that we call words. Its metrical structure, though, groups the syllables into three units called stress feet, _Oma HAne BRAska_, each of which carries a beat of the rhythm. Each stress foot, in turn, consists of a stressed syllable followed by one or more unstressed syllables. The metrical units and linguistic units are coordinated, but distinct.

Since there is not a one-to-one correspondence between the traditional grammatical descriptions of language and the metrical character of speech, linguists have been pursuing new descriptions.

The metrical structures of current linguistic theory include not only words, which have their own particular stress patterns, but also <u>phonological</u> <u>phrases</u> and <u>intonation</u> <u>phrases</u> in addition to the more familiar <u>stress</u> <u>feet</u>. A phonological phrase falls between the word and the syntactic phrase in size and includes all the words "up to and including the head . . . [which is] the main word around which the phrase is organized" (Gee & Grosjean, 1983, pp. 432-433). Phonological phrases are organized into larger intonational phrases. (See Gee & Grosjean, 1983; Selkirk, 1980, 1984.)

In sum, metrical phonology serves as an example of the new linguistic interest in the metrical aspects of speech and language. (See Nespor & Vogel, 1986; Selkirk, 1984.) This area of linguistics tries to account for various metrical phenomena such as phrase-level stress patterns. Rules are developed to account for the metrical patterns present in speech.

<u>Psycholinguistics</u>

Psycholinguists have been particularly interested in performance structures--i.e., regularities immediately observable in a talker's output--and have investigated their relationship to formal linguistic structures (Cooper, 1976; Cooper et al., 1977; Cooper & Eady, 1986; Gee & Grosjean, 1983, Kelly & Bock, 1988), including current metrical structures. Psycholinguists see the potential of performance structures to provide insight into a speaker's mental representation of various metrical phenomena. For example, in one study (Gee & Grosjean, 1983) an algorithm based on current metrical theory was tested--and to some extent found wanting--regarding its efficacy in predicting the durations of the pauses between all words of a sentence. The authors noted several common properties of performance structures. One is that the relationship between a performance structure and a linguistic structure is not perfect. For example, in actual performance, the verb is often clustered with the subject instead of with the noun phrase object, as linguistic theory would predict. Another property of performance structures is that utterances are divided into small units, often smaller than syntactic phrases. Finally, performance structures exhibit a symmetry of pause breaks, with a main pause break occurring near the midpoint of the sentence, then each half being broken up into segments of relatively equal length and so on. Gee and Grosjean thought this symmetry results from syntactic <u>and</u> metrical factors working together.

Gee and Grosjean (1983) were able to account for 92% of the pause variances of 14 sentences by taking into account phonological phrases, intonational phrases, and syntactic structures, as well as differences in the information content of stress level between content and function words. Phonological and intonational phrases are metrical units that "partly, but not wholly, match the phonological and syntactic units of the sentence" (p. 432). This is considerably better than the 56% that resulted from the application of an algorithm that was primarily based on syntactic rather than metrical structures (Cooper & Paccia-Cooper, 1980). An example of this is shown in Figure 1. Traditional linguistic theory would predict that the greatest pause would occur where the strongest syntactic break is found, i.e., between files and the lawyer in the sentence, "In addition to his files the lawyer bought the office's best adding-machine." The next greatest pause should occur between the noun phrase and the verb phrase, i.e., between the lawyer and bought. However, the Gee and Grosjean algorithm predicts that the longest and the next longest pauses should occur between files and the lawyer and then between bought and the office's. This was confirmed by the pause data collected by Grosjean et al. (1979).

Speech Synthesis

Prosody of synthesized speech must be improved if it is going to approach the naturalness of human speech. Early speech synthesis focused on the segmental level of speech. Two of the earliest devices included the Voder, developed at Bell Telephone Laboratories (Dudley, Reisz, & Watkins,

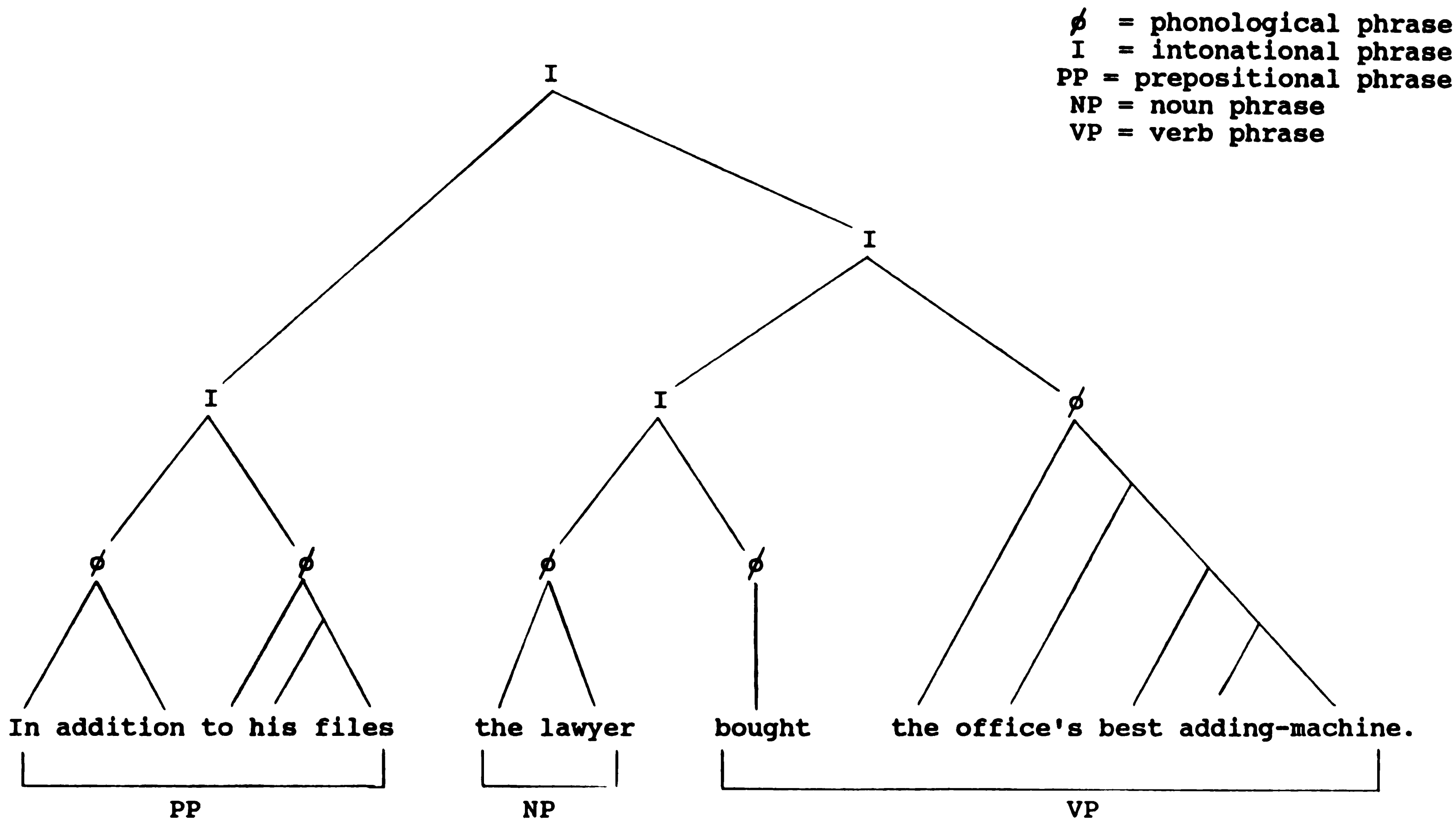

Figure 1. Example of phonological and intonational phrase boundaries (from Gee & Grosjean, 1983).

1939), and the Pattern Playback, developed at Haskins Laboratories (Cooper, Liberman, & Borst, 1951). Whereas the Voder's intelligibility was extremely limited, words in sentence lists produced by the Pattern Playback were approximately 85% intelligible (Cooper et al., 1951). Improvements have been made in the naturalness and intelligibility of synthesized speech, with the intelligibility of words in the Harvard sentences (Egan, 1948) produced by some commercial speech synthesizers approaching 95% (Pisoni, Nusbaum, & Greene, 1985). However, there is still an unnaturalness to this speech. Improving the naturalness will necessitate a better understanding of certain features of speech and an improvement in the rules used for synthesis (Klatt, 1987). Among the areas cited that require better understanding are the durational rules and prosodic specification (Klatt, 1987).

Speech-Language Pathology

In speech-language pathology, the prosodic structures of speech are of interest to those who work with persons having a variety of different speech disorders, such as the speech of those who stutter, who have any of the various motor speech disorders, or who are severely hearing impaired. This interest is obvious in the area of stuttering, where it has been proposed that stuttering is a prosodic disorder closely related to the stress of a syllable (Wingate, 1984) or, more generally, that stuttering involves a deficit in the formulation of the temporal components of speech programs (Kent, 1984).

The following paragraphs provide examples of some of the research that is being generated in the field of speech-language pathology that concerns prosody. The examples are meant only to tie together the present study's focus on a particular prosodic phenomenon with the concern that speech-language pathology has with prosody. A complete review of the literature in this area is not intended.

Until recently, prosody was viewed as being of secondary importance in the treatment of motor speech disorders (i.e., the dysarthrias and apraxia of speech). However, its essential importance for the intelligibility and naturalness of speech is now well established (Beukelman & Yorkston, 1977; Linebaugh & Wolfe, 1984; Murry, 1983; Rosenbek & LaPointe, 1985; Yorkston & Beukelman, 1981, 1991; and Yorkston, Beukelman, & Bell, 1988).

Disorders of prosody are characteristic of all motor speech disorders (Darley, Aronson, & Brown, 1975) and are responsible for much of the reduced intelligibility and unnaturalness inherent in these disorders. In parkinsonism, for example, Darley and his colleagues found the following prosodic features among the 10 most deviant speech dimensions: monopitch, reduced stress, monoloudness, short rushes of speech, and a variable rate of speech. The same study showed excess and equal stress, prolonged phonemes, prolonged intervals, monopitch, monoloudness, and a slow rate to be among the most deviant dimensions in ataxic dysarthria. Adding to this, these speakers have a tendency to produce the syllables in a sentence with little variation in duration and to produce intersyllabic intervals which also have a tendency toward similarity (Kent & Rosenbek, 1982).

Not surprisingly, the various deviant prosodic (and suprasegmental) characteristics interact with each other in various ways. For example, Linebaugh & Wolfe (1984) found that a group of speakers with spastic dysarthria and a group with ataxic dysarthria each produced longer syllable durations than in normal speakers but that were essentially the same as those produced by the other dysarthric group. However, only for the group with spastic dysarthria were the longer syllable durations inversely correlated with intelligibility and naturalness.

Research in the past 10 years has indicated that treatment of the deviant prosodic characteristics in motor speech disorders can lead to improvement in intelligibility and naturalness (Barnes, 1983; Beukelman, 1983; Caligiuri & Murry, 1983; Rosenbek, 1983; Rosenbek & LaPointe, 1985; Yorkston & Beukelman, 1981, 1991; Yorkston et al., 1988). The improvements in naturalness depend upon improvements in stress patterning, rate-rhythm, and intonation (Yorkston & Beukelman, 1991). Most attention has centered on rate and stress.

Researchers and clinicians have found that reducing the rate of speech--sometimes only temporarily--benefits the intelligibility and naturalness in some dysarthric speakers (Beukelman, 1983; Hammen, Yorkston, & Beukelman, 1989; Yorkston & Beukelman, 1981, 1991); which dysarthric speakers must be determined on an individual basis (Hammen et al., 1989). In speakers with ataxic dysarthria, improvements in intelligibility and naturalness often follow a controlled increase in rate (Murry, 1983; Yorkston & Beukelman 1981), though a reduction in rate is often brought about first. Clinically, Yorkston and Beukelman (1991) work to obtain a consistent rate reduction and, while also working on other prosodic features, generalize it to spontaneous speech. In one of their clients (Yorkston & Beukelman, 1981), a patient having traumatic brain injury and ataxic dysarthria, speech intelligibility was 20% shortly after the onset of symptoms. Initial rate reduction increased the intelligibility to 70%. This reached nearly 100% following several months of systematically increasing the rate while working on other prosodic features (Yorkston & Beukelman, 1981). Rate control is brought about by one of two general techniques: rigid or rhythmic cuing (Yorkston et al., 1988). Rhythmic cuing maintains greater naturalness; but the rigid technique, which sacrifices naturalness, may be necessary to effect a change. Both techniques have been computerized (Beukelman, Yorkston, & Tice, 1988).

Accurate stress patterning is necessary for the efficient transfer of meaning in speech. Apparent in the speech of certain motor speech disorders, however, are deficits in the production of stress (Barnes, 1983; Darley et al., 1975; Kent & Rosenbek, 1982), prolonged interword or intersyllabic intervals (Darley et al., 1975), and an alteration in syllabic durations (Kent, Netsell, & Abbs, 1979). As part of the Kent et al. (1979) study, changes in the durations of base words were measured as unstressed syllables were added (e.g., please--pleasing--pleasingly). In the speech of normal speaking subjects, the base grew increasingly brief as more unstressed syllables were added. This is in agreement with other studies, including studies that motivate the present work (Cooper et al., 1977; Fowler, 1977; Huggins, 1975; Lehiste, 1972; Rakerd, Sennett, & Fowler, 1987). The base in three-syllable words was an average of 0.78 of the durations in the single-syllable words. In the speech of subjects with ataxic dysarthria, however, the reductions were inconsistent or relatively small; sometimes the base actually grew longer. For these subjects, the base in three-syllable words was an average of 0.94 of the durations in the single-syllable words. Other studies have shown that speakers with ataxic dysarthria are idiosyncratic in the way in which they produce stress (Yorkston et al., 1984) and that dysarthric speakers with predominantly spastic, ataxic, or hypokinetic signs are ineffective or inconsistent in the use of the three parameters of stress--fundamental frequency, intensity, and duration (Murry, 1983).

Yorkston et al. (1988) pointed out the usefulness of an acoustic analysis of the three parameters of stress to determine how a client is utilizing any of them successfully. In clinical treatment, the contrastive stress drill of Fairbanks (1960) is commonly used (Miller, 1990; Rosenbek and LaPointe, 1985). Working with two levels of stress--stressed versus unstressed syllables--is considered sufficient. A dysarthric client often cannot alter all three parameters. Altering the fundamental frequency or intensity often leads to "bizarre" speech, whereas altering duration can lead to more natural speech (Beukelman, 1983; Yorkston et al., 1988).

Deviant prosodic characteristics are also present in the speech of the hearing-impaired. For example, hearing-impaired speakers have been noted to produce durational contrasts that are less pronounced than those of normal-hearing speakers and to produce inappropriate domain-final lengthening (Osberger & Levitt, 1979; Stevens, Nickerson, & Rollins, 1978). Inconsistencies are also found with prelingually deaf speakers regarding the control of durations of target stressed syllables produced in multisyllabic contexts (Tye-Murray & Woodworth, 1989). An example of one test-set is shade--shady--shadier--shading--shadiness--the shade lingered--the shade was refreshing. In normal-hearing speakers, the target grew shorter when followed by another syllable, with the shortening being greatest if the syllable was unstressed. For deaf speakers, the shortening effects were inconsistent. This shortening phenomenon, discussed below in detail, is the central focus of the current research.

D. Foot-Level Shortening

Over the past three decades investigators have uncovered a number of durational regularities in speech. There are, for example, demonstrated durational interactions among the phonological segments that make up a syllable. Vowels are longer when they precede voiced rather than voiceless consonants (House, 1961; Peterson & Lehiste, 1960), and consonants are shorter in clusters than when alone (Fowler & Tassinary, 1981; Klatt, 1976). The duration of a syllable's vowel decreases as a function of the number of consonants which follow it (Fowler, 1977; Lehiste, 1970; Lindblom & Rapp, 1973) and, to a lesser extent, of the number which precede it (Fowler & Tassinary, 1981; Lindblom & Rapp, 1973).

Looking at linguistic units of somewhat larger size, durational interactions among the syllables of a word are observed. Syllables in longer words become shorter in duration than when found in shorter words (Lehiste, 1970; Lindblom, 1968). "Anticipatory" shortening of a stressed syllable takes place when unstressed syllables are added after the stressed syllable (Barnwell, 1971; Fowler, 1977, 1981; Huggins, 1975; Lehiste, 1970, 1972; Lindblom & Rapp, 1973; Nakatani, O'Connor, & Aston, 1981; Nooteboom, 1972); a weaker, "backward" shortening of a stressed syllable occurs with the addition of preceding unstressed syllables (Fowler, 1977, 1981; Huggins, 1975; Lindblom & Rapp, 1973).

In addition, there are durational interactions between the words of a sentence, particularly neighboring words (Cooper, Lapointe, & Paccia, 1977; Fowler, 1977; Huggins, 1975; Rakerd et al., 1987; Sennett, Rakerd, & Fowler, 1986); but there is much debate concerning whether and how these interactions are constrained. One question addressed in previous research (Rakerd et al., 1987) is whether durational interactions are constrained by syntactic relations between the words (see also Cooper et al., 1977; Huggins, 1974, 1975). Other concerns are whether these interactions depend upon the phonetic characteristics of the words themselves (Cooper et al., 1977) and/or upon variables thought to affect the overall rhythm of spoken language (Beckman & Edwards, 1986; Gee & Grosjean, 1983; Liberman & Prince, 1977; Selkirk, 1980a).

One between-word durational interaction found in spoken English is <u>foot-level shortening</u>. A stress foot, the fundamental rhythmic unit of stress-timed languages such as English (Abercrombie, 1964), consists of a stressed syllable followed by zero, one, or more unstressed syllables. Each foot carries a single major stress, and the overall rhythm of an utterance is defined with respect to its stress feet.

Foot-level shortening occurs when unstressed syllables are added to a foot, making its internal structure more complex. These additions generally give rise to a shortening of the stressed syllable that is the focus of the foot (Barnwell, 1971; Fowler, 1977; Huggins, 1975; Lehiste, 1970, 1972; Lindblom & Rapp, 1973). It also appears that some shortening occurs in unstressed syllables (Jassem, Hill, & Witten, 1984). The foot-level shortening effect is illustrated in Figure 2, which shows the duration of a target stressed syllable as a function of the number of unstressed syllables that are added to the stress foot. In the case shown in the figure, the stressed target syllable is the word _fact_. It is referred to in the notational scheme at the upper left of the figure by an uppercase _T_. In the various sentences listed, the target word is immediately followed by one of the following: a word boundary, indicated by the pound symbol (_#_); a stressed syllable, indicated by an uppercase _S_; or an unstressed syllable, indicated by an lowercase _u_. In all of the cases where the target is followed by an unstressed syllable, whether or not the unstressed syllable is in the same word, shortening of the target occurs (i.e., there is foot-level shortening). Again, it is not necessary that the unstressed syllables be within the same word as the stressed syllable in order to produce this shortening.

Two different accounts of foot-level shortening have been offered. One proposes that speakers of stress-timed languages are strongly inclined to maintain equal intervals

T#S	The fact started the argument.
T#uS	The fact restarted the argument.
Tu#S	The factor started the argument.
Tu#uS	The factor restarted the argument.
Tuu#S	The factory started the argument.

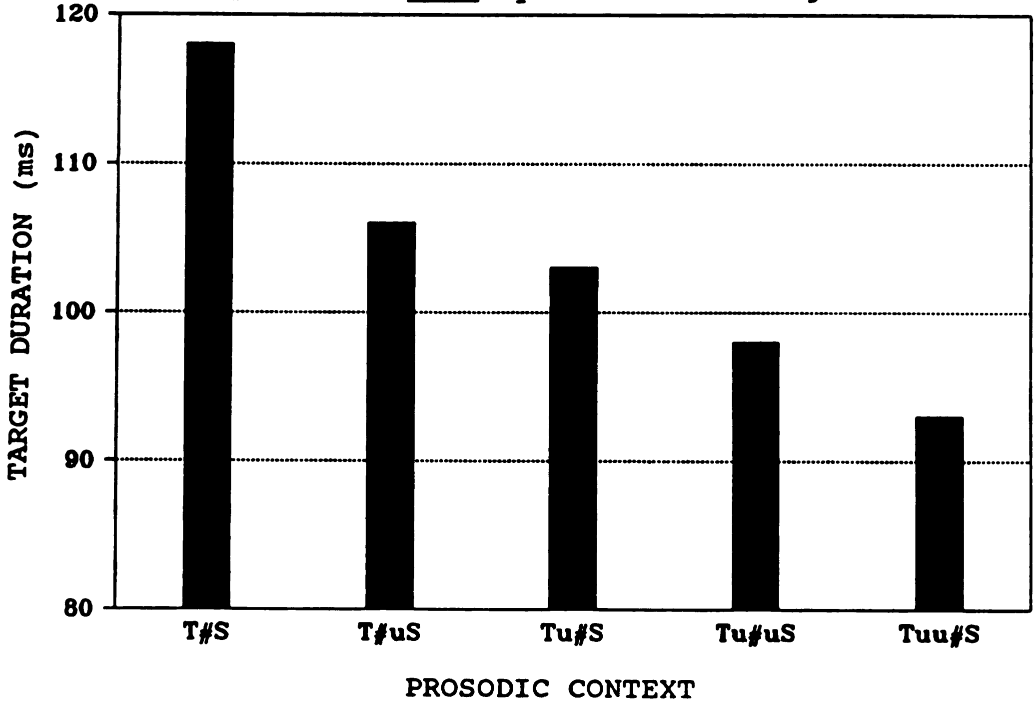

Figure 2. Example of foot-level shortening (from Fowler, 1977). Target syllables (T) were followed by a word boundary (#), a stressed syllable (S), or an unstressed syllable (u).

between the stress beats of an utterance, that is, to speak *isochronously* (Classe, 1939; Pike, 1945). In the isochronous account, English and other stress-timed languages are seen to be organized into metric feet (Abercrombie, 1964; Pike, 1945). Linguists have proposed that this organization somehow imposes on the speaker a tendency to produce each metric foot isochronously (Classe, 1939; Pike, 1945). To achieve this, the speaker must shorten the stressed syllable heading a foot in order to "make room" for any unstressed syllables that follow. However, although some evidence of an articulatory tendency toward isochrony exists (Lehiste, 1973), it is also true that there is a positive correlation between the duration of a metric foot and the number of syllables within it (Huggins, 1978; Lehiste, 1972). The presence of a correlation indicates that perfect isochrony is not achieved. Another aspect of isochrony is that it is sometimes perceived even in instances where it does not appear to have been produced by a talker (Allen, 1975; Lehiste, 1977). This may account for why linguists thought that isochrony was actually present in the first place.

The second account of foot-level shortening emphasizes coarticulation, or the overlapping in speech production of neighboring phonetic gestures. Fowler (1981) has proposed that there is a greater coarticulatory overlap (or, in her term, greater *cohesion*) of a stressed syllable with a following than with a preceding unstressed syllable.

Consistent with this account is evidence of extensive coarticulatory overlap (i.e., coproduction) of a stressed syllable with an unstressed syllable that follows (Bell-Berti & Harris, 1976; Fowler, 1977, 1981). The overlap with a preceding unstressed syllable is much less marked.

Fowler's (1981, 1985) model of asymmetrical articulatory overlap is schematized in Figure 3 (from Fowler, 1985). The three solid lines represent, respectively, a stressed syllable, an unstressed syllable, and another stressed syllable. If the metric foot existed without the presence of an unstressed syllable, there would be a small overlap of the two stressed syllables. An acoustic measurement of each syllable would include just a bit less than their total articulatory durations: from a to c for the first syllable and from c to e for the second. If an unstressed syllable were to be added, its coarticulatory overlap would be much greater with the preceding than with the following syllable. The duration of the first stressed syllable would, therefore, be measurably shortened, measuring only from a to b. The shortening of the second stressed syllable would be minimal, measuring from d to e rather than from c to e.

It has been pointed out (Rakerd et al., 1987) that both accounts of foot-level shortening lead to the prediction that foot-level shortening should be reduced or completely blocked by <u>syntactic lengthening</u>. The final word or two of a phrase are produced with a longer duration than those

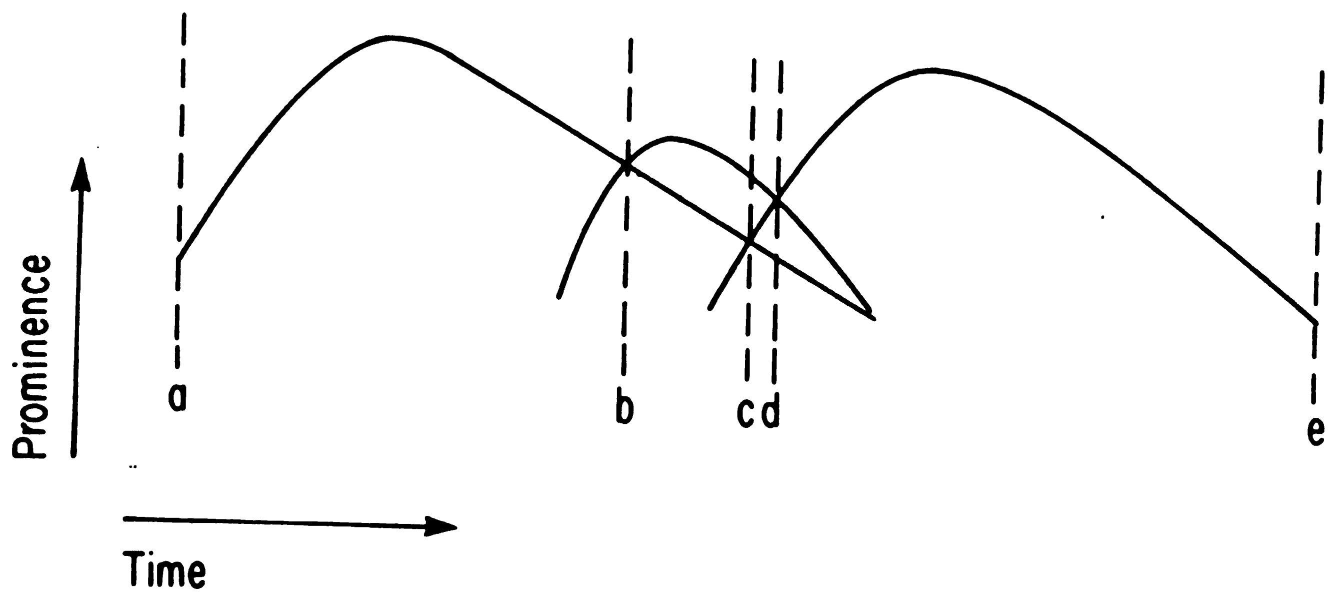

Figure 3. Representation of asymmetrical articulatory overlap (from Fowler, 1985). Acoustically, the first stressed syllable ranges from a to c and the second stressed syllable from c to e. An unstressed syllable would range from b to d, causing an apparent shrinkage of the first syllable.

words would have if produced in other locations. This has been termed 'prepausal lengthening' (Klatt, 1976) or 'domain-final lengthening' (Cooper & Paccia-Cooper, 1980). The lengthening is greatest at the very end of a sentence not complete a sentence (Cooper & Danly, 1981; Oller, 1973).

Phrase-final lengthening appears to occur for stressed but not for unstressed syllables (Nakatani et al., 1981). This lengthening should, at the least, reduce the amount of foot-level shortening, no matter whether the shortening results from an effort to maintain isochrony or articulatory cohesion. Surprisingly, however, Rakerd and his colleagues did not find a reduction of foot-level shortening at the syntactic boundary they tested.

Whether foot-level shortening is ultimately a phenomenon of isochrony, of articulatory cohesion, or of a combination, it is of interest to specify the intervals over which it occurs. An understanding of this also may provide insight into the cause of the phenomenon. In the present research, Experiment 1 focuses on a major syntactic break--a noun-phrase/verb-phrase (NP/VP) boundary--as a potential delimiting boundary. Other potential boundaries exist, of course, such as clause or sentence boundaries, which could be the focus of future research. Experiment 2 focuses on the role of <u>pause</u> <u>duration</u> as a possible delimiter rather than on syntactic boundaries per se. Significant between-word pauses are frequently present at syntactic boundaries (Cooper et al., 1977), but they also occur elsewhere (Gee &

Grosjean, 1983). Experiment 2 looks at foot-level shortening as realized across a variety of between-word pause intervals.

E. Experiment 1: Does Syntax Matter?

As noted above, an issue regarding foot-level shortening is the factors that constrain it. One area which is being investigated--and which continues to generate debate--is whether or not syntax blocks foot-level shortening (Cooper et al., 1977; Huggins, 1975; Rakerd et al., 1987).

Evidence For

Huggins (1975) was the first to propose that syntactic lengthening may interrupt stress timing. Similar shortening effects to those found by Fowler (1977) were seen in Huggins's study but with an important difference: Foot-level shortening was found to occur in a case in which the stressed target word and the following unstressed syllable were present within the same phrase (the abbreviation WPH will be used to represent this case of two words within the same phrase), but shortening did not occur when the words were separated by a major syntactic break (abbreviated MSB).

Huggins's evidence came from a study of several forms of the rather unusual sentence, Cheese(s) (a)bound(ed) (ab)out. The syllables shown in parentheses were added to the base sentence, Cheese bound out, to derive other sentences, such as, Cheese bound about and Cheese abound out. When the stressed syllable bound served as the target, the addition of an unstressed syllable to the following word out, to give about, produced foot-level shortening. In this case, both the target word and following word are in the same (verb) phrase (WPH). However, when the stressed syllable cheese served as the target, no shortening occurred when the unstressed prefix was added to the following word bound, which was separated from the target by the NP/VP boundary.

Any strong claim regarding the power of syntactic blocking was weakened by Huggins's subsequent failure to replicate his result with a larger sample of subjects and sentences (Huggins, 1974). However, a second study indicating that syntax may block foot-level shortening is one by Cooper et al. (1977). They conjectured that Huggins's failure to replicate his syntactic effect resulted from a lack of phonetic control, especially of the sounds of the target and immediately surrounding words. Cooper and his colleagues therefore looked at sentences that were closely matched phonetically, as seen in the following pair:

(1) The police kept Clint until nine o'clock that night.

(2) The police kept Clinton till nine o'clock that night.

The target stressed syllable (T) of interest in both sentences is Clint. Sentence (1) contains an unstressed syllable (u) at the beginning of the word following the target ("un-"), whereas sentence (2) has an unstressed syllable "attached" to the target itself ("-on"). Equally important is the fact that in (1) there is an MSB that intervenes between T and u. Cooper et al. found that there was measurable foot-level shortening (referred to as trochaic shortening in the study) in (2) but not in (1) and they attributed this result to a blocking of shortening by the MSB. The same results occurred when they looked at a variety of different syntactic boundaries, leading them to the conclusion that syntactic blocking is a quite general phenomenon. Boundaries that produced the above results included noun-phrase/prepositional-phrase, prepositional-phrase/prepositional-phrase, prepostional-phrase/clause, and prepositional-phrase/noun-phrase.

Evidence Against

The results of a recent study by Rakerd et al. (1987) encourage an alternative interpretation. It was undertaken to address certain methodological limitations associated with the previous work. Improvements on the Huggins study included the use of (1) stimulus sentences that were semantically reasonable in all forms, (2) a greater number of sentences, (3) more subjects, and (4) a data collection paradigm that had proven useful in recent studies of sentence production (Cooper, 1976; Cooper et al., 1977).

The Rakerd et al. study also corrected for a confounding of syntactic and word boundaries present in Cooper et al. (1977). In type (1) sentences of Cooper et al., the unstressed syllable was simultaneously in a different phrase and a different word from the target syllable. In type (2) sentences, the unstressed syllable was both within the same phrase and within the same word as the target. (See the example above.) Thus the greater shortening seen in type (2) sentences could have resulted from word, rather than syntactic, boundary effects. Word boundary effects have in fact been found by previous investigators (Huggins, 1975; Fowler, 1977).

The sentences for the Rakerd et al. study are shown in Table 1. Note that target words for the MSB and WPH conditions were matched phonetically. All target syllables examined were CVCs beginning with obstruent consonants and containing long vowels. The specific targets in the different syntactic conditions were nevertheless different. Also differing were the immediate phonetic environments surrounding the targets. The syllables that followed a target differed in the T#S and T#uS conditions (i.e., stressed target syllable, followed by a word boundary, and then either a stressed syllable or an unstressed syllable). Also, no equating of the larger phonetic environments occurred between the MSB and WPH conditions. In light of the findings of Huggins (1975) and Cooper et al. (1977), the results were surprising because the researchers failed to

Table 1. Test sentences from Rakerd et al. (1987).

<u>MSB</u>

1. His first <u>date</u> (a)roused some anxiety [for obvious reasons].
2. That young <u>duke</u> (dis)armed his subjects [against the advice of his counselors].
3. [I have heard that] the new <u>coach</u> (dis)trusts his players.
4. [Contrary to expectations] those new <u>bees</u> (re)acted with fury.

<u>WPH</u>

5. The strong <u>peach</u> (de)light was unpleasant [but better than nothing].
6. John must <u>bike</u> (a)round the block [because it is too far to walk].
7. [The coaches say] he can <u>fake</u> (un)reasonably well.
8. [As you might expect] the young group's <u>deep</u> (di)visions did disrupt them.

<u>Note</u>. The target word is underlined, the unstressed syllable that follows the target is in parentheses, and the phrase for the long sentence condition is in brackets.

find an interaction between syntax and foot-structure. The major finding of Rakerd et al. (1987) was that the NP/VP boundary did not block foot-level shortening. To the contrary, a slightly greater degree of foot-level shortening occurred for stressed syllables immediately preceding a phrase boundary than for stressed syllables occurring elsewhere in a phrase. Rakerd et al. speculated that the results reported by Cooper et al. were actually <u>word</u> boundary effects rather than syntactic boundary effects, as these had been confounded in the study. Rakerd et al. (1987) also noted that if foot-level shortening does, in fact, occur across the ever present NP/VP boundary as well as within phrases, this would help to explain how a stress timing tendency was perceptually identified by phoneticians such as Classe (1939).

<u>Current Status</u>

What seems clear from the research reviewed is that the foot-level shortening phenomenon exists (e.g., Cooper et al., 1977; Fowler, 1977; Huggins, 1975; Rakerd et al., 1987). It is also apparent that the effect is greater when an unstressed syllable is directly "attached" to the end of the stressed syllable that begins a foot than to the beginning of the following word (Fowler, 1977; Huggins, 1975). What is still uncertain is which factors, if any, constrain foot-level shortening when the stressed and unstressed syllables are separated by a NP/VP boundary. In particular, it is unclear whether an MSB in fact acts to restrict the effect of stress timing, to block it altogether, or whether the boundary has no effect at all.

F. Experiment 2: Effects of Pauses on Foot-Level Shortening

The effects of syntax noted above could be considered to be abstract in the sense that they apply at boundaries defined in some formal grammatical system. In this spirit, Cooper and colleagues (1977) proposed a phonological rule, termed the trochaic shortening rule--trochaic shortening being their term for foot-level shortening--to account for blocking of trochaic shortening by a syntactic boundary. This boundary would act as a barrier to a speaker's linguistic processing, not allowing the stress type of any syllables following the boundary to influence the durations of syllables preceding it.

An alternative possibility is that the effects of syntax are mediated by the physical acts that talkers use--albeit imperfectly--to signal a syntactic boundary. A strong candidate for this is the duration of between-word pausing. Other things being equal, talkers pause longer between words that straddle a phrase or clause boundary than between other words (Cooper & Paccia-Cooper, 1980). It may be, then, the greater separation of a target and following words at a major syntactic boundary that accounts for the finding by some researchers that syntax blocks foot-level shortening. Cooper et al. (1977) discounted this possibility because they had found a syntactic effect at syntactic boundaries that differ markedly in the amount of pausing that they give rise to. However, the method used by Cooper and his colleagues has been questioned on the basis of a confounding variable (see Section E). In light of the concerns with that study, a further investigation of the effect that pause duration per se has on foot-level shortening seems warranted.

Experiment 2 specifically addressed the question of whether pause has a significant effect on foot-level shortening. The method used was very different from that of Cooper et al. (1977), and the results should at least provide a new perspective on this issue.

G. Purpose

The area of prosody is generating substantial interest on the part of researchers from several fields, as is apparent from the foregoing discussion. It was the purpose of this dissertation to answer some questions regarding one aspect of prosody, namely, stress timing.

The specific purpose of Experiment 1 was to investigate whether syntactic factors would constrain foot-level shortening. In particular, the study attempted to answer the following question: Is foot-level shortening blocked by a major syntactic break, in this case, a NP/VP boundary?

The syntactic boundary effect tested in Experiment 1 is primarily a psychological effect. It concerns a formal linguistic relationship between words, and the experimental question is whether this relationship will condition foot-level shortening. The emphasis of Experiment 2 was different. It focused on the physical output of a talker. In particular, it focused on the potential effect of pauses, whatever their origins, on the degree of foot-level shortening. Concretely, Experiment 2 sought to answer the following question: Is there a relationship between the magnitude of foot-level shortening and the duration of the pause between the target word and the word that follows?

CHAPTER II

GENERAL METHODS

A. Subjects

All of the subjects were native speakers of American English. Three were men (subjects 2, 8, and 9) and seven were women (subjects 1, 3, 4, 5, 6, 7, and 10). The subjects ranged in age from 16 to 35 years. All were volunteers recruited from the Department of Audiology and Speech Sciences at Michigan State University.

All subjects had bilateral hearing within normal limits at the frequencies of 500, 1000, 2000, and 4000 Hz as determined by pure tone audiometric screening performed at 20 dB HL (ANSI S3.6-1969). None of the subjects had a history of speech disorders except one speaker who had received one year of speech therapy for an articulation error early in elementary school. Subjects did not have a knowledge of the experimental questions under investigation. Half participated in Experiment 1 first and half in Experiment 2 first.

B. Speech Materials

Experiment 1

The purpose of Experiment 1 was to determine whether a major syntactic boundary does or does not block foot-level shortening. Speech materials for Experiment 1 consisted of the 24 sentences listed in Appendix A. These sentences contrast in terms of their (1) foot structure and (2) syntactic structure. A foot structure contrast is exhibited by the comparison of sentence 1MSB-T#S, "The first knight views the small army," and 1MSB-T#uS, "The first knight reviews the small army." In the first sentence, the foot of interest contains only the single stressed monosyllabic target (T) word knight. This is followed, in the next foot, by the stressed monosyllabic word views. In the second sentence, the foot includes the target word plus the unstressed (u) syllable re-.

A syntactic structure contrast is seen between the 1MSB sentences above and the 1WPH sentences (e.g., 1MSB-T#S, "The first knight views the small army," and 1WPH-T#S, "The first night views are quite pleasant."). In the MSB sentences, the target word and following word are each separated by a major syntactic break, whereas in each WPH sentence, target and following word fall within the same phrase.

A final consideration concerned the phonetics of the targets. Rakerd et al. (1987) strictly controlled the semantic content of their sentences but at the expense of phonetic control. In the present study, the phonetic environment of the target and following word was controlled by either using the same word or a homonym for the target word and the following word in the MSB and WPH conditions. Furthermore, the first four words in each base sentence are phonetically the same.

The phonetic characteristics of the target words were restricted to promote the ease and accuracy of acoustic analysis. In this regard, it was preferable that the initial and final consonants be stops or affricates whenever possible. Likewise, it was desirable that tense vowels or diphthongs be used as the syllable nuclei since they are more likely to "shrink" in duration by measurable amounts in response to foot-level manipulations.

Experiment 2

The purpose of Experiment 2 was to determine whether the length of pause duration between a target word and its following word would be a constraining factor on the degree of any foot-level shortening present. As in Experiment 1, to obtain foot-level shortening, it was necessary to have the stressed target word be followed by a stressed syllable in some sentences and by an unstressed syllable in others. However, to obtain a correlation between foot-level shortening and pause duration, Experiment 2 required a range of pauses between the target and following words for its sentences.

The variables of interest, then, were pause duration and foot-level shortening. Sentences were borrowed from previous studies by Grosjean and associates (Gee & Grosjean, 1983; Grosjean, Grosjean, & Lane, 1979) and modified to satisfy the constraints of experimentation on foot-level shortening. By using these sentences and making relatively minor modifications to them, it was anticipated that the requirement of having a range of pause durations between the targets and following words would be met. To provide a sense of this technique, one of the sentences and its modifications is presented below. Gee and Grosjean (1983) reported the following data for their form of the sentence. The numbers in parentheses represent the percentage of total pause duration for the sentence that was contributed by each between-word gap.

That (5) a (5) solution (15) couldn't (7)
be (3) found (30) seemed (9) quite (6)
clear (17) to (3) them.

For the present study, the first step was to choose sentences which had adjacent pairs of words that would result in the desired broad range of pause durations. For instance, in the sentence above, the percent pause duration between the words <u>quite</u> and <u>clear</u> was six; it was expected that this would yield a short duration pause. If a longer pause were desired, the focus could have been placed on <u>found</u> and <u>seemed</u>, where the percent pause duration was 30.

The next step was to perform modifications on the words "straddling' a pause in order to obtain the proper foot structure and phonetic characteristics. Constraints were the same as in Experiment 1, namely, that the foot structure should be such that the word following the target could be changed to give T#S and T#uS conditions and that the target word's phonetic characteristics should promote the accuracy of acoustic measurement. The modified version of the above sentence was as follows:

That a solution couldn't be found seemed quite logical to them.

That a solution couldn't be found seemed quite illogical to them.

In all, there were 15 modified sentences. Five with percent pause durations less than 10 were chosen with the expectation that they would yield "short" pauses in the present study. Five with percent pause durations from 10 to 20 were chosen for "medium" pause sentences, and five with percent pauses greater than 20 were chosen for "long" pause sentences. The original sentences from Gee and Grosjean (1983) and the modified versions of the sentences used in Experiment 2 can be found in Appendix B.

C. Procedures

Each subject was tested individually while seated with the experimenter in a sound-attenuated room. Prior to a subject's participation, he or she signed an informed consent form. The experiments were randomly assigned so that half of the subjects participated in Experiment 1 first and half in Experiment 2 first. Furthermore, the subjects read the blocks of stimulus sentences for each experiment in random order.

Experiment 1

The 24 sentences for Experiment 1 were pseudo-randomly assigned to two blocks of 12 sentences each. (See Appendix A.) Randomization constraints were (1) that at least one of each sentence type (i.e., having the same target word) appeared in each block and (2) that no two sentences from a sentence type be adjacent. The order in which these blocks were read was counterbalanced. Subjects produced a minimum of four repetitions of each sentence, pausing for at least 2 seconds between each repetition, and resting for two minutes between blocks. Each sentence was spoken on a separate breath. The recording session for Experiment 1 took approximately 30 minutes per subject.

To combat the awkwardness and unnaturalness that can accompany normal reading procedures, the data were collected using a paradigm developed by Cooper and his associates (Cooper, 1976; Cooper et al., 1977). Subjects' productions were prompted by sentences printed individually on index cards. The experimenter asked each subject to read over a sentence several times and then produce it as if spontaneously making a statement of fact, avoiding the word-by-word production that often accompanies reading and avoiding the use of contrastive or emphatic stress. When ready, the subject produced the four repetitions of the sentence. These were recorded on audiotape for later analysis, and the subject moved on to the next card and repeated the same process.

The subject was instructed to repeat any sentence production when--in the judgment of the experimenter--it was produced with emphatic or contrastive stress or with mispronunciations. The sentence productions were also repeated if--in the subject's self-evaluation--they were thought to be unnatural. Emphatic stress was to be avoided because it carries the potential of affecting foot-level shortening, especially if the emphasis falls on the target word or on the word that follows. In talking, speakers tend to stress content words such as nouns, verbs, and adjectives; function words such as articles and prepositions are normally unstressed. However, the speaker can change the focus of a sentence by giving a particular word greater stress. This is seen in the following sentences in which the boldface type indicates the word receiving emphatic stress, the underline indicates normal stress, and the absence of an underline indicates the word was unstressed:

The **first** knight views the small army.

The first **knight** views the small army.

The first knight views the **small** army.

Prior to the production of the test sentences, each subject produced a block of eight practice sentences using the above procedures. At the end of the practice block, the subject was invited to ask questions of clarification about the techniques.

Experiment 2

The 30 sentences for this study were pseudo-randomly assigned to three blocks of 10 sentences each using similar constraints as in Experiment 1. (See Appendix B.) In this case, no two sentences from a single sentence type were adjacent. The order in which the blocks were read was counterbalanced. Subjects produced four repetitions of each sentence, pausing for at least 2 seconds between each repetition, and resting for at least 2 minutes between blocks. The instructions, reading paradigm, practice procedures, and recording procedures were the same as in Experiment 1. The recording procedures took approximately 40 minutes per subject.

D. Instrumentation

The same instrumentation was used for both experiments. Audio recordings of each subject's sentence productions were made with a studio-grade reel-to-reel tape deck (TEAC A-2340). These recordings were low pass filtered at 4 kHz (Frequency Devices 901F) and digitized for temporal analysis on a computer (IBM-AT). The sampling rate for analog-to-digital conversion was 10 kHz. The amplitude resolution of the A/D converter (Data Translation DT 2801-A) was 12 bits.

Speech waveforms were displayed on the computer monitor and measured via the placement of vertical cursors at the beginning and end of a segment of interest. The marked segments could be played back acoustically to assist the measurement process. Figure 4 shows an example of a segmented waveform, with cursors indicating the beginning and the end of the target word.

E. Measurement Procedures

Experiment 1

For each subject, the experimenter digitized three tokens of a sentence. The target of a sentence, plus sufficient portions of the preceding and following pauses and/or words to allow for a later measurement of the entire target word, was saved in a computer file. Target durations were measured from the digitized waveforms. Cursors were set at the zero-crossing nearest to the beginning and ending of a target, and the time difference between these points was automatically calculated by the computer program to the nearest tenth of a millisecond. Durations were recorded to the nearest millisecond for analysis. The beginning point for those targets initiated by a stop consonant was measured from the onset of the release burst. When a target began with a nasal consonant, such as the /n/ in knight and night, the cursors were set at the beginning of the nasal murmur. The end of each target segment was marked at the last glottal pulse for the vowel nucleus.

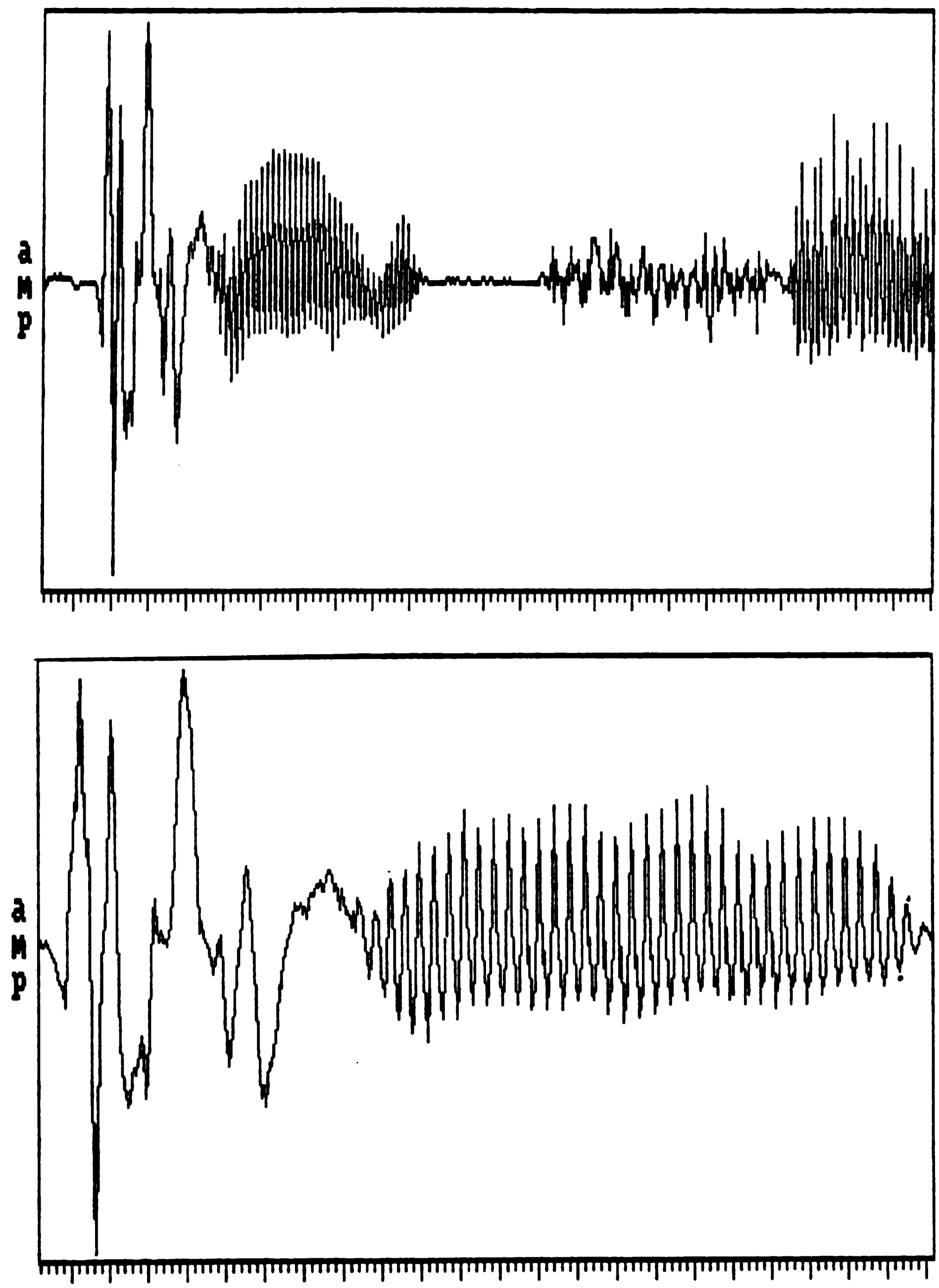

Figure 4. Examples of oscillographic displays. Above is a 619 ms window containing a portion of the sentence, The new packed signs are beautiful. Below is a 230 ms window containing only the target word packed from the same sentence.

Experiment 2

Again, each subject's first three recorded productions of each sentence not having been judged in need of repetition by the experimenter or the subject were digitized. Because pause durations were to be measured as well, it was necessary to save in computer files the target word, a portion of the preceding pause and/or word, all of the following pause, and at least a portion of the following word. Measurements of the target word durations for this experiment were made in the same manner as in Experiment 1. Pause duration measurements were made from the end of the target word, as measured above, to the acoustic onset of the following word. A mean pause duration was determined for each sentence type. Pause duration, then, was the mean of six pauses, three each from the T#S and T#uS conditions.

F. Data Analysis

Experiment 1

Experiment 1 utilized a repeated measures randomized block factorial design with two factors, each of which had two levels (Kirk, 1982). Factor one was Syntax; its levels were MSB (major syntactic break) and WPH (within phrase). Factor two was Foot Structure; its levels were T#S (target followed by a word boundary and then a stressed syllable) and T#uS (target followed by a word boundary and then an unstressed syllable). As required in this design, subjects participated in all treatment combinations and did so in random order.

The sentences chosen for this study represent a random sample from all possible sentences, and so Sentence represents a random factor in the analysis (Clark, 1973), as does Subject. To test the generalizability of the findings across subjects, the first ANOVA (to be referred to as $F_{subject}$) included sentence as a fixed factor and subject as a random factor. The second ANOVA (to be referred to as $F_{sentence}$) included subject as a fixed and sentence as a random factor. (See Rakerd et al., (1987) for similar treatment of the data.)

Experiment 2

Experiment 2 was a correlational study with amount of foot-level shortening the y ("dependent") variable and amount of between-word pause duration the x ("independent") variable.

G. Reliability

Two factors constrain the accuracy of durational measurements of this type. One is the analog-to-digital sampling rate of 10 kHz, which allows the measurements to be physically accurate to within 0.1 ms. The other is the experimenter's ability to determine the precise points of acoustic onset and offset of a target. Durational measurements were rounded to the nearest millisecond, an increment more easily measured than a tenth of a millisecond and in line with other durational studies (Cooper et al., 1977; Huggins, 1975; Rakerd et al., 1987).

Reliability was assessed by having an individual skilled in phonetic analysis remeasure the target words of two of the ten subjects, chosen at random. These measurements and those of the experimenter were then compared using the Pearson r. The resulting reliability was 0.97 for Experiment 1. For Experiment 2, the reliability was 0.95 for the target words and 0.98 for the pauses.

CHAPTER III

RESULTS

A. Experiment 1

Analysis 6S (Complete Data Set)

Each subject produced six groups of four sentences each (two levels of Syntax x two levels of Foot Structure per four sentence group), as shown in Appendix A. This section summarizes the results of an analysis of the complete data set. ANOVA tables for Experiment 1 are located in Appendix C. A subsequent section details analyses on subsets of the data.

Main Effects

Syntax. Results of the present study were consistent with previous findings in showing that syllables just before syntactic boundaries are lengthened relative to the same syllables located elswhere within a phrase (Cooper & Paccia-Cooper, 1980; Klatt, 1976). The mean duration of targets in the MSB condition was 197 ms, whereas the mean for the WPH condition was 175 ms, a 22 ms difference. These data are plotted in the left panel of Figure 5. The difference between the MSB and WPH conditions was significant [$F_{subject}(1,9) = 12.18$, $p < 0.01$; $F_{sentence}(1,5) = 37.56$, $p < 0.01$].

Table 2, which reports the syntactic data by individual sentences, and Table 3, which reports the data by

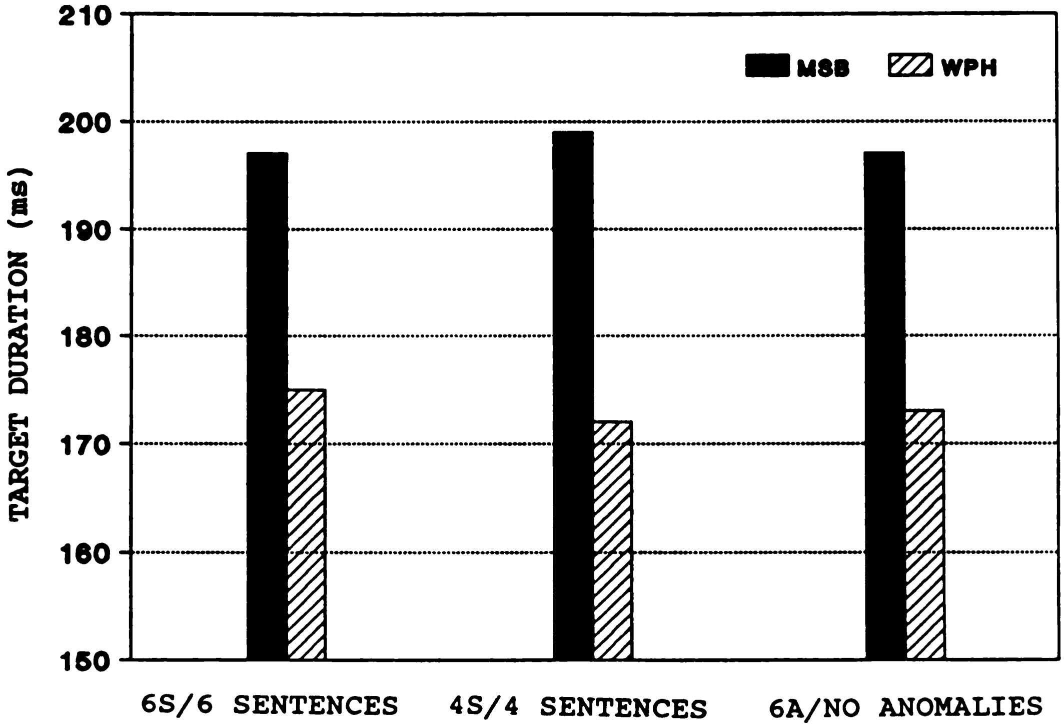

Figure 5. Mean target durations in Experiment 1 for syntax. Target syllables were produced before a major syntactic break (MSB) or elsewhere within a phrase (WPH).

Table 2. Mean target durations (in ms) of syntax for the sentences of Experiment 1, Analysis 6S.

	Syntax		
Sentence	MSB	WPH	Diff.
1	183	151	32
2	186	177	9
3	202	177	25
4	160	143	17
5	204	185	19
6	250	218	32
M	197	175	22

Table 3. Mean target durations (in ms) of syntax for the subjects of Experiment 1, Analysis 6S.

			Syntax		
Subject	Sex	Age	MSB	WPH	Diff.
1	F	23	242	201	41
2	M	31	197	191	6
3	F	23	185	182	3
4	F	26	172	169	3
5	F	23	154	141	13
6	F	23	204	177	27
7	F	27	213	184	29
8	M	35	186	178	8
9	M	16	196	168	28
10	F	22	226	160	66
Means			198	175	23
			M F	M F	M F
			193 199	179 173	14 26

subject and by sex and age, show that the domain-final lengthening effect was quite general. In every sentence, a target was longer in the MSB than in the WPH condition, with differences ranging from 9 ms to 32 ms. The effect was also present for all subjects, though there were substantial individual differences regarding its magnitude. When looked at by sex, domain-final lengthening was about twice as long for females as for males (26 ms versus 14 ms). Individual subject values ranged from 3 ms to 66 ms.

Foot structure. The mean target durations were 189 ms in the T#S condition and 184 ms in the T#uS condition, as shown in the left panel of Figure 6. Therefore, there were 5 ms of overall foot-level shortening (T#S minus T#uS) observed here, a value comparable to that observed by Rakerd et al. (1987).

Mean target durations for each of the six sentences are displayed in Table 4. Foot-level shortening ranging between 7 ms and 19 ms occurred in four of the sentences, but foot-level *lengthening* of 13 ms and 6 ms occurred in sentences 2 and 5 respectively. Table 5 shows that foot-level shortening from 1 ms to 17 ms occurred for eight of the 10 subjects. Two subjects-- 4 and 6--produced *negative* foot-level shortening of 7 ms. When looked at by sex, the magnitude of foot-level shortening was essentially the same for males (6 ms) and females (5 ms).

The foot structure factor was not significant in the ANOVAs across subjects [Fsubject(1,9) = 4.11, p < 0.07] and

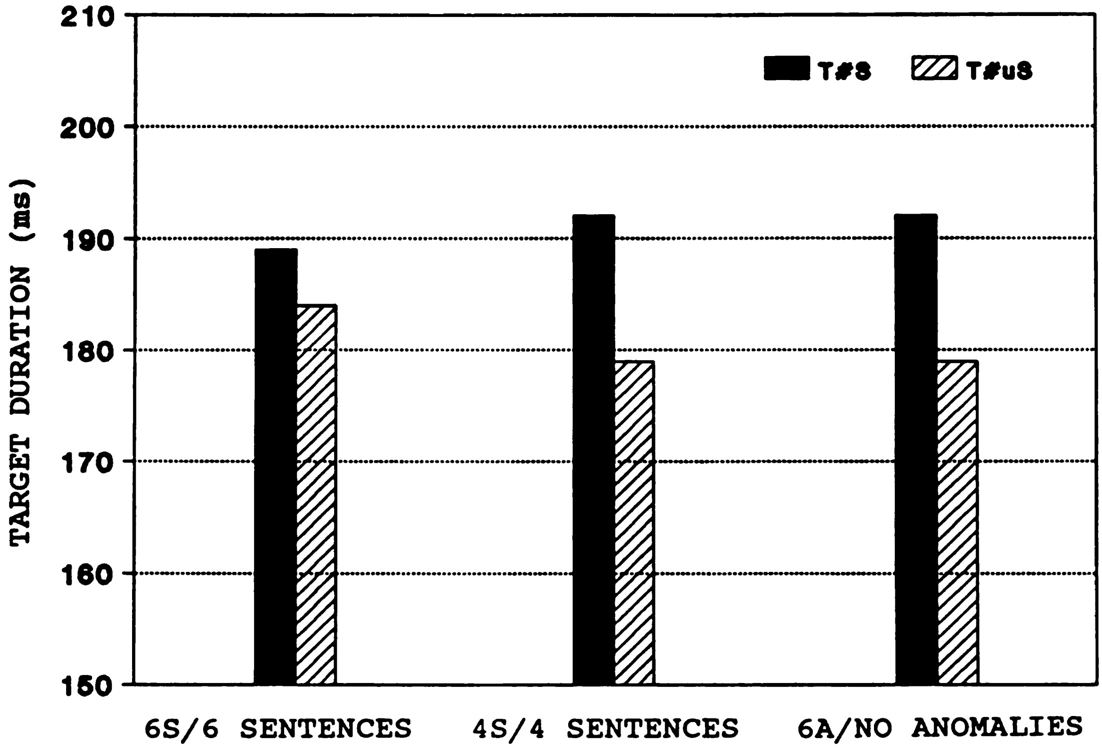

Figure 6. Mean target durations in Experiment 1 for foot structure. Target syllables (T) were followed by a word boundary (#) and then either a stressed (S) or an unstressed (u) syllable.

Table 4. Mean target durations (in ms) of foot structure for the sentences of Experiment 1, Analysis 6S.

	Foot Structure		
Sentence	T#S	T#uS	Diff.
1	175	159	16
2	175	188	-13
3	193	186	7
4	161	142	19
5	191	197	-6
6	238	230	8
M	189	184	5

Table 5. Mean target durations (in ms) of foot structure for the subjects of Experiment 1, Analysis 6S.

			Foot Structure					
Subject	Sex	Age	MSB		WPH		Diff.	
1	F	23	225		218		7	
2	M	31	195		193		2	
3	F	23	190		178		12	
4	F	26	167		174		-7	
5	F	23	148		147		1	
6	F	23	187		194		-7	
7	F	27	207		190		17	
8	M	35	186		178		8	
9	M	16	185		179		6	
10	F	22	199		187		12	
Means			189		184		5	
			M	F	M	F	M	F
			189	189	183	184	6	5

across sentences [Fsentence(1,5) = 1.01, $p = 0.36$] at the 0.05 level.

Syntax x Foot Structure

Means pertaining to the potential interaction of syntax and foot structure are presented at the left of Figure 7. They evidence a blocking of foot-level shortening in the MSB condition comparable to the blocking previously reported by Cooper et al. (1977). The data show that mean target durations for the MSB sentences were 197 ms and 198 ms for the T#S and T#uS conditions, respectively, resulting in a difference of just 1 ms. By contrast, the mean target durations for the WPH sentences were 181 ms for T#S and 170 ms for T#uS, reflecting foot-level shortening of 11 ms on the average. This interaction between syntax and foot structure was significant in both ANOVAs [Fsubject(1,9) = 14.38, $p < 0.01$; Fsentence(1,5) = 9.72, $p < 0.05$].

Mean data for the six sentences and the 10 subjects are shown in Tables 6 and 7, respectively. Only subject 4 showed negative foot-level shortening (i.e., an average increase in T#uS target durations over T#S targets) in the WPH condition. For the others, foot-level shortening ranged from 0 ms to 28 ms. In the MSB condition, foot-level shortening was negative for four of the 10 subjects (three of them female), ranging from -2 ms to -14 ms. For the others, foot-level shortening ranged from 0 ms to 14 ms. Males and females exhibited the same magnitude of foot-level shortening in the MSB condition, but greater shortening was

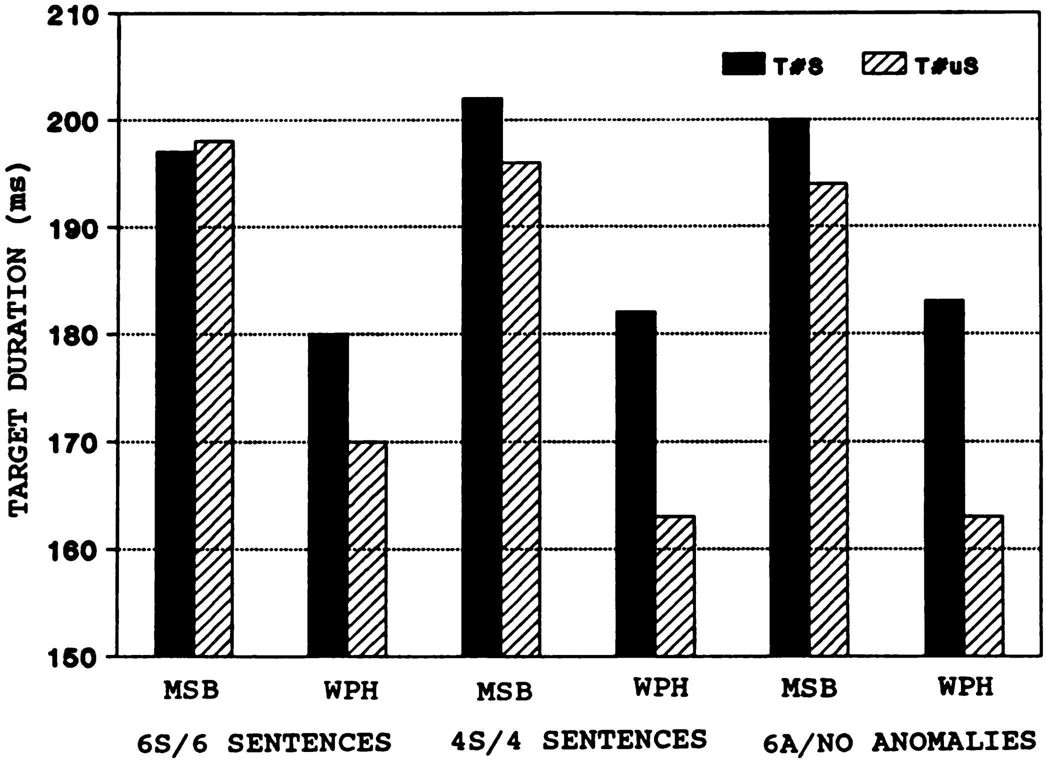

Figure 7. Mean target durations in Experiment 1 for syntax by foot structure. (MSB = major syntactic break, WPH = within phrase; T = stressed target syllable, # = word boundary, S = stressed syllable, u = unstressed syllable.)

Table 6. Mean target durations (in ms) of syntax by foot structure for the sentences of Experiment 1, Analysis 6S.

	Syntax					
	MSB			WPH		
Sentence	T#S	T#uS	Diff.	T#S	T#uS	Diff.
1	184	181	3	166	137	29
2	177	195	-18	173	181	-8
3	201	202	-1	184	170	14
4	169	151	18	154	133	21
5	200	207	-7	183	187	-4
6	252	249	3	225	211	14
M	197	198	-1	181	170	11

Table 7. Mean target durations (in ms) of syntax by foot structure for the subjects of Experiment 1, Analysis 6S.

		Syntax					
		MSB			WPH		
Subject	Sex	T#S	T#uS	Diff.	T#S	T#uS	Diff.
1	F	242	242	0	208	194	14
2	M	191	203	-12	198	183	15
3	F	192	178	14	118	178	10
4	F	167	177	-10	167	171	-4
5	F	153	155	-2	144	139	5
6	F	197	211	-14	177	177	0
7	F	216	209	7	198	170	28
8	M	187	186	1	186	170	16
9	M	197	194	3	173	163	10
10	F	231	219	12	166	154	12
Means		197	198	-1	180	170	10
		M F	M F	M F	M F	M F	M F
		192 198	194 199	-2 -1	186 178	172 169	14 9

produced by males (14 ms) than by females (9 ms) in the WPH condition.

Further Evaluation of Data

In order to meaningfully address the question of whether a major syntactic boundary blocks stress timing, the MSB data need to be compared to a "control" condition in which there is no major syntactic boundary--that is, to the WPH condition. The WPH data thus serve as a baseline for the analysis. Previous research has consistently found that foot-level shortening occurs in WPH sentences, and the same results were expected for the present study. Table 6 nevertheless shows that while four of the sentences (1, 3, 4, and 6) did conform to the expectation, with WPH shortening effects ranging from 14 ms to 29 ms, two other sentences were anomalous, not only showing no foot-level shortening, but actually showing "negative" shortening (i.e., lengthening). Eight subjects showed this odd effect for at least one of these two sentences, and six subjects showed it for both sentences. The effect rarely occurred for the other sentences.

Re-Analysis 4S

Sentences 2 and 5 thus were found to be significantly different from the others in that they provided no appropriate baseline for the assessment of syntactic effects. It was decided to reanalyze the data using a repeated subjects ANOVA but with the data from sentences 2 and 5 omitted. This will be referred to as Analysis 4S.

Mean target durations for the individual sentences and subjects are located in Appendix D.

Re-Analysis 6A

In analysis 4S, sentences 2 and 5 were omitted because they exhibited, on the average, lengthening instead of the expected foot-level shortening in their WPH forms. However, individual subjects interacted idiosyncratically with the various sentences. For example, a few subjects produced foot-level shortening for one or both of sentences 2 and 5 but produced lengthening for other sentences. A second re-re-analysis (Analysis 6A) was therefore performed after certain anomalies were removed. In this re-analysis, each of an individual subject's sentences exhibiting lengthening in the WPH condition were deleted; that is, if a subject produced a sentence in which lengthening of the target occurred in the WPH condition, both WPH and MSB versions of the sentence were dropped from the analysis.

Mean target durations for the individual sentences and subjects that resulted from this procedure are reported in Appendix D.

Analysis 4S (Four Sentence Data Set)

Main Effects

Syntax. In re-analysis 4S, the target word was again significantly longer in the MSB sentences than in the WPH sentences, as seen in the middle panel of Figure 5 (see page

49) [Fsubject = 16.63, $p < 0.01$; Fsentence(1,3) = 55.74, $p < 0.001$].

Foot structure. The histogram bars in the middle of Figure 6 (see page 53) show mean target durations of 192 ms and 179 ms for the T#S and T#uS conditions respectively, reflecting foot-level shortening of 13 ms. This is substantially longer than the 5 ms of shortening in the six-sentence data set. The main effect of foot structure proved significant in both ANOVAs [Fsubject(1,9) = 17.65, $p < 0.001$; Fsentence(1,3) = 16.46, $p < 0.05$].

Syntax x Foot Structure

In contrast to the six sentence data set in the left panel of Figure 7 (see page 57), the histogram bars in the middle panel show a shrinking rather than a blocking of foot-level shortening in the MSB condition. In analysis 6S, we saw no foot-level shortening in the MSB condition and 11 ms in the WPH conditon. Here we see foot-level shortening of 6 ms and 19 ms respectively. A significant interaction between syntax and foot structure was found in the ANOVA on subjects [Fsubject(1,9) = 10.60, $p < 0.01$] but not on sentences [Fsentence(1,3) = 7.98, $p = 0.07$].

Analysis 6A (Anomalies Removed)

The results of analysis 6A were very similar to those from analysis 4S. This is readily apparent when comparing the bar graphs for 6A, in the right panel of Figure 7, with the bar graphs for 4S in the middle panel of the figure.

Because of the unequal number of sentences for the various subjects, only one of the two ANOVAs could be performed on the data set with individual anomalous sentences removed--that in which subjects served as the random factor.

Main Effects

Syntax. The bars in the right panel of Figure 5, again show the expected difference between the MSB and the WPH conditions. Target durations for the MSB and WPH conditions differed by 20 ms on the average, a similar value to that seen in the first two analyses. The difference was significant [$F(1,9) = 10.39$, $p < 0.01$].

Foot structure. The bars in the right panel of Figure 6 show that foot-level shortening occurred. The durations of 192 ms for T#S and 179 ms for T#uS, with 13 ms of foot-level shortening, were identical to those in the four sentence analysis. As in that analysis, the difference here was also significant [$F(1,9) = 60.75$, $p < 0.00001$].

Syntax x Foot Structure

Figure 7 shows almost identical foot-level shortening in the MSB and WPH conditions for both the four sentence data and the data with anomalous data removed. Mean target durations in the MSB condition of 200 ms for T#S and 194 ms for T#uS produced foot-level shortening of 6 ms. This matched results found in the four sentence data set. For the WPH condition, mean targets of 183 ms for T#S and 163 ms for T#uS produced foot-level shortening of 20 ms, compared to 19 ms for the four sentence data set. The interaction between syntax and foot structure was significant [$F(1,9) = 21.65$, $p < 0.001$].

B. Experiment 2

In Experiment 2, an investigation was made into the possibility that it is not a syntactic break per se that blocks foot-level shortening but rather the frequently co-occurring pause which separates a target word and the word that follows it. Hence, Experiment 2 explicitly looked for a relationship between the magnitude of foot-level shortening and the duration of the pause that separates a stressed target word from the word that follows it. It was hypothesized that a negative correlation would exist between foot-level shortening and pause duration and/or that foot-level shortening would be measurably present at pauses shorter than some threshold value and absent at longer pause values.

Initial Analysis

Pause Duration

Pause range. One preliminary issue was whether there would be a sufficiently broad range of pause durations for a meaningful analysis of their effect. A previous analysis of related sentences (Gee & Grosjean, 1983) gave an expectation that the target words were placed at sentence locations that would result in a range of pauses, but the absolute values remained in question. Analysis of the subjects' productions revealed an overall pause range from 35 ms to 243 ms, a sevenfold increase from shortest to longest, as seen in Table 8. Even if sentence 15, which has a pause that is 75 ms longer than the next longest pause sentence, were to be eliminated, there still would be an almost five-fold increase in pause durations.

Expected pause spread. A second preliminary concern was that the pause durations should not be bunched together unevenly. Rather, it was hoped that they would spread somewhat evenly across the whole range. A scan of Table 8 (column 2) shows that a fairly even spread was observed.

When preparing the sentence stimuli, sentences 1 through 5 were projected (based on Gee and Grosjean's findings) to have relatively short pauses, sentences 6 through 10 relatively moderate pauses, and sentences 11 through 15 relatively long pauses. Mean pause durations in these three sentence groups were 83 ms, 94 ms, and 159 ms, respectively. To determine whether these were significantly different, a one-way ANOVA of these three levels was performed. (ANOVA tables for Experiment 2 are located in Appendix E.) It indicated a significant difference [$F(2,138) = 27.61$, $p < 0.001$]. When a Tukey's HSD test for multiple comparisons (Tukey, 1953) was performed, it showed that the difference occurred between the long pause level versus the short and moderate levels ($p < 0.05$). A significant difference did not exist between the short and

Table 8. Mean pause durations and mean foot-level shortening (in ms) for the 15 sentences of Experiment 2, ranked in ascending order by pause duration.

Sentence	Pause	Foot-Level Shortening
6	35	14
2	61	-11
4	74	6
1	81	11
10	86	1
3	88	11
9	104	4
5	109	10
14	115	-3
8	115	-1
11	115	11
7	129	13
12	151	5
13	168	-9
15	243	7
M	117	5

moderate levels.

Performance data pause spread. It was not important, however, for the specific sentences to fall into particular projected categories based upon pauses. A second one-way ANOVA was therefore performed in which the sentence productions were divided into the three pause categories based upon the actual performance data instead of on projected pauses. Sentences were rank ordered by mean pause across subjects and then divided into three groups. The mean pause durations for these "trichotomized" data were 62 ms for the short pause sentences, 101 ms for the medium pause sentences, and 172 ms for the long pause sentences. These group means were significantly different overall [$F(2,138) = 78.61$, $p < 0.001$] and significantly different from one another (Tukey's HSD, all $p < 0.05$).

Pause Duration and Foot-Level Shortening: Is There a Relationship?

The purpose of Experiment 2 was to determine whether the magnitude of foot-level shortening is related to the magnitude of pause duration between the target and the word that follows. The mean value of foot-level shortening for each of the 15 sentences can be seen in Table 8. The sentences are rank ordered by the magnitude of pause duration. On visual inspection, there does not appear to be a relationship between pause duration and foot-level shortening. (Compare columns 2 and 3.) This is confirmed by the lack of a significant correlation (Pearson $r = -0.107$, $p > 0.5$).

Additional Analysis of the Original Data

The lack of correlation between pause duration and foot-level shortening was a surprise and led to further exploration of the original data in an attempt to find any hidden trends. One analysis ranked the subjects' data by pause durations and then looked for regularities in foot-level shortening. Another analysis examined the effects of syntax on both pause durations and foot-level shortening.

Analysis Considering Subject Differences

Rank order correlation. The initial correlation was performed on data in which the sentences were ranked by the mean pause across all subjects. In a follow-up analysis, each subject's data first were ranked from 1 to 15 by personal pause duration. Next, the mean pause and the mean foot-level shortening were obtained across all subjects for each of the 15 levels. The correlation of pause and foot-level shortening on this data set was $r = -0.203$ ($p > 0.2$), an insignificant value only slightly higher than that obtained in the original analysis.

Analysis of variance. An analysis was performed on foot-level shortening using the three performance data driven pause categories above, i.e., short pause, medium pause, and long pause sentences. Mean foot-level shortening was 7 ms for the short, 5 ms for the medium, and 2 ms for the long pause sentences. A one-way ANOVA did not find these differences to be significant [$F(2,138) = 0.63$, $p = 0.535$].

Analysis of the Relationship of Pause Duration and of Foot-Level Shortening to Syntactic Environment

Syntactic environment. It was thought useful to look at the role that the syntactic environment might be having on the pause duration and foot-level shortening effects that were present in Experiment 2. Target words and following words occurred in three different syntactic environments: (1) both words found within the same phrase (WPH), as in sentences 1, 2, 3, 4, 6, and 7; (2) both words separated by a phrase boundary (MSB), usually a noun-phrase/verb-phrase boundary, as in sentences 5, 8, 9, 10, 11, and 12; and (3) both words separated by a clause boundary (CLB), always a subordinate-clause/main-clause boundary, as in sentences 13, 14, and 15.

Pause duration and syntactic environment. The mean pauses for the three syntactic categories just indicated were 96 ms for WPH, 95 ms for MSB, and 175 ms for CLB. A one-way ANOVA for the three levels of syntactic environment indicated an overall significant difference [$F(2,18) = 12.11$, $p < 0.001$]. A Tukey's HSD test confirmed that the only significant difference was between CLB and the other two levels.

Foot-level shortening and syntactic environment. Mean durations of foot-level shortening for the three level of syntactic environment were 5 ms for WPH, 8 ms for MSB, and 2 ms for CLB. A one-way ANOVA indicated no significant difference among these means [$F(2,18) = 1.56$, $p = 0.237$].

Analysis of Anomalous Data

Negative foot-level shortening (i.e., lengthening) occurred in some speech samples in both experiments. This phenomenon, whatever its origins, was not relevant to the studies. In Experiment 1, one group of analyses dealt with a data set in which certain anomalous data had been deleted to eliminate a subject's sentences in which lengthening had occurred in the WPH condition. An identical process of deleting data could not be performed in Experiment 2 because matched syntactic levels of MSB and WPH--the latter representing a baseline condition--were not a part of the experiment. However, a somewhat analogous procedure was carried out. It was decided to omit any data pairs (i.e., pause data and foot-level shortening data for a sentence) in which lengthening was greater than -25 ms, about two times the magnitude of foot-level shortening seen in Experiment 1. The analyses that had been performed on the original data set were then performed on the remaining data.

Results paralleled those from the earlier analysis. The mean pauses were 61 ms for the short pause, 102 ms for the medium pause, and 173 ms for the long pause sentences. A one-way ANOVA indicated a significant difference [$F(2,18) = 76.95$, $p < 0.001$], and a Tukey's HSD test showed this to be significant for all three levels at the 0.05 level.

Pause Duration, Foot-Level Shortening, and Syntactic Environment

The result of the Pearson *r* for the data set with anomalies deleted, *r* = -0.097 (*p* > 0.5), remained essentially unchanged from that of the complete data set, *r* = -0.107 (*p* > 0.5).

Mean foot-level shortening for the three pause categories were 9 ms for short pause, 8 ms for medium pause, and 6 ms for long pause sentences. Although foot-level shortening was the smallest for sentences with the longest pauses, an ANOVA failed to indicate a significant difference [$F(2,18) = 0.21$, $p = 0.81$].

Next, analyses to determine the relationship of both pause duration and foot-level shortening to three levels of syntax (WPH, MSB, and CLB) were repeated. Results of the one-way ANOVA on pause duration paralleled results on the complete data. Significant differences occurred in the degree of pause as a function of syntax, but only the CLB level differed from the others ($F(2,18)=12.89$, $p<0.001$; Tukey's HSD test was set at 0.05). Foot-level shortening was 8 ms for WPH, 10 ms for MSB, and 2 ms for CLB. The one-way ANOVA on foot-level shortening showed no significant difference with syntactic environment ($F(2,18) = 1.76$, $p = 0.201$).

CHAPTER IV

DISCUSSION

A. Experiment 1

Primary Issue

Foot-level shortening is a phenomenon in which the stressed syllable heading a stress foot shrinks in duration as one or more unstressed syllables are added to the foot. Foot-level shortening occurs whether the unstressed syllable is added to the word containing the stressed syllable or to the word that follows. It has been proposed that a major syntactic break at the word boundary will block foot-level shortening (Cooper et al., 1977; Huggins, 1975), but this has been recently challenged (Rakerd et al., 1987). The purpose of Experiment 1 was to gather more evidence as to whether a major syntactic break--specifically an NP/VP break--completely blocks foot-level shortening (Cooper et al., 1977), has only a moderating effect (Huggins, 1974, 1975), or has no effect at all (Rakerd et al., 1987). Unfortunately, the results were somewhat equivocal.

Analysis 6S--involving the complete data set--indicated that a major syntactic break does indeed block foot-level shortening. The WPH condition exhibited on the order of 10 ms of shortening, whereas essentially no shortening occurred in the MSB condition. Analysis 6S agrees with Huggins's (1975) hypothesis that syntax blocks foot-level shortening.

In fact, the analysis shows even stronger blocking than in the Huggins study where it was found that foot-level shortening was completely blocked by an MSB for one subject but only reduced for the other subject. It is not possible to make a direct comparison with Cooper et al. (1977) because of the confounding of word boundary effects with syntactic boundary effects in their study (see Section IV of the Introduction). However, results of Analysis 6S are in agreement with their hypothesis that syntactic boundaries act as processing junctures which block the application of the trochaic shortening rule (their term for foot-level shortening).

Analyses 4S and 6A--in which certain anomalous data were omitted from the original data set--point to a different conclusion. Both showed that the effect of MSB was to limit, but not completely block, foot-level shortening. This indicates that, whatever the cause of the phenomenon, foot-level shortening at least partially transcends a NP/VP boundary. The presence of a significant interaction between syntax and foot structure is in general agreement with Cooper and his colleagues, but the presence of some foot-level shortening in the MSB condition is not. Also, the presence of relatively large differences in the degree of foot-level shortening between the two syntactic conditions, with less shortening in MSB, is not in full agreement with the results of Rakerd et al. (1987) either.

Experiment 1 does not resolve the issue of the effect on foot-level shortening of a syntactic break but leaves us with two possibilities in mind. One is that a major syntactic break completely blocks the shortening phenomenon. The other is that it has a moderating influence on the phenomenon. There is no evidence to indicate that it lacks any influence at all.

Speculation about the cause of the differences seen between the present study and the study with the most closely related methods (Rakerd et al., 1987) centers, in part, around the differences in target durations. It has been noted that there is a limit to the temporal compressibility of speech segments (Klatt, 1973, 1976; Lindblom, Lyberg, & Holmgren, 1977). In analysis 6S, the mean target duration was 198 ms for MSB sentences and 23 ms shorter, or 175 ms, for WPH sentences. In comparison, the target durations were 176 ms and 133 ms, respectively, for the MSB and WPH conditions in the normal rate study of Rakerd et al. and 135 ms and 109 ms for the MSB and WPH conditions in the fast rate study.

It is speculated that the short WPH target durations in the fast rate condition were at the limits of compressibility and, if so, this could account for the absence of foot-level shortening in WPH that was observed there. Likewise, it is speculated that the WPH target durations in the normal rate were approaching the limits of compressibility. This may have limited the degree of foot-level shortening in WPH that could occur in Rakerd et al.

and, in turn, account for why the observed value was less than in the present study. In contrast, the WPH targets of the present study are much longer, leaving them open to larger shortening effects. It is conceivable, then, that longer WPH target durations would have resulted in greater foot-level shortening in the Rakerd study, perhaps producing a shift in overall results toward those of the present study.

It is possible to look at the preceding discussion of target duration from the perspective of speaking rate. The phonetic details for the target words differ between Rakerd et al. (1987) and the current study, but the targets do consist of similar monosyllabic words in each case. An assumption could be made that the mean durations of the targets should be similar between the two studies and that any differences could be caused by changes in speaking rate. Mean target duration in Analysis 6S (187 ms) was longer (and by inference spoken more slowly) by 32 ms than in the normal rate (155 ms) and by 65 ms than in the fast rate (122 ms) conditions of Rakerd et al. The inference that can be drawn from this parallels that drawn in the previous discussion of target duration. Speakers in Rakerd et al., especially in the fast rate condition, likely spoke rapidly enough to leave little room for foot-level shortening in the WPH condition; speakers in the current study apeared to speak slowly enough that substantial shortening could occur.

Differences in the amount of phonetic control between the present study and that of Rakerd et al. (1987) also might have been a factor in some of the dissimilarities. The target words and words that followed in Rakerd et al. differed between MSB and WPH conditions. The potential effect of this on the foot-level shortening in MSB versus WPH cannot be discounted. Experiment 1 of this study, by contrast, consisted of pertinent words that were phonetically identical in the comparison conditions (cf., Cooper et al., 1977).

Other Issues

Magnitude of Main Effects

Magnitude of domain-final lengthening. It is of interest to compare the quantities of domain-final lengthening and foot-level shortening, as these may help to illuminate some of the similarities and differences seen among the studies. The significant main effect of syntax in the analyses of Experiment 1 is in agreement with other studies that show that a word preceding a pause is longer in duration than the same word in other positions (Cooper, 1975; Huggins, 1975; Klatt, 1975; Lindblom & Rapp, 1973; Rakerd et al., 1987). This phenomenon has been referred to as prepausal lengthening (Klatt, 1976) or domain-final lengthening (Cooper & Paccia-Cooper, 1980; Rakerd et al., 1987). It has been thought to exist either to mark a phrase boundary to help the listener decode the message or as a function of slowing down at the end of motor or planning units (Klatt, 1976).

Domain-final lengthening effects of 22 ms seen in Experiment 1 (and 26 ms for Experiment 2) were comparable to the 26 ms effect seen in Rakerd et al. (1987) when the subjects produced the materials at a fast rate of speech. However, these differences were only about half that observed in Rakerd et al. when the subjects spoke at a normal rate: 43 ms. It is uncertain why this was so. Subjects did not receive instructions to speak rapidly, and there is no evidence that they did so. They produced mean target durations of 197 ms and 175 ms for MSB and WPH respectively, which are much longer than the 135 ms and 109 ms seen in the fast rate study of Rakerd et al.

Magnitude of foot-level shortening. Concerning foot structure, the presence of a main effect--which was significant in analyses 4S and 6A but not in 6S--replicates the findings of other studies which showed the existence of the foot-level shortening phenomenon(Cooper et al., 1977; Fowler, 1977; Huggins, 1975; Rakerd et al., 1987). The magnitude of shortening in analyses 6S (5 ms) and 6A (13 ms) is to be compared with shortening in the normal rate (9 ms) and fast rate (2 ms) conditions of Rakerd et al. (1987). It is not surprising that analysis 6A exhibited the greatest amount of shortening; no attempt had been made in the other studies to eliminate sentences in which negative foot-level shortening occurred in WPH.

Negative Foot-Level Shortening

An issue arose in the study concerning negative foot-level shortening (i.e., lengthening). From the perspective of all subjects together, lengthening was present in WPH for sentences 2 and 5. From the perspective of individual subjects, lengthening was present in WPH for various sentences. It is uncertain why this lengthening occurred, as foot-level shortening has been found to be a consistent, albeit small, effect. It is also uncertain how often lengthening occurs. In the one article that presented the results in such a way that any lengthening that occurred would be demonstrated (Huggins, 1974), occasional lengthening was present. One subject demonstrated lengthening in two from among three sentence types, whereas two other subjects demonstrated it for one sentence type.

In Experiment 1 of the present study, subjects 4 and 6 exhibited mean lengthening rather than foot-level shortening for the foot structure factor (see Table 5). Looking at foot-level shortening when the syntax factor is separated into its two levels, one subject (subject 4) still exhibited lengthening for WPH and four subjects (including 4 and 6) exhibited lengthening for MSB.

Further studies might increase our understanding of these individual differences. Perhaps the individual subject differences indicate different motoric strategies, and perhaps a better understanding of individual differences will help to rationalize the conflicting reports in the literature. One thing that does not seem to be a factor in the subjects (and the sentences) that exhibited anomalous foot-level lengthening is speaking rate. (See earlier discussion of target duration and speaking rate.) The anomalous subjects and sentences did not differ markedly from the other subjects and sentences in overall duration.

Intention Versus Performance

A different issue involves experimenter intention versus subject performance. All studies of foot-level shortening have developed speech materials that have specific stress patterns (e.g., T#S or T#uS) that the researchers intend the subjects to produce. No study has determined, in detail, the actual stress patterns produced by the subjects. It is possible that one or several subjects could have exhibited some inconsistency. An informal analysis of all of the subjects' productions in this study indicated that they did perform as desired. However, a closer analysis by a trained phonetician might reveal differences in stress, especially regarding the level of relative destressing in the T#uS conditions.

There is reason to believe that at least some speakers may alter the stress characteristics of certain words or syllables from expected production. A phenomenon known as stress clash is present in half of all sentence stimuli for the present experiment (all of the T#S sentences are characterized by stress clash). Stress clash occurs when two stressed syllables are adjacent to each other in an utterance, thereby eliminating the preferred alternation of stressed and unstressed syllables. The study of metrical phonology has been concerned with describing the generation of rhythm, especially the tendency for speakers to alternate stressed and unstressed syllables. Several of these studies have focused on the generation of stress within an individual word and then on what happens when stress clash occurs with an adjacent word. Some theories of metrical phonology focus on describing how stress clash is avoided and alternation is maintained (Kelly & Bock, 1988; Liberman & Prince, 1977; Selkirk, 1984).

The experiments of the present study, as well as the other studies of foot-level shortening, used sentence pairs in which one of the sentences included a stressed target word followed immediately by another stressed word. Although an informal assessment of stress characteristics in Experiments 1 and 2 indicated that the words were stressed as anticipated, a closer analysis might have found individual subject differences that were not apparent. In light of the possibility of stress clash, it might be fruitful to attend more closely to the actual performance, rather than to the anticipated performance, of the stress placed on the words of interest in studying foot-level shortening. It is conceivable that some of the negative foot-level shortening seen in the study resulted from stress clash.

Phonetic Control

Still another issue involves the attempt to obtain good phonetic control over the sentence materials. Tradeoffs permeate this line of research. The present study controls for phonetic factors but at the expense of some semantic goodness. For example, the sentence The low caste (a)roused is seldom seen would be better stated One seldom sees the low caste (a)roused. Cooper et al. (1977) developed a set of sentences with good phonetic control, but their method of doing so resulted in a confounding of word and syntactic boundary effects. Rakerd et al. (1987) developed a set of semantically reasonable sentences but lost a certain degree of control over phonetic details. Some of the differences among the studies may reflect the choices in experimental tradeoffs that have been made.

Consistency Effect

A final issue involves the possibility of a consistency effect. In Experiment 1, three sentences (3,4, and 6) have the same word (i.e., (a)roused) following the target (either coach, date, or cast(e)). It is of interest to know whether it has the same degree of foot-level shortening effect on the target words. As it turns out, the effect of the word varies with target differences between T#S and T#uS of 7 ms, 19 ms, and 8 ms. Clearly features beyond the local phonetic environment are modulating the effect.

B. Experiment 2

Primary Issue

Studies investigating factors that may constrain foot-level shortening have focused primarily on syntactic factors (Cooper et al., 1977; Huggins, 1975; Rakerd et al., 1987). The purpose of Experiment 2 was to investigate another potential constraining factor--pause duration--to see what effect it might have on foot-level shortening. The question, then, was this: Is there a relationship between the magnitude of foot-level shortening and the duration of the pause between the target word and the word that follows?

None of the analyses--the initial correlation, the rank order correlation, the ANOVA on the performance-driven pause categories, nor the reanalyses after omitting negative foot-level shortening--gave any indication of a relationship between pause duration and foot-level shortening.

One speculation regarding the cause of foot-level shortening (see the Introduction, Section D) was that it resulted from coarticulatory overlap. Fowler (1981) had proposed that the shortening of a stressed syllable when an unstressed syllabel is added after it (i.e., foot-level shortening) might be the result of a coarticulatory overlap between the syllables. Indeed, evidence for overlap occurs (Bell-Berti & Harris, 1976; Fowler, 1977, 1981a; Ohman, 1966). It had been proposed that foot-level shortening (and by extension, the coarticulatory overlap) would show a decrease commensurate with the degree of pause duration between syllables for the sentence stimuli of Experiment 2. The lack of correlation might have been explained by a relationship that was not linear, but no significant differences were found in the amount of foot-level shortening for the three performance-driven pause categories (i.e., short, medium, and long pauses). The lack of any relationship between pause duration and foot-level shortening fails to provide support for coarticulatory overlap being a factor in foot-level shortening.

There are no studies with which Experiment 2 may be directly compared. Only Cooper et al. (1977) have commented on any potential relationship between pause duration and foot-level shortening. They noted that foot-level shortening was blocked by a variety of different syntactic boundaries that normally give rise to different pause durations. This would lead to a prediction of no correlation but, of course, the confounding of word and syntactic boundary effects in their study would call that prediction into question.

Some similarities exist between Experiment 2 and Experiment 1, Rakerd et al. (1987), and Huggins (1975). This is especially true of the results of analyses done to determine whether syntactic environments (WPH, MSB, and CLB) differed in their amount of foot-level shortening in Experiment 2. These results parallel Rakerd et al. in indicating no significant difference in foot-level shortening among syntactic conditions. In fact, the amount of shortening for the different conditions in one study closely resembles that in the other. In Rakerd et al., foot-level shortening was 6 ms in WPH and 8 ms in MSB. In Experiment 2, these were 5 ms in WPH and 8 ms in MSB (and 2 ms in CLB). Of course the methodological issues mentioned below involving any syntactic analyses in Experiment 2 suggest that caution be taken before drawing any conclusions from the results.

Other Issues

There are a few methodological issues involving Experiment 2. Some of these are shared with Experiment 1, such as individual subject differences and the intention versus the performance of the stress patterns of the speech materials. Of special concern in Experiment 2 are the degree of phonetic control, the locations in the sentences of the target/following-word boundaries, and the variability in sentence lengths.

In Experiment 1, close attention had been paid to phonetically matching the targets and their following words between the MSB and WPH conditions. No such control had been--nor indeed could have been--placed on the sentences in Experiment 2. Likewise in Experiment 1, the targets and following words all fell in the same location within the sentences (i.e., word 3 and word 4), and the sentence lengths were all essentially the same (i.e., 6 to 7 words).

In attempting to generate sentences for Experiment 2, a tradeoff was made between these factors and the need to have a wide range of pause durations. It is uncertain what effect the lack of control over these factors could have had on the outcome of the study, but it is conceivable that it might have obscured some of the expected results.

C. Implications

Theoretical Implications

Linguistic Versus Physical Phenomenon

The results of the two experiments in this study allow for speculation about the effects that syntactic boundaries have on foot-level shortening. They do not, however, allow for a definite conclusion concerning whether it is a linguistic or motor phenomenon. Of course foot-level shortening is carried out motorically; but whether it results from linguistic planning, as suggested by Cooper et al. (1977), or whether it is a byproduct of coarticulation, or whether both factors enter in, cannot be fully answered by the results.

Analysis 6S of Experiment 1 is particularly compatible with the speculation by Cooper et al. (1977) who viewed foot-level shortening as the result of a phonological rule they termed the trochaic shortening rule. They studied the effect that syntactic boundaries could have on foot-level shortening because "for cases in which a syntactic boundary blocks a rule normally applicable across word boundaries, we can infer that the boundary acts as a juncture in the speaker's processing, prohibiting any following information from influencing segments preceding the boundary" (p. 1314). Analysis 6S certainly indicates that a NP/VP boundary blocks foot-level shortening. However, by itself the analysis does not answer the question of how foot-level shortening originates, if only because the results for two of the six test sentences were uninterpretable.

Analyses 4S and 6A of Experiment 1 offer some support to the competing idea that foot-level shortening is a lower level, motor phenomenon. According to Fowler's (1985) coarticulatory overlap model, foot-level shortening arises from the overlap of a stressed syllable with the following unstressed syllable. These additional analyses show a limiting of foot-level shortening rather than a total blocking when a NP/VP boundary separates the syllables. This is the kind of result that would be expected if coarticulatory overlap were involved in foot-level shortening and if the syntactic boundary were marked by prepausal lengthening of the stressed syllable and/or by some pausing between the syllables. More specifically, shortening would be expected to occur robustly within a phrase, probably not at all when the words were separated by a clause boundary (which would involve prepausal lengthening and a long pause), and would be weakened rather than blocked by a phrase boundary such as NP/VP, assuming again that the latter were signalled acoustically.

Results of Experiment 2, like those of Experiment 1, seem more indicative of linguistic, rather than physical, factors driving foot-level shortening. The complete lack of a relationship between pause duration and foot-level shortening indicates that pause duration did not play a part in the constraining effect of syntax seen in Experiment 1, as was speculated above. If syntactic and not physical factors block shortening, this shortening phenomenon very well could be the result of a linguistic rule such as Cooper et al. (1977) had proposed. This can only be speculated on, however, since some of its supportive data can be drawn into question. The methodological concerns about the Cooper et al. (1977) study have already been raised. Also, the absence of significant differences for foot-level shortening among the syntactic categories in the post hoc analyses of Experiment 2 runs counter to the proposal that it is syntactic factors that drive foot-level shortening.

Future Research

Future research could focus on systematic analysis of the effects of other syntactic boundaries on foot-level shortening, as it appears that linguistic factors do indeed constrain the phenomenon. Only Cooper et al. (1977) have attempted to do this previously. Alternatively, focusing on metrical structures may provide a fruitful basis for determining potential constraints on foot-level shortening. In the Introduction it was pointed out that metrical structures include the individual words and the stress feet of an utterance, as well as phonological and intonational phrases. Gee and Grosjean (1983) used these metrical phrase boundaries to generate an algorithm that was better able to account for inter-word pause durations than was another algorithm based on traditional syntactic structures. It is possible that phonological and intonational phrase boundaries, rather than syntactic boundaries, would give a more accurate idea of constraining factors on a prosodic phenomenon such as foot-level shortening.

Future research might also be performed with an awareness of the effect that stress clash may have on individual subject's results. It was pointed out earlier that there differences could arise between experimenter intention versus subject performance when it comes to the stress characteristics of key words in sentence stimuli. Closer attention to this might shed some more light on negative foot-level shortening as well.

Clinical Implications

It may be too early to apply certain findings of this and related studies to clinical populations since the results are somewhat ambiguous. For example, depending upon which analysis is considered from Experiment 1, a syntactic break could be viewed as completely blocking or only limiting foot-level shortening. However, this shortening phenomenon appears to occur with regularity in WPH situations across all studies. Foot-level shortening, along with other word-word and within-word interactions, could be studied in certain clinical populations, such as in the dysarthric, dysfluent, or hearing impaired populations. For example, an acoustic study of these interactions could be performed on dysarthric speakers much as Darley et al. (1975) did a perceptual study two decades ago. This would provide descriptive data that could be compared to data from non-impaired speakers. Clinical benefits could include a better understanding of the behaviors to target when trying to improve the prosody of an individual's speech patterns.

APPENDICES

APPENDIX A

Sentence Materials for Experiment 1

Table A1. Test sentences for Experiment 1.

(1MSB-T#S)	The first <u>knight</u> views the small army.
(1MSB-T#uS)	The first <u>knight</u> reviews the small army.
(1WPH-T#S)	The first <u>night</u> views are quite pleasant.
(1WPH-T#uS)	The first <u>night</u> reviews are quite pleasant.
(2MSB-T#S)	The new <u>pact</u> signs a lasting peace.
(2MSB-T#uS)	The new <u>pact</u> designs a lasting peace.
(2WPH-T#S)	The new <u>packed</u> signs are works of art.
(2WPH-T#uS)	The new <u>packed</u> designs are works of art.
(3MSB-T#S)	A strong <u>coach</u> roused the hockey team.
(3MSB-T#uS)	A strong <u>coach</u> aroused the hockey team.
(3WPH-T#S)	A strong <u>coach</u> roused is often seen.
(3WPH-T#uS)	A strong <u>coach</u> aroused is often seen.
(4MSB-T#S)	His first <u>date</u> roused alarming fear.
(4MSB-T#uS)	His first <u>data</u> aroused alarming fear.
(4WPH-T#S)	His first <u>date</u> roused, they talked quite late.
(4WPH-T#uS)	His first <u>date</u> aroused, they talked quite late.
(5MSB-T#S)	The new <u>tax</u> doubled the opposition.
(5MSB-T#uS)	The new <u>tax</u> redoubled the opposition.
(5WPH-T#S)	The new <u>tax</u> doubled, they sold their house.
(5WPH-T#uS)	The new <u>tax</u> redoubled, they sold their house.
(6MSB-T#S)	The low <u>cast</u> roused the fisherman.
(6MSB-T#uS)	The low <u>cast</u> aroused the fisherman.
(6WPH-T#S)	The low <u>caste</u> roused is seldom seen.
(6WPH-T#uS)	The low <u>caste</u> aroused is seldom seen.

<u>Note</u>. Sentence group is indicated by number, Syntax by MSB or WPH, and Foot Structure by T#S or T#uS.

Table A2. Pseudo-randomized sentence lists for Experiment 1.

<u>List 1</u>

The new <u>packed</u> signs are works of art.
The first <u>night</u> views are quite pleasant.
The low <u>cast</u> roused the fisherman.
The first <u>knight</u> reviews the small army.
A strong <u>coach</u> roused the hockey team.
The new <u>tax</u> redoubled the opposition.
The low <u>caste</u> roused is seldom seen.
The new <u>packed</u> designs are works of art.
His first <u>date</u> aroused, they talked quite late.
A strong <u>coach</u> aroused the hockey team.
The new <u>tax</u> doubled the opposition.
His first <u>date</u> aroused alarming fear.

<u>List 2</u>

The new <u>tax</u> redoubled, they sold their house.
The first <u>night</u> reviews are quite pleasant.
His first <u>date</u> roused, they talked quite late.
The first <u>knight</u> views the small army.
The low <u>caste</u> aroused is seldom seen.
The new <u>tax</u> doubled, they sold their house.
The new <u>pact</u> designs a lasting peace.
A strong <u>coach</u> aroused is often seen.
His first <u>date</u> roused alarming fear.
The new <u>pact</u> signs a lasting peace.
The low <u>cast</u> aroused the fisherman.
A strong <u>coach</u> roused is often seen.

APPENDIX B

Sentence Materials for Experiment 2

Table B1. Sentences from Gee and Grosjean (1983).

1. When the new lawyer called up Reynolds the plan was discussed thoroughly.
2. In addition to his files the lawyer brought the office's best adding-machine.
3. By making his plan known he brought out the objections of everyone.
4. That a solution couldn't be found seemed quite clear to them.
5. Not quite all of the recent files were examined that day.
6. That the matter was dealt with so fast was a shock to him.
7. John asked the strange young man to be quick on the task.
8. Closing his client's book the young expert wondered about this extraordinary story.
9. The expert who couldn't see what to criticize sat back in despair.
10. After the cold winter of that year most people were totally fed-up.
11. The agent consulted the agency's book in which they offered numerous tours.
12. She discussed the pros and cons to get over her surprisingly apprehensive feelings.
13. Our disappointed woman lost her optimism since the prospects were too limited.
14. Since she was indecisive that day her friend asked her to wait.

Table B2. Test sentences for Experiment 2, modified from Gee and Grosjean (1983).

(1-T#S)	When the <u>bright</u> viewer called up Reynolds the plan was discussed thoroughly.
(1-T#uS)	When the <u>bright</u> reviewer called up Reynolds the plan was discussed thoroughly.
(2-T#S)	After the <u>deep</u> visions of that year most people were totally fed-up.
(2-T#uS)	After the <u>deep</u> divisions of that year most people were totally fed-up.
(3-T#S)	John asked the strange <u>trite</u> porter to be quick on the task.
(3-T#uS)	John asked the strange <u>trite</u> reporter to be quick on the task.
(4-T#S)	That a solution couldn't be found seemed <u>quite</u> logical to them.
(4-T#uS)	That a solution couldn't be found seemed <u>quite</u> illogical to them.
(5-T#S)	In addition to his files the <u>cop</u> moved the office's best adding-machine.
(5-T#uS)	In addition to his files the <u>cop</u> removed the office's best adding-machine.
(6-T#S)	Not <u>quite</u> one of the recent files was examined that day.
(6-T#uS)	Not <u>quite</u> a-one of the recent files was examined that day.
(7-T#S)	The agent consulted the agency's book in which they <u>tout</u> rousing tours.
(7-T#uS)	The agent consulted the agency's book in which they <u>tout</u> arousing tours.
(8-T#S)	Since she was indecisive that day her <u>bank</u> told her to wait.
(8-T#uS)	Since she was indecisive that day her <u>bank</u> retold her to wait.
(9-T#S)	Closing his client's book the young <u>clerk</u> thought about this extraordinary story.
(9-T#uS)	Closing his client's book the young <u>clerk</u> rethought about this extraordinary story.
(10-T#S)	John asked the strange young man to be <u>quick</u> 'bout the task.
(10-T#uS)	John asked the strange young man to be <u>quick</u> about the task.
(11-T#S)	When the new <u>pope</u> called Reynolds the plan was discussed thoroughly.
(11-T#uS)	When the new <u>pope</u> recalled Reynolds the plan was discussed thoroughly.
(12-T#S)	Our disappointed <u>duke</u> trusted his optimism since the prospects were too limited.
(12-T#uS)	Our disappointed <u>duke</u> mistrusted his optimism since the prospects were too limited.

Table B2 (cont.)

(13-T#S)	That a solution couldn't be <u>built</u> 'peared quite clear to them.
(13-T#uS)	That a solution couldn't be <u>built</u> appeared quite clear to them.
(14-T#S)	After the cold weather to that <u>point</u> reasonable people were totally fed-up.
(14-T#uS)	After the cold weather to that <u>point</u> unreasonable people were totally fed-up.
(15-T#S)	Since she was indecisive that <u>date</u> Lisa's friend asked her to wait.
(15-T#uS)	Since she was indecisive that <u>date</u> Alicia's friend asked her to wait.

<u>Note</u>. Sentences are arranged with gradually increasing pause durations between target and following words, based on Gee and Grosjean's measurements. Numbers indicate sentence groups and T#S or T#uS indicate foot structure.

Table B3. Pseudo-randomized sentence lists for Experiment 2.

<u>List 1</u>

1. When the new <u>pope</u> recalled Reynolds the plan was discussed thoroughly.
2. After the cold weather to that <u>point</u> reasonable people were totally fed-up.
3. John asked the strange young man to be <u>quick</u> about the task.
4. Since she was indecisive that day her <u>bank</u> retold her to wait.
5. Closing his client's book the young <u>clerk</u> thought about this extraordinary story.
6. Since she was indecisive that <u>date</u> Alicia's friend asked her to wait.
7. In addition to his files the <u>cop</u> moved the office's best adding-machine.
8. Not <u>quite</u> a-one of the recent files was examined that day.
9. After the <u>deep</u> visions of that year most people were totally fed-up.
10. That a solution couldn't be <u>built</u> appeared quite clear to them.

<u>List 2</u>

1. Our disappointed <u>duke</u> mistrusted his optimism since the prospects were too limited.
2. Since she was indecisive that day her <u>bank</u> told her to wait.
3. Not <u>quite</u> one of the recent files was examined that day.
4. Closing his client's book the young <u>clerk</u> rethought about this extraordinary story.
5. In addition to his files the <u>cop</u> removed the office's best adding-machine.
6. When the new <u>pope</u> called Reynolds the plan was discussed thoroughly.
7. John asked the strange <u>trite</u> porter to be quick on the task.
8. After the <u>deep</u> divisions of that year most people were totally fed-up.
9. That a solution couldn't be found seemed <u>quite</u> logical to them.
10. The agent consulted the agency's book in which they <u>tout</u> rousing tours.

Table B3 (cont.)

<u>List 3</u>

1. When the <u>bright</u> viewer called up Reynolds the plan was discussed thoroughly.
2. Our disappointed <u>duke</u> trusted his optimism since the prospects were too limited.
3. John asked the strange young man to be <u>quick</u> 'bout the task.
4. That a solution couldn't be <u>built</u> 'peared quite clear to them.
5. When the <u>bright</u> reviewer called up Reynolds the plan was discussed thoroughly.
6. After the cold weather to that <u>point</u> unreasonable people were totally fed-up.
7. That a solution couldn't be found seemed <u>quite</u> illogical to them.
8. Since she was indecisive that <u>date</u> Lisa's friend asked her to wait.
9. The agent consulted the agency's book in which they <u>tout</u> arousing tours.
10. John asked the strange <u>trite</u> reporter to be quick on the task.

APPENDIX C

ANOVA Tables for Experiment 1

Table C1. ANOVA summary table for Analysis 6S of Experiment 1.

Source	SS	df	MS	$F_{subject}$	$F_{sentence}$
1 Syntax	89333.59	1	89333.59	[1/5] = 12.18**	[1/9] = 37.56**
2 Foot Structure	4794.60	1	4794.60	[2/6] = 4.11	[2/10] = 1.01
3 1 x 2	5195.39	1	5195.39	[3/7] = 14.38**	[3/11] = 9.72*
4 Subject	238182.20	9	26464.69		[4/4x8] = 6.74**
5 4 x 1	65998.45	9	7333.16		[5/1x8x4] = 11.76**
6 4 x 2	10492.12	9	1165.79		[6/2x8x4] = 1.86
7 4 x 1 x 2	3250.66	9	361.18		[7/1x2x8x4] = 0.74
8 Sentence	473648.80	5	94729.75	[8/8x4] = 24.14**	
9 8 x 1	11890.84	5	2378.17	[9/1x8x4] = 3.81**	
10 8 x 2	23809.83	5	47611.97	[10/2x8x4] = 7.60**	
11 8 x 1 x 2	2671.97	5	534.39	[11/1x2x8x4] = 1.09	

Note: * $p < 0.05$; ** $p < 0.01$

Table C2. ANOVA summary table for Analysis 4S of Experiment 1.

Source	SS	df	MS	Fsubject	Fsentence
1 Syntax	83423.84	1	83423.84	[1/5] = 16.63**	[1/9] = 55.74**
2 Foot Structure	18799.98	1	18799.98	[2/6] = 17.65**	[2/10] = 16.46*
3 1 x 2	5227.45	1	5227.45	[3/7] = 10.60**	[3/11] = 7.98
4 Subject	163182.90	9	18131.43		[4/8x4] = 3.72**
5 4 x 1	45142.23	9	5015.80		[5/1x8x4] = 7.17**
6 4 x 2	9586.92	9	1065.21		[6/2x8x4] = 1.92
7 4 x 1 x 2	4440.02	9	493.34		[7/1x2x8x4] = 0.82
8 Sentence	463245.90	3	154415.30	[8/8x4] = 31.67**	
9 8 x 1	4489.59	3	1496.53	[9/1x8x4] = 2.14	
10 8 x 2	3427.44	3	1142.48	[10/2x8x4] = 2.06	
11 8 x 1 x 2	1966.15	3	655.38	[11/1x2x8x4] = 1.09	

Note: * $p < 0.05$; ** $p < 0.01$

Table C3. ANOVA summary table for Analysis 6A of Experiment 1.

	Source	SS	df	MS	F
1	Syntax	54683.21	1	54683.21	[1/3] = 10.39**
2	Foot Structure	20326.13	1	20326.21	[2/3] = 60.75**
3	1 x 2	5364.61	1	5364.61	[3/5] = 21.65**
4	Subject	196309.30	9	21812.14	[4/6] = 17.82**
5	4 x 1 x 2	2229.88	9	247.76	[5/6] = 0.20
6	Error	582532.80	476	1223.81	

Note: * $p < 0.05$; ** $p < 0.01$

APPENDIX D

Mean Target Durations for Experiment 1

Table D1. Mean target durations (in ms) of syntax for the subjects of Experiment 1, Analysis 4S.

Subject	Syntax		
	MSB	WPH	Diff.
1	243	198	45
2	199	193	6
3	180	172	8
4	170	160	10
5	162	144	18
6	199	175	24
7	217	185	32
8	184	169	15
9	201	170	31
10	234	162	72
<u>M</u>	199	173	26

Table D2. Mean target durations (in ms) of foot structure for the subjects of Experiment 1, Analysis 4S.

	Foot Structure		
Subject	T#S	T#uS	Diff.
1	231	210	21
2	196	196	0
3	185	166	19
4	167	163	4
5	156	150	6
6	187	187	0
7	212	189	23
8	189	164	25
9	193	178	15
10	204	193	11
M	192	180	12

Table D3. Mean target durations (in ms) of syntax by foot structure for the subjects of Experiment 1, Analysis 4S.

	Syntax					
	MSB			WPH		
Subject	T#S	T#uS	Diff.	T#S	T#uS	Diff.
1	251	235	16	210	185	25
2	190	208	-18	202	184	18
3	191	168	23	179	164	15
4	170	170	0	164	156	8
5	162	161	1	149	138	11
6	196	202	-6	178	171	7
7	220	213	7	204	165	39
8	193	175	18	185	152	33
9	206	195	11	180	160	20
10	238	230	8	169	155	14
M	202	196	6	182	163	19

Table D4. Mean target durations (in ms) of syntax for the subjects of Experiment 1, Analysis 6A.

	Syntax		
Subject	MSB	WPH	Diff.
1	242	200	42
2	197	191	6
3	169	172	-3
4	157	160	-3
5	151	132	19
6	186	168	18
7	213	184	29
8	186	175	11
9	200	170	30
10	216	149	67
M	192	170	22

Table D5. Mean target durations (in ms) of foot structure for the subjects of Experiment 1, Analysis 6A.

	Foot Structure		
Subject	T#S	T#uS	Diff.
1	227	214	13
2	195	193	2
3	181	161	20
4	165	151	14
5	148	135	13
6	181	173	8
7	207	190	17
8	190	172	18
9	193	177	16
10	189	176	13
<u>M</u>	188	174	14

Table D6. Mean target durations (in ms) of syntax by foot structure for the subjects of Experiment 1, Analysis 6A.

	Syntax					
	MSB			WPH		
Subject	T#S	T#uS	Diff.	T#S	T#uS	Diff.
1	245	239	6	210	189	21
2	191	203	-12	198	184	14
3	180	159	21	181	163	18
4	160	154	6	171	149	22
5	156	147	9	141	123	18
6	184	189	-5	177	158	19
7	216	210	6	198	170	28
8	190	182	8	189	162	27
9	206	195	11	180	160	20
10	221	210	1	157	142	15
M	195	189	6	180	160	20

APPENDIX E

ANOVA Tables for Experiment 2

Table E1. ANOVA summary table of pause duration for three experimenter-constructed pause categories.

	Source	SS	df	MS	F
1	Pause Category	168145	2	84072	[1/3] = 27.61**
2	Subject	23948	9	2661	[2/3] = 0.87
3	Error	420262	138	3045	
4	Total	612354			

Note: * $p < 0.05$; ** $p < 0.01$

Table E2. ANOVA summary table of pause duration for three performance-driven pause categories.

	Source	SS	df	MS	F
1	Pause Category	31352	2	156676	[1/3] = 78.61**
2	Subject	23948	9	2661	[2/3] = 1.33
3	Error	275055	138	1993	
4	Total	612354	149		

Note: * $p < 0.05$; ** $p < 0.01$

Table E3. ANOVA summary table of foot-level shortening for three rank-order-driven pause categories

	Source	SS	df	MS	F
1	Pause Category	562.9	2	281.4	[1/3] = 0.63
2	Subject	4346.3	9	482.9	[2/3] = 1.08
3	Error	61880.6	138	448.4	
4	Total	66789.8	149		

Note: * $p < 0.05$; ** $p < 0.01$

Table E4. ANOVA summary table of pause duration for three syntactic categories.

	Source	SS	df	MS	F
1	Syntactic Category	42424	2	21212	[1/3] = 12.11**
2	Subject	7835	9	871	[2/3] = 0.50
3	Error	31516	18	1751	
4	Total	81775	29		

Note: * $p < 0.05$; ** $p < 0.01$

Table E5. ANOVA summary table of foot-level shortening for three syntactic categories.

	Source	SS	df	MS	F
1	Syntactic Category	464.7	2	232.4	[1/3] = 1/56
2	Subject	1020.3	9	113.4	[2/3] = 0.76
3	Error	2675.7	18	148.7	
4	Total	4160.8	29		

Note: * $p < 0.05$; ** $p < 0.01$

Table E6. ANOVA summary table of pause duration for three performance-driven pause categories using data with deletions.

	Source	SS	df	MS	F
1	Pause Category	64095.1	2	32047.5	[1/3] = 76.95**
2	Subject	4450.7	9	494.5	[2/3] = 1.19
3	Error	7496.2	18	416.5	
4	Total	76042.0	29		

Note: * $p < 0.05$; ** $p < 0.01$

Table E7. ANOVA summary table of foot-level shortening for three performance-driven pause categories using data with deletions.

	Source	SS	df	MS	F
1	Pause Category	56.9	2	28.4	[1/3] = 0.21
2	Subject	563.1	9	62.6	[2/3] = 0.47
3	Error	2396/6	18	133.1	
4	Total	3016.5	29		

Note: * $p < 0.05$; ** $p < 0.01$

Table E8. ANOVA summary table of pause duration for three syntactic categories using data with deletions.

	Source	SS	df	MS	F
1	Syntactic Category	47244	2	23622	[1/3] = 12.89**
2	Subject	8121	9	902	[2/3] = 049
3	Error	32991	18	1833	
4	Total	88356			

Note: * $p < 0.05$; ** $p < 0.01$

Table E9. ANOVA summary table of foot-level shortening for three syntactic categories using data with deletions.

Source	SS	df	MS	F
1 Syntactic Category	363.9	2	182.0	[1/3] = 1.76
2 Subject	544.6	9	60.5	[2/3] = 0.58
3 Error	1862.7	18	103.5	
4 Total	2771.2	29		

Note: * $p < 0.05$; ** $p < 0.01$

LIST OF REFERENCES

LIST OF REFERENCES

Abercrombie, D. (1964). Syllable quantity and enclitics in English. In D. Abercrombie, D. Fry, P MacCarthy, & J. Trim (Eds.), In honour of Daniel Jones. London: Longman.

Allen, G. D. (1975). Speech rhythm: Its relation to performance universals and articulatory timing. Journal of Phonetics, 3, 75-86.

American National Standards Institute (1969). American national standards specifications for audiometers (ANSI S3.6-1969). New York: American National Standards Institute.

Barlow, S. M., Cole, K., & Abbs, J. H. (1983). A new headmounted lip-jaw movement transduction system for the study of motor speech disorders. Journal of Speech and Hearing Research, 26, 283-288.

Barnes, G. J. (1983). Suprasegmental and prosodic considerations in motor speech disorders. In W. Berry (Ed.), Clinical dysarthria. San Diego: College-Hill.

Barnwell, T. P. (1971). An algorithm for segment duration in a reading machine context (Technical Report 479). Cambridge, MA: MIT, Research Laboratory of Electronics.

Beckman, M. E., & Edwards, J. (1987). The phonological domains of final lengthening [Abstract]. Program: 113th Meeting of the Acoustical Society of America, Supplement 1, 81, S67.

Bell-Berti, F., & Harris, K. S. (1976). Some aspects of coarticulation. Haskins Laboratories Status Report on Speech Research, 45/46, 197-204.

Beukelman, D. R. (1983). Treatment of mixed dysarthria. In W. H. Perkins (Ed.), Current therapy of communication disorders: Apraxia and dysarthria. New York: Thieme-Stratton.

Beukelman, D. R., & Yorkston, K. M. (1977). A communication system for the severely dysarthric speaker with an intact language system. Journal of Speech and Hearing Disorders, 42, 265-270.

Beukelman, D. R., Yorkston, K. M., & Tice, R. (1988). PACER/TALLY. Tucson: Communication Skill Builders.

Borden, G. J., & Harris, K. S. (1984). Speech science primer: Physiology, acoustics, and perception of speech (2nd ed.). Baltimore: Williams & Wilkins.

Caligiuri, M. P., & Murry, T. (1983). The use of visual feedback to enhance prosodic control in dysarthria. In W. R. Berry (Ed.), Clinical dysarthria. San Diego: College-Hill.

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. Journal of Verbal Learning and Verbal Behavior, 12, 335-359.

Classe, A. (1939). The rhythm of English prose. Oxford: Blackwell.

Cooper, F. S., Liberman, A. M., & Borst, J. M. (1951). The interconversion of audible and visible patterns as a basis for research in the perception of speech. Proceedings of the National Academy of Science, 37, 318-325.

Cooper, W. E. (1976). Syntactic control of timing in speech production: A study of complement clauses. Journal of Phonetics, 4, 151-171.

Cooper, W. E., & Danly, M. (1981). Segmental and temporal aspects of utterance-final lengthening. Phonetica, 38, 106-115.

Cooper, W. E., & Eady, S. J. (1986). Metrical phonology and speech production. Journal of Memory and Language, 25, 369-384.

Cooper, W. E., Lapointe, S. G., & Paccia, J. M. (1977). Syntactic blocking of phonological rules in speech production. Journal of the Acoustical Society of America, 61, 1314-1320.

Cooper, W. E., & Paccia-Cooper, J. M. (1980). Syntax and speech. Cambridge, MA: Harvard University Press.

Crystal, D. (1969). Prosodic systems and intonation in English. London: Cambridge University Press.

Darley, F. L., Aronson, A. E., & Brown J. R. (1975). Motor speech disorders. Philadelphia: W. B. Saunders.

Dauer, R. M. (1983). Stress-timing and syllable-timing reanalyzed. Journal of Phonetics, 11, 51-62.

Dudley, H., Reisz, R. R., & Watkins, S. A. (1939). A synthetic speaker. Journal of the Franklin Institute, 227, 739-764.

Egan, J. P. (1948). Articulation testing methods. Laryngoscope, 58, 955-991.

Fairbanks, G. (1960). Voice and articulation drillbook (2nd ed.). New York: Harper & Row.

Forest, K., Adams, S., McNeil, M. R., & Southwood, H. (1991). Kinematic, electromyographic, and perceptual evaluation of speech apraxia, conduction aphasia, ataxic dysarthria, and normal speech production. In C. A. Moore, K. M. Yorkston, & D. R. Beukelman (Eds.), Dysarthria and apraxia of speech: Perspectives on management. Baltimore: Paul H. Brookes.

Fowler, C. A. (1977). Timing control in speech production. Bloomington, IN: Indiana University Linguistics Club.

Fowler, C. A. (1981). A relationship between coarticulation and compensatory shortening. Phonetica, 38, 35-50.

Fowler, C. A. (1985). Current perspectives on language and speech: A critical overview. In R. Daniloff (Ed.), Speech science. San Diego: College-Hill.

Fowler, C. A., & Tassinary, L. G. (1981). Natural measurement criteria for speech: The anisochrony illusion. In J. Long & A. Baddeley (Eds.), Attention and performance (vol. IX). Hillsdale, NJ: Lawrence Erlbaum.

Freeman, F. J. (1982). Prosody in perception, production, and pathologies. In N. J. Lass, L. V. McReynolds, J. L. Northern, & D. E. Yoder (Eds.), Speech, language, and hearing, vol. 1: Normal processes. Philadelphia: W. B. Saunders.

Fry, D. B. (1955). Duration and intensity as physical correlates of linguistic stress. Journal of the Acoustical Society of America, 27, 765-768.

Fry, D. B. (1958). Experiments in the perception of stress. Language and Speech, 1, 126-152.

Gee, J. P., & Grosjean, F. (1983). Performance structures: A psycholinguistic and linguistic appraisal. Cognitive Psychology, 15, 411-458.

Grosjean, F., Grosjean, L., & Lane, H. (1979). The patterns of silence: Performance structures in sentence production. Cognitive Psychology, 11, 58-81.

Hammen, V. I., Yorkston, K. M., & Beukelman, D. R. (1989). Pausal and speech duration characteristics as a function of speaking rate in normal and parkinsonian dysarthric individuals. In K. M. Yorkston & D. R. Beukelman (Eds.), Recent advances in clinical dysarthria. Boston: College-Hill.

Handel, S. (1989). Listening: An introduction to the perception of auditory events. Cambridge, MA: MIT Press.

House, A. S. (1961). On vowel duration in English. Journal of the Acoustical Society of America, 33, 1174-1178.

Huggins, A. W. F. (1974). An effect of syntax on syllable timing (Quarterly Progress Report No. 14). Cambridge, MA: MIT, Research Laboratory of Electronics.

Huggins, A. W. F. (1975). On isochrony and speech. In G. Fant & M. A. A. Tatham (Eds.), Auditory analysis and perception of speech. London: Academic.

Huggins, A. W. F. (1978). Speech timing and intelligibility. In J. Requin (Ed.), Attention and performance (vol. VII). Hillsdale, NJ: Lawrence Erlbaum.

Jassem, W., Hill, D. R., & Witten, I. H. (1984). Isochrony in English speech: Its statistical validity and linguistic relevance. In D. Gibbon & H. Richter (Eds.), Intonation, accent, and rhythm. Berlin: De Gruyter.

Kelly, M. H., & Bock, J. K. (1988). Stress in time. Journal of Experimental Psychology: Human Perception and Performance, 14, 389-403.

Kent, R. D. (1984). Stuttering as a temporal programming disorder. In R. F. Curlee & W. H. Perkins (Eds.), Nature and treatment of stuttering: New directions. San Diego: College-Hill.

Kent, R. D., Netsell, R., & Abbs, J. H. (1979). Acoustic characteristics of dysarthria associated with cerebellar disease. Journal of Speech and Hearing Research, 22, 627-648.

Kent, R. D., & Rosenbek, J. C. (1982). Prosodic disturbance and neurological lesion. Brain and Language, 15, 259-291.

Kent, R. D., & Rosenbek, J. C. (1983). Acoustic patterns of apraxia of speech. Journal of Speech and Hearing Research, 26, 231-249.

Kiparsky, P. (1979). Metrical structure assignment is cyclic. Linguistic Inquiry, 10, 421-441.

Kirk, R. E. (1982). Experimental design (2nd ed.). Pacific Grove, CA: Brooks/Cole.

Klatt, D. H. (1973). Interaction between two factors that influence vowel duration. Journal of the Acoustical Society of America, 54, 1102-1104.

Klatt, D. H. (1975). Vowel lengthening is syntactically determined in a connected discourse. Journal of Phonetics, 3, 129-140.

Klatt, D. H. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. Journal of the Acoustical Society of America, 59, 1208-1221.

Klatt, D. H. (1987). Review of text-to-speech conversion for English. Journal of the Acoustical Society of America, 82, 737-793.

Kozhevnikov, F. A., & Chistovich, L. A. (1965). Rech: Artikulyatisiya i vospriyatiye. Moscow-Leningrad. Translated as Speech: Articulation and perception. Springfield, VA: United States Department of Commerce, Joint Publications Research Service, Vol. 30, 1966.

Ladd, D. R., & Cutler, A. (1983). Introduction, models, and measurements in the study of prosody. In D. R. Ladd & A. Cutler (Eds.), Prosody: Models and measurements. Berlin: Springer-Verlag.

Lehiste, I. (1970). Suprasegmentals. Cambridge, MA: MIT Press.

Lehiste, I. (1972). The timing of utterances and linguistic boundaries. Journal of the Acoustical Society of America, 51, 2018-2024.

Lehiste, I. (1973). Rhythmic units and syntactic units in production and perception. Journal of the Acoustical Society of America, 54, 1228-1234.

Lehiste, I. (1976). Suprasegmental features of speech. In N. Lass (Ed.), Contemporary issues in experimental phonetics. New York: Academic.

Lehiste, I. (1977). Isochrony reconsidered. Journal of Phonetics, 5, 253-263.

Liberman, M., & Prince, A. (1977). On stress and linguistic rhythm. Linguistic Inquiry, 8, 249-336.

Lieberman, P. (1960). Some acoustic correlates of word stress in American English. Journal of the Acoustical Society of America, 32, 451-454.

Lieberman, P. (1967). Intonation, perception, and language. Cambridge, MA: MIT Press.

Lindblom, B. (1968). Temporal organization of syllable production (Quarterly Progress and Status Report 2-3). Stockholm: Royal Institute of Technology.

Lindblom, B., & Rapp, K. (1973). Some temporal regularities of spoken Swedish. Papers in Linguistics from the University of Stockholm, 21, 1-59.

Linebaugh, C. W., & Wolfe, V. E. (1984). Relationships between articulation rate, intelligibility, and naturalness in spastic and ataxic speakers. In M. McNeil, J. Rosenbek, & A. Aronson (Eds.), The dysarthrias: Physiology, acoustics, perception, management. San Diego: College-Hill.

McNeil, M. R., Caligiuri, M. A., & Rosenbek, J. C. (1989). A comparison of labiomendibular kinematic durations, displacements, velocities, and dysmetrias in apraxic and normal adults. In T. E. Prescott (Ed.), Clinical aphasiology. San Diego: College-Hill.

Miller, N. (1990). Acquired speech disorders. In K. Grundy (Ed.), Linguistics in clinical practice. London: Whurr.

Morris, D. W. H. (1988). A dictionary of speech therapy. London: Whurr.

Murry, T. (1983). The production of stress in three types of dysarthric speech. In W. R. Berry (Ed.), Clinical dysarthria. San Diego: College-Hill.

Nakatani, L. H., O'Connor, J. D., & Aston, C. H. (1981). Prosodic aspects of American English speech rhythm. Phonetica, 38, 84-106.

Nation, J. E., & Aram, D. M. (1984). Diagnosis of speech and language disorders (2nd ed.). San Diego: College-Hill.

Nespor, M., & Vogel, I. (1986). Prosodic phonology. Dordrecht: Foris.

Netsell, R. (1973). Speech physiology. In F. Minifie, T. Hixon, & F. Williams (Eds.), Normal aspects of speech, hearing, and language. Englewood Cliffs, NJ: Prentice-Hall.

Nicolosi, L., Harryman, E., & Kresheck, J. (1978). Terminology of communication disorders: Speech, language, hearing. Baltimore: Williams & Wilkins.

Nooteboom, S. (1972). Production and perception of vowel duration: A study of durational properties of vowels in Dutch. Unpublished doctoral dissertation, University of Ultrecht.

Ohman, S. E. G. (1966). Coarticulation in VCV utterances: Spectrographic measures. Journal of the Acoustical Society of America, 39, 151-168.

Oller, D. K. (1973). The duration of speech segments: The effect of position in an utterance on word length. Journal of the Acoustical Society of America, 54, 1235-1247.

Osberger, M. J., & Levitt, H. (1979). The effect of timing errors on the intelligibility of deaf children's speech. Journal of the Acoustical Society of America, 66, 1316-1324.

Peterson, G. E., & Lehiste, I. (1960). Duration of syllable nuclei in English. Journal of the Acoustical Society of America, 32, 693-703.

Pike, K. L. (1945). Intonation of American English. Ann Arbor: University of Michigan Press.

Pisoni, D. B., Nusbum, H. C., & Greene, B. G. (1985). Perception of synthetic speech generated by rule. IEEE, 73, 1665-1676.

Rakerd, B., Sennett, W. F., & Fowler, C. A. (1987). Domain-final lengthening and foot-level shortening in spoken English. Phonetica, 44, 147-155.

Robin, D. A., Klouda, G. V., & Hug, L. N. (1991). Neurogenic disorders of prosody. In D. Vogel & M. P. Cannito (Eds.), Treating disordered speech motor control: For clinicians by clinicians. Austin, TX: PRO-ED.

Rosenbek, J. C. (1983). Treatment for apraxia of speech in adults. In W. H. Perkins (Ed.), Current therapy of communication disorders: Dysarthria and apraxia. New York: Thieme-Stratton.

Rosenbek, J. C., & LaPointe, L. L. (1985). The dysarthrias: Description, diagnosis, and treatment. In D. Johns (Ed.), Clinical management of neurogenic communicative disorders. Boston: Little, Brown and Company.

Selkirk, E. O. (1980a). On prosodic structure and its relation to syntactic structures. Bloomington, IN: Indiana University Linguistics Club.

Selkirk, E. O. (1980b). The role of prosodic categories in English word stress. Linguistic Inquiry, 11, 563-605.

Selkirk, E. E. (1984). Phonology and syntax: The relation between sound and structure. Cambridge, MA: MIT Press.

Sennett, W. F., Rakerd, B., & Fowler, C. A. (1986). Stress-timing constraints on sentence production. Paper presented at the annual convention of the American Speech-Language-Hearing Association, Detroit, MI.

Stevens, K. N., Nickerson, R. S., & Rollins, A. M. (1978). On describing the suprasegmental properties of the speech of deaf children. In D. McPherson & M. Davids (Eds.), Advances in prosthetic devices for the deaf: A technical workshop. Rochester: National Technical Institute for the Deaf.

Tukey, J. W. (1953). The problem of multiple comparisons. Unpublished manuscript, Princeton University, Princeton, NJ.

Tye-Marray, N. & Woodworth, G. (1989). The influence of final-syllable position on the vowel and word duration of deaf talkers. Journal of the Acoustical Society of America, 85, 313-321.

Wingate, M. E. (1984). Stuttering as a prosodic disorder. In R. F. Curlee & W. H. Perkins (Eds.), Nature and treatment of stuttering: New directions. San Diego: College-Hill.

Yorkston, K. M., & Beukelman, D. R. (1981). Ataxic dysarthria: Treatment sequences based on intelligibility and prosodic considerations. Journal of Speech and Hearing Disorders, 46, 398-404.

Yorkston, K. M., & Beukelman, D. R. (1991). Motor speech disorders. In D. R. Beukelman & K. M. Yorkston (Eds.), Communication disorders following traumatic brain injury: Management of cognitive, language, and motor impairments. Austin, TX: PRO-ED.

Yorkston, K. M., Beukelman, D. R., & Bell, K. R. (1988). Clinical management of dysarthric speakers. Boston: College-Hill.

Yorkston, K. M., Beukelman, D. R., Minifie, F. D., & Sapir, S. (1984). Assessment of stress patterning. In M. R. McNeil, J. C. Rosenbek, & A. Aronson (Eds.), The dysarthrias: Physiology, acoustics, perception, management. San Diego: College-Hill.