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An Investigation of Speech Timing in Individuals with Cleft Palate

by

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AN INVESTIGATION OF SPEECH TIMING

IN INDIVIDUALS WITH CLEFT PALATE

by

LINDA D'ANTONIO

ABSTRACT

This study documented some of the timing patterns observed in the speech of individuals with cleft palate. Two experiments were conducted.

Experiment 1 explored the effects of speaking rate on listener judgements of cleft and noncleft speech. The results indicated:

1. Cleft speakers spoke more slowly than noncleft speakers at the habitual speaking rate. However, there was less difference between the groups at the rapid speaking rate.
2. Increased speaking rate resulted in poorer articulation and intelligibility ratings for both groups but had a more complex effect on nasality ratings.
3. For the cleft group there was a significant correlation between speech sample duration and attribute ratings within each rate condition; i.e., the longer the speech sample duration, the poorer the speech ratings.

Experiment 2 compared acoustically defined segment durations in the speech of noncleft, high intelligibility

cleft, and low intelligibility cleft speakers. CVC nonsense syllables were produced within a carrier phrase at habitual and rapid speaking rates. The acoustic waveforms of the speech samples were interactively displayed, segmented and measured employing digital signal processing techniques. The results indicated:

1. Cleft speakers produced longer segments than did non-cleft speakers.

2. Some segment types were more prolonged than others in cleft speech.

3. Vowel environment had stronger effects (particularly carryover effects) on durations of adjacent segments for cleft speakers compared with noncleft speakers.

4. Segment durations were generally more variable in cleft speech than in noncleft speech. Segment durations were usually more variable for both cleft and noncleft speakers in the rapid rate condition.

5. When speaking rate was increased, noncleft and high intelligibility cleft groups reduced vocalic intervals more than consonant intervals. In contrast the low intelligibility cleft group showed the greatest reduction in excessively long consonant intervals.

The combined results indicate that temporal abnormalities exist in the speech of some individuals with cleft palate, and there is a relationship between the presence and magnitude of these irregularities and intelligibility. These results are discussed with respect to information concerning speech timing in general, cleft palate speech in particular, implications for treatment, and directions for future research.

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I. INTRODUCTION

General objective and motivation

The general objective of this thesis is to document some of the timing patterns in the speech of individuals with cleft lip and palate in comparison with timing patterns observed in speakers without clefts.

This investigation was motivated by three observations from disparate aspects of the literature:

1. The timing or temporal characteristics of speech are known to relate to "speech naturalness" and intelligibility.

2. Abnormal timing is linked with reduced speech intelligibility in at least one clinical population; i.e., deaf speakers.

3. Limited research suggests that the temporal properties of speech are affected in individuals with cleft lip and palate. Bradley (1977), suggested if:

> "temporal characteristics of speech are related to speech intelligibility and comprehension, then it becomes important to study these aspects among individuals with cleft palate. It may be feasible to modify these aspects when it is not possible to modify articulatory skills, thus increasing the intelligibility... of speech" (p. 324).

Many studies indicate that the timing or temporal characteristics of speech do relate to speech quality and intelligibility. Furthermore, it has long been recognized that abnormal timing may contribute to speech/articulation deficits among individuals with such conditions as stuttering, dysarthria, cerebral palsy, and particularly, hearing impairment. However, information pertaining to the temporal characteristics of cleft speech is sparse. Many issues concerning the temporal characteristics of speech have only recently been addressed in noncleft populations and a comprehensive model of timing in "normal" speech still lies in the future. Therefore, a systematic, comprehensive investigation of timing in cleft palate speech must address a multitude of questions concerning both production and perception, and would necessarily raise numerous other questions.

The major objective of this thesis is to document some of the temporal patterns present in the speech of a sample of individuals with cleft lip and palate in comparison with a group of noncleft speakers. The goal is to present data which reveal whether temporal patterns in cleft speech differ from noncleft speech. This information will have two potential effects:

1. To lay a foundation for future studies of timing in cleft palate speech, perhaps specifying questions to be addressed in more invasive, yet potentially more informative investigations of interarticulatory timing and coordination.

2. To contribute data for a broader theory or model of speech timing.

Overview

Two experiments were conducted to fulfill the objective of this thesis. The first experiment explored the effects of increased speaking rate on listener ratings of cleft and noncleft speech. The second experiment compared acoustically defined segment durations in cleft and noncleft speech at two speaking rates.

Chapter II reviews the background information pertinent to both experiments. First the anatomic, physiologic and speech characteristics of individuals with cleft palate are summarized. Next, the literature on speech timing is discussed for "normal", hearing impaired, and cleft palate populations. A comprehensive literature review of these three areas stimulates several broad questions concerning the nature and role of timing in cleft palate speech. Some of these general questions are listed at the conclusion of Chapter II. No attempt is made to address all of these issues experimentally; rather, they are listed to accentuate the relative lack of data pertaining to this specific topic.

Chapter III addresses two specific questions through a study of the effects of speaking rate on listener ratings of nasality, articulation and intelligibility in cleft and noncleft speech. These questions are:

1. What are the effects of increased speaking rate on listener ratings of nasality, articulation and intelligibil-

ity?

2. Are speech ratings for individuals with cleft palate affected more by increased speaking rate than speech ratings for individuals without cleft palate?

Chapter IV reports a comparative study of acoustically defined segment durations in cleft and noncleft speech. Five specific questions are addressed:

1. Do cleft subjects produce longer utterances than noncleft subjects, i.e., do cleft speakers spend more time phonating/articulating than noncleft speakers?

2. Are some segments more prolonged than others?

3. Are segment durations more variable in cleft than noncleft speech?

4. When cleft speakers increase speaking rate, do they alter segment durations in the same manner as noncleft speakers?

5. When speaking rate is increased, do some segment durations become more or less variable?

Finally, Chapter V discusses the limitations of the study and the combined results of the two experiments with respect to the contributions of the data:

1. To an understanding of cleft palate speech.

2. To a general understanding of speech timing.

3. To implications for speech therapy.

4. To directions for future research.

II. BACKGROUND

Cleft palate

The term "cleft palate" is commonly used to refer to the broad, heterogeneous group of individuals with congenital malformations of the lip and/or palate resulting from the embryologic failure of tissue fusion. Additionally, the term is often used in the context "cleft palate speech" to describe the speech characteristics of the individual with cleft lip and/or palate. (In some instances, use of the term has been extended to describe similar speech characteristics in individuals who have no anatomical cleft.)

While individuals with cleft lip and/or palate do comprise a definite clinical population with several characteristics in common, they are, nonetheless, individuals. Therefore, when discussing the anatomic, physiologic and speech correlates of "cleft palate" it is important to bear in mind that most statements about the disorder are generalizations. This is particularly true when referring to speech.

.ndividuals with cleft lip and/or palate present a wide variety and range of communication difficulties. Speech involvement will differ as a function of several variables (such as type of cleft, anatomical involvement, age, hearing acuity, and intelligence, to name only a few). Notwithstanding the previous cautions, there are several research findings which generally characterize individuals with cleft lip and/or palate. The following section will provide a broad overview of the prevalent anatomic, physiologic and speech correlates of cleft lip and/or palate.

Finally, a note on terminology is in order. For the purpose of this investigation, the term "cleft palate" will be used to refer to individuals with cleft lip and palate or cleft palate alone. Furthermore, for convenience, the term "cleft palate speech" will be used to mean: the speech of individuals with cleft palate. (The term is not used as a descriptor, denoting nasal voice quality).

Anatomy. As the name suggests, a "cleft" is an opening or separation of a structure or structures which are typically joined. Orofacial clefts may be acquired or congenital. Clefts of the lip and palate are predominantly congenital and are generally classified in two ways: 1) according to the principal anatomic structures involved and 2) the extent of the involvement. There are many classification systems for congenital orofacial clefts. A particularly straightforward system is presented by Berlin (1971) who identifies two general types of cleft.

1. Primary palate disorders: clefts of the lip and/or alveolar process and palate anterior to the incisive foramen.

2. Secondary palate disorders: clefts of the hard and/or

soft palate.

Clefts of these structures may be unilateral or bilateral, complete or incomplete, and may occur in various combinations.

Clefts of the lip are generally repaired between birth and twelve weeks of age to ensure adequate feeding and establish muscle continuity. Unilateral lip clefts commonly require only one surgical procedure while bilateral clefts of the lip may necessitate two or more surgeries for adequate repair.

Clefts of the palate are surgically repaired at a later age and often require multiple surgeries. Initial palate repair is commonly undertaken between ages one and two. Secondary procedures are often necessary for reasons such as: treatment of velopharyngeal incompetence via a "pharyngeal flap" procedure, realignment of the dental arches, closure of residual openings in the palate, and elimination of scar tissue. Timing of such procedures is determined by management strategies (Ewanowski and Saxman, 1980).

Speech. There are several anatomic and physiologic factors associated with cleft palate which may affect speech. Morris (1968) discusses six etiological factors which may contribute to speech disorders in individuals with clefts.

1. Velopharyngeal mechanism. The role of the velum in

speech is to separate the oral pharynx from the nasal pharynx. When the velum is raised and velopharyngeal closure is achieved, air pressure moves through the oral cavity. The air pressure may be temporarily occluded, built-up, and released (as for the stop consonants such as /p/ and /b/). However, when the velum is unable to achieve closure, air pressure escapes through both the oral and nasal cavities and adequate air pressure cannot be built up. "Tissue deficiency" and/or "inadequate movement" are the principal contributors to velopharyngeal incompetence in the individual with cleft palate. Inadequate velopharyngeal function is the primary cause of poor speech in cleft palate individuals and commonly results in misarticulations, hypernasality, and reduced loudness (Ewanowski and Saxman, 1980).

2. Cleft lip. The effects of a repaired cleft lip on speech are uncertain. West et al. (1957) suggest that only sounds produced with the upper-lip are affected. On the other hand, Spriestersbach et al. (1961) suggest the repaired cleft lip has no effect on speech. However, studies with normal speakers indicate that restraints on one articulator generally require compensatory movements from other articulators to preserve relevant acoustic contrasts (Lindbloom and Sundberg, 1971; Riordan, 1977). Furthermore, the speech articulators must act together in a coordinated manner in order to produce intelligible speech. Reduced mobility of the cleft lip (due to scar tissue or motor impairment) may require compensatory movements of other

articulators such as the jaw (Hanson and D'Antonio, 1979). The existence of compensatory movements and their role in speech production in the cleft palate speaker is a matter for further study. Therefore, we cannot say with certainty what effects a cleft lip has on speech. While we may perceive no misarticulations directly attributable to reduced lip mobility there may be compensatory movements which indirectly result in reduced speech quality.

3. Dentition. Most authors agree that abnormal dentition in individuals with cleft palate often results in speech articulation disturbances. Dental abnormalities associated with cleft palate include malpositioned teeth and missing teeth and malocclusions. These anomalies may result in irregular air stream modulation, particularly in the friction sounds such as /s/ and /z/.

4. Tongue motility and carriage. It has been suggested that tongue mobility and carriage may be different for cleft palate subjects than for normals (Brown and Oliver, 1940; Matthews and Byrne, 1953). However, after reviewing the literature on the topic, Morris (1968) concluded that tongue coordination and flexibility are not affected by the coexistence of a cleft lip and/or palate and therefore have no effect on speech. While this conclusion may be technically accurate, Westlake and Rutherford (1966) insightfully comment on the interrelatedness of the tongue, maxillary arch and teeth for speech production.

> "Many speech sounds require rapid and precise lingual adjustments that are tight enough to control the direction of air, to stop it momentarily, or to regulate the aperture through which it escapes. To do this, there must be enough space in which the tongue can work, and the alveolar and dental surfaces which the tongue must contact should be fairly even. Consequently, the clinician is interested in arch and vault dimensions and in any irregularities in the teeth or arch that could interfere with the tongue. Any significant variation is a hazard to speech" (p. 93).

5. Nasal cavities. Partial nasal obstruction may occur in cleft palate individuals as the result of a deviated septum. Morris (1968) suggests that nasal obstruction and/or nares constriction may facilitate adequate intraoral air pressure build-up resulting in improved speech quality. However, nasal obstruction may also result in oral respiration which may in turn affect tongue and jaw carriage. The effects of oral respiration on speech are not known.

6. Hearing acuity. There is a high incidence of hearing loss in individuals with cleft palate. This may be the result of congenital abnormalities in the auditory system or inadequate muscle function. Middle ear infections are particularly prevalent in children with cleft palate, resulting from abnormal Eustachian tube function (Prather and Kos, 1968). Hearing acuity may fluctuate significantly during critical periods for speech and language development, often resulting in disordered speech.

The speech of individuals with cleft palate may be characterized by three general speech disorders as described by Ewanowski and Saxman (1980).

1. Misarticulation of speech sounds. Cleft palate children are commonly delayed in articulation development due to the etiological factors discussed above. Common misarticulations occur for stop consonants, fricatives and affricates resulting from inadequate intraoral air pressure. Furthermore, voiceless consonants are generally more defective than their voiced cognates (Moll, 1968). The glottis and pharynx may be used to articulate sounds normally produced orally. For example glottal stops may replace normal stop plosives and pharyngeal fricatives may replace normally produced fricatives (Bzoch, 1971).

2. Hypernasal voice quality. Abnormalities in the velopharyngeal mechanism generally result in perceived hypernasality of the voiced sounds.

3. Reduced loudness. Incomplete velopharyngeal closure may also result in reduced loudness as acoustic energy is highly absorbed as it passes through the nasal passages (Curtis, 1968).

The preceding discussion indicates that the anatomic and physiologic factors commonly associated with cleft palate may combine to produce a variety of disturbances in speech production. Traditionally, cleft palate speech has been viewed in a static, isolated manner. The focus has been on the relationship between anatomic structure and production of correct, static acoustic or articulatory targets. Lisker (1976) points out that in the past, linguists (and speech pathologists) have perpetuated the view of speech as a series of phonemes strung together like beads on a string. This representation of speech suggests that vocal tract shapes occur one after the other without overlap. Each vocal tract configuration occurs for a specified duration and the only timing implied is the order of segments in relation to one another.

A more modern view of speech defines it as a continuous dynamic process (Lisker, 1974, 1976). The vocal tract is in a continuous state of change. Thus, the dynamic temporal aspects of speech become critical components which must be addressed and described. In speech sound production the temporal coordination of the articulators becomes a significant factor for consideration rather than focusing on absolute articulator placement. Bell-Berti (1979) suggests, "We might, in fact, imagine speech to be the result of a series of instructions to the articulators to move first toward and then away from one position and then another, but never to hold a particular set of positions."

It is likely that impairments of the speech articulators associated with cleft palate result in abnormal interarticulator coordination and timing. These dynamic processes may in turn contribute to perceived speech deficiencies like those discussed in the preceding section, and may result in speech timing errors such as reduced speaking rate, prolongation of sounds, inappropriate pause placement, and elongation of pauses.

Speech timing in normal speakers

Prior to the study of speech timing in individuals with cleft palate, it is important to consider the temporal properties of speech in general. In this section some of the temporal characteristics of normal speech will be discussed. The purpose is not to provide an exhaustive review of the speech timing literature but to establish a framework for discussions of the temporal characteristics of the speech of individuals with cleft palate.

Generally, when we think of timing in speech we think of the prosodic properties such as speaking rate and rhythm. This is only one aspect of speech timing. The temporal properties of speech include:

1. Prosodic properties: rate, rhythm, and pause placement.
2. Durations of linguistic components: phonemes, syllables and words.
3. Interarticulatory timing. (This property of speech has not been considered in traditional discussions of speech timing. However, as Allen (1975) suggests, the inherent rhythmic nature of speech is partially the result of "a sequence of articulations that have a temporal structure of their own".)

Rate. Individuals may speak at a variety of rates; however, an average speaking rate is approximately 3.3 syllables per second (Pickett, 1968). Speaking rate can be substantially reduced or increased from the average without affecting intelligibility and tends to vary with the content of the speech sample. Alterations in speaking rate are accomplished through changes in pause durations and articulation rate.

Rhythm. Speech is uniformly characterized as being rhythmic. Syllables within a phrase or sentence are not equally stressed or emphasized. In English stressed and unstressed syllables tend to alternate, producing a rhythmic quality. The rules governing speech rhythm are not well understood.

Pause placement. Pauses are necessary in speech to maintain an adequate breath supply. Placement and duration of pauses, however, serve linguistic functions as well. There are basically two types of pauses: pauses associated with linguistic junctures and hesitation pauses (Goldman-Eisler, 1968). Pauses associated with linguistic juncture do not interrupt speech flow and tend to occur predictably following major syntactic units. Furthermore, normal speakers inhale during junctural pauses but not during hesitation pauses (Goldman-Eisler, 1968).

Duration of linguistic units. Nickerson, Huggins and Stevens (1978) indicate that individual speech sound duration may vary as a function of several factors: 1) phoneme type, 2) phonetic context, 3) location within a word and within a larger linguistic unit, 4) linguistic stress, 5) grammatical function, 6) familiarity of the word in which the sound occurs, and 7) speaking rate.

Interarticulatory timing. Fowler (1977) demonstrates that speech timing effects may be observed in the acoustic and articulatory records of an utterance. She suggests that measurements of acoustic segments as a function of context reveal "coarse-grained" effects of timing control. "Fine-grained" effects may be revealed through observations of the speech production system via techniques such as electromyography, cineradiography and electropalatography. Traditional studies of speech timing have segmented oscillographic or spectrographic displays of speech for various purposes. However, we know that the sounds of speech are coproduced or coarticulated, that is, they overlap in time (Fant, 1962; Lisker, 1974; 1976). Most traditional timing studies reveal little about the underlying timing plan or constraints on timing during speech production. Current theories of speech production acknowledge that speech is the result of "coordinative structures," i.e. groups of muscles which are constrained to act as a system (Fowler, 1977). Therefore, a comprehensive model of speech timing must include observations of "coordinative structures" that include the respiratory, laryngeal and supralaryngeal systems. A model of this nature contributes substantially to our understanding of speech timing as observed at the acoustic level. While there is implicit experimental support for such a model, a comprehensive theory of speech timing which incorporates interarticulatory timing remains incomplete.

Speech timing in hearing impaired speakers

While there is no comprehensive model of what constitutes normal speech timing, it is clear, nonetheless, that inappropriate timing contributes to reduced speech quality and intelligibility. This fact may be relevant to several clinical populations; however, it has been most thoroughly substantiated for speakers who are deaf. As with the preceding section, the present discussion is not intended to be a comprehensive review of the literature. Rather it is included here to illustrate the contributions of timing studies to a particular clinical population.

Inappropriate timing has long been considered a major cause of reduced intelligibility in the speech of the deaf (Bell, 1916; Hudgins and Numbers, 1942; John and Howarth, 1965; Boone, 1966; and Nickerson et al., 1974). Osberger (1978), enumerated the timing errors characteristic of deaf speech.

> "Such errors include a reduced speaking rate, excessive prolongation of speech segments, insertion of long pauses, introduction of adventitious sounds between phonemes and syllables, failure to temporally differentiate stressed and unstressed syllables and failure to modify segment duration as a function of phonetic environment" (p. 15).

Once the existence of timing errors is well established in a clinical population (as with deaf speakers) the next logical step is to relate timing errors to intelligibility. Several studies have attempted to establish the relationship between abnormal timing and intelligibility in deaf speech. The results of correlational studies indicate there is a strong relationship between abnormal timing patterns (such as inappropriate pauses; excessive pause length; prolonged phoneme, syllable, or word duration; and intrusion of adventitious sounds) and reduced intelligibility (Hudgins and Numbers, 1942; Monsen and Leiter, 1975; Parkhurst and Levitt, 1978).

Nickerson (1975) cautions, however, "While gross timing deficiencies may be easily recognized it is difficult to say with assurance precisely how the timing of a given utterance should be modified to make it right". According to Osberger (1978), several investigations have attempted to alter timing patterns through intensive speech-training, to determine the causal effects of timing patterns on intelligibility; these training studies, however, have produced disparate, conflicting results, presumably due to differences in experimental design. One technique which has proven useful in further understanding the relationship between timing errors in deaf speech and intelligibility is digital signal processing. Osberger (1978) employed this computer technique to alter selectively several types of timing errors in the speech of deaf children. The results indicated that correction of relative timing errors produced a moderate improvement in intelligibility.

In a discussion of Osberger's results, Harris and

McGarr (1980) suggest that when speech is grossly abnormal, improvement of overall timing alone may be "insufficient to allow the listener to decode adequately." They argue that errors in interarticulatory timing contribute substantially to the reduced intelligibility of deaf speech and "temporal coordination, rather than absolute articulator placement deserves more investigation than it has thus far received."

Nickerson et al. (1974) point out that the relationship between speech timing and intelligibility in deaf speech is quite complex. The authors suggest that other speech problems "contribute to, or are based on, timing deficiencies to some degree." The speech problems in deaf speech which investigators have related to speech timing are: breathing, nasality, and articulation.

Hudgins (1946) summarizes the breathing problems common to deaf speech which relate to speech timing. They include: 1) short irregular breath groups, 2) excessive breath on single syllables, 3) inappropriate syllable grouping 4) slow, labored utterances, and 5) lack of proper coordination between breathing muscles and the speech articulators.

Nickerson and his coauthors cite discussions in the literature (Colton and Cooker, 1968) which suggest that nasality may be a by-product of slow speech even in normal speakers, and that perceived nasality in deaf speech may in part result from reduced speaking rate. It is more likely that the slow rate and nasality are the results of inappropriate articulator coordination.

Indeed, as Nickerson et al. suggest, "A distinction is often made between timing problems and problems of articulation. While the distinction is a helpful one for some purposes, it should not be pressed too far. Articulation itself depends upon proper timing at the level of individual speech sounds and transitions between them". It is not surprising, therefore, that there is a relationship between articulation of individual speech sounds and the temporal properties of speech. For example, the intrusive sounds common in deaf speech are considered articulation errors and generally result in perceived timing errors as well.

In fact, several authors suggest the possibility that articulation training itself (as it has been traditionally approached) may interfere with appropriate speech timing (John and Howarth, 1965; Boone, 1966). For example, intrusive sounds are most likely the result of inappropriate "transitional" movements between two sounds. The deaf speaker's preoccupation with the articulation of individual phonemes, may interfere with the smooth coarticulation of sounds, thus resulting in inappropriate timing and distorted speech.

Therefore, the importance of timing to intelligibility and quality is now recognized in many speech-training programs for the deaf. It is likely that the temporal properties of speech in individuals with cleft palate are also related to overall speech quality and should be considered in speech-training.

<u>Speech timing in cleft vs. noncleft speakers</u>

As discussed earlier, few studies have been directly concerned with the temporal properties of speech in individuals with cleft palate. However, there are scattered reports in the literature which suggest that some of the timing patterns observed in the speech of individuals with cleft palate (like those observed in the speech of the deaf) are different from the timing patterns of "normal speech".

For example, in a study of fundamental frequency characteristics in children with cleft palate, Tarlow and Saxman (1970) unexpectedly found cleft subjects to have a slower speaking rate and to spend more time phonating than noncleft subjects. They concluded that differences in rate and phonation time, in addition to pitch variation, were "differentiating features of the speech of cleft and noncleft children..."

In the only systematic study of speaking rate in individuals with cleft palate, Lass and Noll (1970) compared rate characteristics of cleft and noncleft adult speakers in three tasks: 1) oral reading, 2) impromptu speaking, and 3) rate alteration. The results indicated that:

1. Cleft subjects exhibited slower reading and speaking rates than noncleft subjects.

2. For oral reading, cleft subjects employed longer

intrasentence speech and pause times, more intrasentence pauses, and longer intersentence pauses.

3. For most oral reading variables studied, cleft subjects showed a greater amount of variability and larger range of performance among members than noncleft subjects.

In the same study, Lass and Noll also described how rate alterations were accomplished at the sentence level. They found that the cleft and noncleft groups employed similar strategies when asked to reduce reading rate. However, the noncleft group achieved a greater change (i.e., a slower rate) than the cleft group. When the groups were asked to increase reading rate they employed slightly different strategies. Again, the noncleft group achieved a greater change (i.e., a faster rate) than the cleft group.

In a study of the effects of stress, rate and rhythm on the speech of individuals with cleft palate, Hess (1971) observed from the results of Lass and Noll, and those of Tarlow and Saxman, that "one might infer that cleft palate speakers generally sense a need to speak more slowly to achieve more proficient articulation, greater intelligibility, and possibly even improved voice quality." Hess based this postulate on his interpretation of information theory predicting that better reception of information should occur at slower speaking rates. (This supposition is in direct conflict with reports by Monsen and Leiter (1975) which indicate that utterances produced by deaf speakers show a significant negative correlation between average word duration and intelligibility. That is, the longer the speech segment, the lower the intelligibility.)

In Hess's study, tape recorded speech samples of cleft subjects were presented to four speech pathologists for ratings of articulatory proficiency, intelligibility, and nasality. The speech samples were designed to represent two rate conditions, two rhythm patterns, two syllabic stress patterns, and two phoneme groupings. Contrary to predictions based on clinical observations and experience, speaking rate had no significant effect on articulation, intelligibility or nasality among the cleft speakers in Hess's study. However, the experimental design may have contributed to this finding; these issues will be considered in detail in Chapter III.

The preceding investigations were concerned with measurements and ratings of relatively long samples of connected speech. Only one reported study measured individual phoneme durations in the speech of individuals with cleft palate. Rolnick and Hoops (1971) compared spectrographic measurements of voiceless plosive phoneme durations in cleft speech as a function of palatopharyngeal adequacy. For patients with inadequate palatopharyngeal function, plosive phoneme duration was significantly shorter when produced with a palatal lift in place to aid closure. Duration increases without the lift in place generally occurred in one of two ways:

1. an increase in aspiration following release of closure;

2. increased duration of high frequency energy preceding the release of closure.

Based on these results, the authors suggested that velopharyngeal inadequacy affects the durations of some phonetic segments by prolonging them.

The studies reviewed thus far suggest there are temporal irregularities which can be observed in the utterances of individuals with cleft palate. These observations have been made at two levels of the speech production process, i.e. perceptual and acoustic. Because perceptual and acoustic output are in part the direct result of articulatory movements, it is important to address timing properties at the articulatory or movement level directly. There are no investigations in the current literature which focus on articulatory timing in cleft palate individuals per se, but at least three reports contribute information concerning this topic. For example, in a comprehensive surgical study of cleft palate, Nylen (1961) employed synchronized cineradiography and sound spectrography to assess velopharyngeal closure during connected speech. He measured the speed and duration of palate movements during speech production from tracings of cineradiographs. Nylen studied two groups of subjects: cleft subjects assessed as "normal speaking" and cleft subjects with severe palatal abnormalities identified as poor speakers, and compared both groups to normal subjects previously described by Bjork (1961). The speeds and durations of palate movements were similar for all three groups. However, while the absolute durations of the movements did not appear to be abnormal for the cleft speakers, it is not known whether the coordination of these movements in time with other articulators was the same between groups.

In another combined cinefluorographic and acoustic study of articulatory movements, Hanson and D'Antonio (1979) reported pilot data concerning articulator movements in two adult speakers with repaired cleft lip and palate. In both subjects, upper lip mobility was severely restricted and the lower lip compensated for the upper with faster, more extensive movements than would be expected in subjects with normal upper lip activity.

Both of the preceding studies addressed absolute speed and duration of articulator movement. However several authors (Huggins, 1972; Lisker, 1974, 1976; Moll and Daniloff, 1971; and Bell-Berti, 1979) have emphasized that the relative timing of events is critical, as well as absolute duration measures. This is true both for observations of speech at the acoustic/phonetic level and at the level of movements or motor programming.

Zimmerman, Karnell and Rettaliata (1982) support the importance of relative timing with data from an unpublished study of interarticulator coordination in two cleft palate speakers with different nasality ratings. The coordination of the velum with jaw, tongue dorsum, tongue tip, and with voicing was analyzed employing cinefluorographic measurements. Velar movements differed dramatically between the two subjects. The speaker with the higher nasality rating achieved velar closure less consistently when compared with the subject with the low nasality rating. Furthermore, when closure was achieved by the more nasal speaker, it often occurred after voice onset or after maximum vocal tract constriction had occurred. The authors hypothesized that the aberrant articulatory timing patterns present in the highly nasal subject were conducive to increased nasal resonance.

General questions

The observations motivating this thesis (and illustrated in the preceding literature review) raise several issues concerning the temporal properties of cleft palate speech that have never been systematically addressed. Questions addressing some major issues are enumerated below. Although no attempt will be made to address each of these questions experimentally, they are listed here to fit the present experiments into a broader context, to stimulate further discussion, and to accentuate the paucity of data concerning the temporal properties and the role of timing in cleft palate speech.

1. If cleft palate speech is commonly slower than noncleft speech, do cleft speakers actually spend more time articulating than noncleft speakers?

2. What is the underlying cause of a slower habitual speaking rate?
   a. A passive mechanical or neuromotor restriction?
   b. A residual habit?
   c. An active strategy for increasing intelligibility, as many clinicians suggest?

3. If the mobility of one articulator is severely impaired (restricted) will its temporal coordination with other articulators be affected?
   a. If so, how?

b. What are the effects on speech quality?

4. If there is an increase in actual phonation time in cleft speech, is this increase reflected in a linear horizontal expansion of the speech signal, or are some phonetic segments affected more than others?

5. If some phonetic segments are affected more than others what might be the effect on intelligibility?

6. Are phonetic durations relatively stable and consistent in cleft palate speech? If not, how might inconsistencies affect intelligibility and/or speech quality?

7. What are the effects of increased speaking rate on perceptual judgments of cleft speech?

8. What are the effects of increased speaking rate on durations of phonetic intervals in cleft speech?

9. How might increased speaking rate alter interarticulator coordination in cleft speakers?

10. To what extent can temporal patterns be altered, thereby affecting speech quality and/or intelligibility in cleft speech?

III. Experiment 1: Effects of speaking rate on listener ratings of cleft and noncleft speech

Introduction

Tarlow and Saxman (1970) and Lass and Noll (1970) demonstrated that speakers with cleft palate generally speak more slowly than individuals without clefts. However, neither of these reports considered the perceptual consequences of reduced speaking rate. Hess (1971), did attempt to determine the effects of speaking rate on judgments of speech. For the subjects of his study, however, the results suggested that speaking rate did not have a significant effect on ratings of articulation proficiency, intelligibility or nasality.

Two design factors may have contributed to the results reported by Hess (1971). First, his subjects were trained to produce the test sentences at predetermined slow and fast speaking rates (3.33 syllables per second and 5.00 syllables per second). The sentences were modeled by a clinician and then practiced by the subjects prior to recording. By predetermining a set speaking rate and training the subjects, the experimenter may have narrowed or expanded an individual's range and may have reduced the variability between subjects. Since it is suggested that inappropriate speaking rate is a characteristic of cleft speech and that inappropriate rate also contributes to reduced intelligibility, then a study of these characteristics should allow speakers to demonstrate their spontaneous, unaffected rate patterns rather than attempting to alter and control the variable under study.

Secondly, while Hess trained his subjects to approximate specified "slow" and "fast" values, no objective measure of rate was made. As Hess himself pointed out, "There was no objective verification that the subjects in the present study performed at a speaking rate exactly as instructed. It was solely a matter of the experimenter's judgment". He concluded, "There might be merit in further study of the effect of speaking rate, objectively determined, of cleft palate speakers on speech proficiency."

Finally, Hess suggested that cleft speakers reduce their speaking rate in an attempt to improve intelligibility. Following his logic, the slower, prolonged utterance should have higher intelligibility ratings than faster, shorter utterances. However, there is no discussion of the correlation between utterance duration and intelligibility in the report by Hess nor in the general literature on cleft palate speech.

Specific Questions

Experiment 1 addresses two specific questions which remain unanswered in the current literature on cleft palate speech:

1. What are the effects of increased speaking rate on listener ratings of nasality, articulation and intelligibility?

2. Are speech ratings for individuals with cleft palate affected more by increased speaking rate than speech ratings for individuals without cleft palate?

<u>Subjects</u>

Ten cleft and ten noncleft males served as subjects in this study. The cleft speakers have both cleft lip and palate and were recruited from the Center for Craniofacial Anomalies at the University of California, San Francisco. The noncleft speakers showed no history or evidence of a craniofacial anomaly and were volunteers recruited from among acquaintances and their families. All subjects are native speakers of Standard American English, and at the time of participation in this study demonstrated hearing sensitivity within normal limits (20 dB HL or better) for the speech frequencies (500, 1000, and 2000 Hz).

The cleft speakers were selected at random from the current patient population at the Center who met the following criteria: 1) male, 2) 16 years or older, 3) Standard American English speakers, and 4) no evidence of current hearing loss. The group selected appears to demonstrate a wide range of speech proficiency. Tables 1 and 2 contain pertinent background information for each of the participants in the study. A more complete anatomic description as well as surgical and speech history for each cleft subject is presented in Appendix A.

Methods

Speech sample. To determine utterance duration and speaking rate and to obtain speech ratings, it was necessary first to obtain speech samples from the subjects. To determine accurately speaking rate in syllables per second, the speech samples must contain an unambiguous syllable count. Furthermore, to control for inherent differences in segment duration, the speech samples must be uniform across subjects. Spontaneous speech samples would not generally meet these requirements.

There appear to be two options which satisfy these needs while sacrificing some degree of naturalness. In the first alternative, the experimenter can model a short sentence or phrase for the subject's repetition. Hess (1971) chose this option. He modeled sentences and allowed his subjects to practice until they could reproduce them. With this method, utterance length is constrained by memory. This procedure is unsuitable if relatively long passages are desired or if practice effects are to be minimized.

The second method, which would accommodate longer, relatively unpracticed passages, employs oral readings as a means for eliciting speech samples. Tarlow and Saxman

TABLE 1

Background data for cleft speakers.

Speaker	Age (yrs)	Type of Cleft
MG	22	Bilateral
PV	20	Bilateral
OL	17	Bilateral
KR	19	Bilateral
MH	16	Unilateral (LT)
JC	20	Unilateral (LT)
JL	22	Unilateral (LT)
CD	19	Bilateral
AC	19	Unilateral (RT)
JD	17	Bilateral

TABLE 2

Background data for noncleft speakers.

Speaker	Age (yrs)
PC	17
SK	26
JB	21
PM	20
BM	28
CC	28
LB	26
MR	24
RF	25
AS	25

(1970) and Lass and Noll (1970) chose this alternative. Their subjects read an excerpt from "The Rainbow Passage" (Fairbanks, 1960) which was then analyzed. Lass and Noll compared some of the values obtained for reading with values obtained from impromptu speech in their subject population. Their results indicated that both cleft and noncleft speakers demonstrated faster reading rates than speaking rates but of a similar magnitude between groups. In addition, oral reading rates showed lower standard deviation values than impromptu speaking rates. The values obtained by Lass and Noll (1970) for oral reading rate and impromptu speaking rate in cleft and noncleft subjects are presented in Table 3. According to these data the impromptu speaking rate for the cleft speakers was 90% of their reading rate and for noncleft speakers, speaking rate was 86% of their reading rate. Due to the contextual variation in the impromptu speech samples of their subjects, and presumably because there appears to be no remarkable difference between speaking and reading rates, Lass and Noll chose oral reading samples for their detailed rate measurements.

For the purposes of the study reported here, oral readings of a standard passage served as the "speech sample." The passage which was employed is presented below:

> Many people want to have relatively heavy breakfasts that include a rich sweet such as cake. Others purposely restrict themselves to a glass of orange juice. Some frequently go without a morning meal. Do those who eat lightly lunch early?

TABLE 3

Mean and standard deviation values of mean sentence rate for cleft palate and noncleft palate groups for oral readings and impromptu speaking rates. (Excerpted from Lass and Noll, 1970)

	Oral Reading Rate syll./sec	Impromptu speaking rate syll./sec
Cleft $\bar{X}$	5.00	4.50
SD	.60	.72
Noncleft $\bar{X}$	5.71	4.90
SD	.44	.85

The paragraph which was selected was constructed and described by Guttman (1966). He discussed the many constraints which were considered in its composition and which made it suitable for use in the present study:

> "The venerable Rainbow Passage used by Fairbanks and Guttman was rejected as a text partly because it is too long. Since a number of studies have shown that specimens of speech at least as short as 10 seconds can be rated reliably (Morrison, 1955; Sherman and Morrison, 1955; Sherman and Cullinan, 1960), a shorter paragraph was constructed...
>
> In composition of this text, an attempt was made to follow a number of constraints besides the one affecting length: (1) Words of uncertain syllabic number (e.g., "general") should be avoided; (2) words of uncertain word count (e.g., "anyone") should be avoided; (3) "and" and "the" should be avoided (since they suffer severe reduction); (4) nearly all General American English phonemes should be represented, and higher than typical representation should be given to frequently mispronounced ones (/l,r,s/); (5) the last sentence should be a question (to try to prevent a reduction of effort); (6) slightly troublesome sequences should be included; (7) phonetic density should be slightly above average. In meeting (7), which, like (6), was imposed to make the text slightly more difficult than an average text, the 40-word passage has a phonetic density of 1.5 syllables per word and 2.6 phonemes per syllable. These two averages slightly exceed the counts of 1.3 syllables per word and 2.4 phonemes per syllable found for conversational English by Denes (1963). Experience has shown that a minor trouble with the text is that some speakers, not realizing that "lunch" is a verb, do not immediately understand the terminal question" (pp. 325-326).

Recording. Each speaker in the experiment was recorded individually in a sound treated room employing a voice microphone (TEAC Electret condenser microphone, Model ME-

120) onto magnetic audio tape via one channel of a four channel AM tape recorder (TEAC Model A3440). Appropriate equipment adjustments were made at the beginning of each recording session (i.e., microphone placement and recording levels). These adjustments were accomplished and the speaker's "habitual" rate was noted by the experimenter while the subject gave his name, age, and date and produced test sentences modeled by the experimenter.

The speaker was then provided with a typed copy of the Guttman passage and asked to read it silently as many times as he wished until he was comfortable that he could produce it without reading errors. The only problem inherent to the paragraph which was discussed by Guttman, i.e., confusion generated by use of the word "lunch" as a verb rather than a noun, was readily alleviated through an explanation to the reader when necessary.

When the subject indicated that he was familiar with the passage, he was instructed to read it twice; once at his "normal", "conversational" speaking rate and a second time at a "rapid" rate. The recorder was then activated and the speaker was instructed to begin.

Occasionally, a subject's "habitual" reading rate was markedly faster than his conversational speaking rate. When this was detected by the experimenter the recording was stopped. The subject was instructed to speak "naturally", and with the aid of the experimenter the "habitual" rate was demonstrated. He was then asked to read the passage at a similar rate. This occurred with relatively few speakers and more often with noncleft subjects. Only one of the 20 subjects demonstrated significant oral reading errors. He was allowed to practice reading the passage aloud prior to the final recording. All subjects produced a rapid speaking rate which was noticeably faster than the habitual rate with little assistance from the experimenter. Therefore, each subject read the passage at two rates; the habitual rate and the rapid rate.

Duration measurements. The tape recorded speech samples were played back from the audio recorder to one channel of a Honeywell Visicorder (Model 1858). A 100 Hz. signal was input to a second channel of the Visicorder. The time waveform of the speech signal and the 100 Hz. timing signal were displayed in parallel on printout paper from the Visicorder. The onset and offset of voicing in the speech signal were marked and the duration of the speech sample was established by counting the 100 Hz. tick marks running parallel with the signal. The duration was calculated to the nearest tenth of a second.

Listener ratings. The tape recorded speech samples were dubbed, randomized, and spliced together to form a new tape for listener ratings. There were 40 original speech samples (10 cleft speakers and 10 noncleft speakers x 2 speaking rates = 40 speech samples). Half of the speech samples were included on the listening tape twice to obtain reliability measures. Therefore, the listening tape contained 60 speech samples to be rated. In order to randomize the samples but control for position effects on the tape, samples were randomized within five organizational blocks. Each block contained 12 samples (5 blocks x 12 samples = 60 speech samples). The composition of the organizational blocks is displayed in Table 4.

The samples on the newly constructed listening tape were numbered consecutively from 1-60. Presentation of each sample was preceded by an identification number, i.e., sample number 1, sample number 2, etc. Presentations were separated by short pauses. Preceding the samples to be rated, five example passages were presented for training. For the purposes of this experiment six speech pathologists served as listeners. They were asked to rate three attributes of each speech sample: nasality, articulation, and intelligibility. Because they served as raters or judges of speech in this specific situation, the listeners will be referred to as raters or judges throughout the text.

The three speech attributes were rated for each of the 60 samples on a seven point equal appearing-interval rating scale (Thurstone and Chave, 1929). A rating of "one" on the nasality scale represented no apparent nasality while a rating of "seven" denoted severe nasality. A rating of "one" on the articulation scale denoted good articulation with no

TABLE 4

Composition of organizational blocks

for the listening tape.

Group	Rate Condition	No. in Each Block
Noncleft	Habitual	2
Noncleft	Rapid	2
Cleft	Habitual	2
Cleft	Rapid	2
Noncleft (repeat)	Habitual	1
Noncleft (repeat)	Rapid	1
Cleft (repeat)	Habitual	1
Cleft (repeat)	Rapid	1
		Total 12

apparent errors; a "seven" represented poor articulation with significant errors. Finally, a "one" on the intelligibility scale represented highly intelligible speech which required no effort to understand. A "seven" represented low intelligibility speech which demanded substantial attention and effort to decode. Therefore, low ratings represented high quality, "normal" speech, while high ratings represented poor quality "defective" speech.

The judges listened to the tape and completed their ratings individually in a quiet room. The tape was played back on the same recorder that had been employed for the original input. Raters listened to the tape via high quality, stereo headphones. They operated the recorder themselves and were allowed to play a sample as many times as they wished; however, they were not permitted to return to a previous sample for any reason.

Prior to beginning the actual rating session, five examples were presented for training purposes. During the training session judges became familiar with the passages that had been selected, with the rating scale, and finally, with the extreme variations in speech which were represented on the tape. The purpose of the experiment was not explained and no background information was provided concerning the speakers represented on the listening tape.

Results

Speech sample duration and speaking rate. Speech sample durations were established as previously reported in the methods section and were expressed in "seconds". The passage which was employed to elicit the speech samples contained 60 syllables. Therefore, to obtain the speaking rate, the syllable count (i.e., 60) was divided by the speech sample duration to yield speaking rate expressed in syllables per second.

Speech sample durations and speaking rate for individual subjects are provided in Appendix B. Mean and standard deviation values for speech sample durations and speaking rate are summarized in Tables 5 and 6. The tables indicate that the cleft group produces longer speech samples and demonstrates a slower speaking rate than the noncleft group. Additionally, the cleft group shows wider ranges and greater standard deviations on duration and rate measures than the noncleft group. These findings are graphically depicted in Figure 1. Tables 7 and 8 display the results of a t-test for independent measures which was conducted to compare the differences in speaking rate between conditions and groups. Table 7 indicates that speaking rate in the habitual and rapid rate conditions differed significantly from one another at the .0001 confidence level for both groups. That is, both the cleft and noncleft groups produced a "rapid rate" of speech which was significantly faster than the

"habitual rate". Table 8 indicates that the cleft group spoke significantly more slowly than the noncleft group in the habitual rate condition. In the rapid rate condition there was a difference in speaking rate between groups; however, it did not reach statistical significance. This suggests the cleft group increased speaking rate more than the noncleft group when altering from the habitual to the rapid rate condition. This suggestion was confirmed by calculating the ratio of speaking rate in the habitual condition to speaking rate in the rapid condition. The results indicate that the habitual: rapid ratio for noncleft subjects was .77 while the habitual: rapid ratio for cleft subjects was .69.

Listener ratings. Listener ratings were collected and tabulated for the three speech attributes: nasality, articulation and intelligibility. Mean ratings over the six judges for individual subjects are tabled in Appendix B. Statistical treatment of the data revealed the following results.

Within and between judge reliability were high for the listeners in this experiment. Within judge reliability measures are summarized in Table 9, 10, and 11. Table 9 indicates judges' ratings for repeated items were either identical or ± 1 point an average of 92% of the time. Table 10 indicates the rapid condition elicited slightly lower reliability scores than the habitual condition. Table 11 demonstrates that ratings of intelligibility were more consistent than measures of articulation or nasality.

Between judge reliability was estimated by an intra-class correlation coefficient (Winer, 1971). The results, which are summarized in Tables 12 and 13, show that the between judge reliability of ratings by a single judge range from .77 to .89, while the between judge reliability for the means of six judges ranged from .95 to .98.

Mean and standard deviation values for ratings of the three speech attributes collapsed over subjects and judges are summarized in Table 14 and plotted in Figure 2. The data indicate that mean ratings of cleft speech are uniformly poorer than ratings of noncleft speech. (It is reiterated here that scores on the rating scale ranged from one to seven with higher numbers representing poorer ratings.) Furthermore, ratings of cleft speech showed greater standard deviations than ratings of noncleft speech.

These data were further analyzed through application of an analysis of variance. The results are shown in Tables 15, 16, and 17 and plotted in Figures 3 and 4. Figure 3 indicates that the cleft group had significantly poorer speech ratings than the noncleft group for all three speech attributes. Figure 4 shows that an increase in speaking rate from the habitual rate condition to the rapid rate condition had no significant effect on nasality but resulted in significantly poorer ratings for articulation and intelligibility. Finally, the results of the analysis of variance show there was no apparent group by rate interaction. This indicates that speech ratings for the cleft and noncleft groups were affected equally by the increased rate condition.

Correlations among variables. The Pearson Product moment correlation coefficient was used to estimate the relationship between mean ratings, speech sample durations and speaking rate. Tables 18 and 19 show the resulting correlation matrices.

These tables show that among the speech attributes, articulation ratings show a stronger relationship with intelligibility ratings than do nasality ratings. This finding is summarized in Table 20.

For the cleft group there is a significant correlation between attribute ratings and speech sample duration; the longer the speech segment, the poorer the speech ratings. Likewise for the cleft group, there is a significant negative correlation between attribute ratings and speaking rate in both rate conditions. That is, the slower the speaking rate, the poorer the speech rating. Figure 5 illustrates the correlation between speaking rate in the habitual rate condition and mean ratings for intelligibility for individual cleft and noncleft speakers.

TABLE 5

Speech sample duration (expressed in seconds)

for cleft and noncleft groups

in the habitual and rapid rate conditions.

Group	Habitual Rate Condition	Rapid Rate Condition
Noncleft		
$\bar{X}$	13.7	10.5
SD	.75	.78
Range	12.5 - 15.0	9.1 - 11.6
Cleft		
$\bar{X}$	18.6	12.5
SD	5.1	2.8
Range	13.9 - 28.9	9.2 - 17.5

TABLE 6

Speaking rate (expressed in syllables per second)

for cleft and noncleft groups

in the habitual and rapid rate conditions.

Group	Habitual Rate Condition	Rapid Rate Condition
Noncleft		
$\bar{X}$	4.4	5.8
SD	.23	.43
Range	4.0 - 4.8	5.2 - 6.6
Cleft		
$\bar{X}$	3.4	5.0
SD	.78	1.09
Range	2.1 - 4.3	3.4 - 6.5

TABLE 7

Summary of t-test procedure for comparison of speaking rate in habitual and rapid rate conditions within cleft and noncleft groups.

Group	T	Significance
Noncleft	9.8	.0001
Cleft	8.7	.0001

TABLE 8

Summary of t-test procedure
for comparison of speaking rate in
habitual and rapid rate conditions
between cleft and noncleft groups.

Condition	df	T	Significance
Habitual rate	10.5	3.73	.003
Rapid rate	11.8	2.06	.061

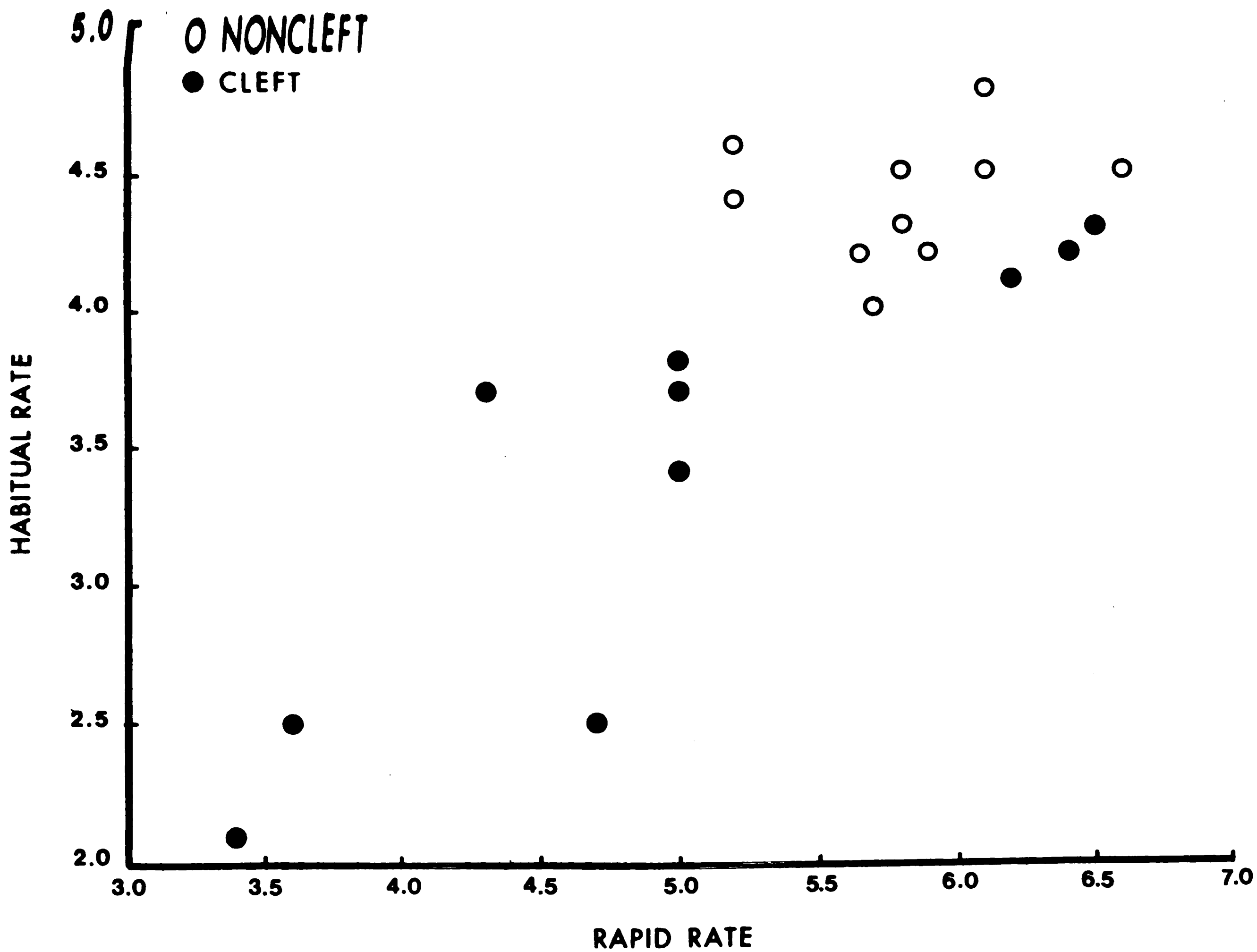

FIGURE 1. Scatter plot of speaking rate in syllables per second for individual cleft and noncleft speakers: habitual rate condition plotted versus rapid rate condition.

TABLE 9

Comparison of within judge discrepancies on repeated ratings between judges. The table is collapsed over 2 rate conditions and 3 speech attributes.

Judge	% Discrepancy on repeat ratings		
	0	$\pm$ 1	Total
1	55	40	95%
2	63	27	90%
3	55	37	92%
4	45	47	92%
5	75	13	88%
6	52	40	92%
$\overline{X}$	-	-	92%

TABLE 10

Comparison of within judge discrepancies on repeated ratings between judges. The table is collapsed over the three speech attributes within each rate condition.

	% Discrepancy on repeat ratings that fall within ± 1 point	
Judge	Habitual Condition	Rapid Condition
1	97%	94%
2	93%	87%
3	90%	93%
4	97%	87%
5	87%	87%
6	93%	90%
$\overline{X}$	93%	90%

TABLE 11

Comparison of within judge discrepancies on repeated ratings between judges. This table is collapsed over two rate conditions within each speech attribute.

	% Discrepancy on repeat ratings that fall within ± 1 point		
Judge	Nasality	Articuation	Intelligibility
1	90%	95%	100%
2	95%	85%	90%
3	95%	85%	95%
4	85%	95%	95%
5	85%	90%	90%
6	80%	85%	100%
$\overline{X}$	88%	89%	95%

TABLE 12

Comparision of between judge reliability of a single judge for three speech attributes and two rate conditions.

	Nasality	Articulation	Intelligibility
Habitual Rate condition	.89	.82	.83
Rapid Rate condition	.88	.77	.80

TABLE 13

Comparison of between judge reliabilities of the mean of six judges for three speech attributes and two rate condtions.

	Nasality	Articulation	Intelligibility
Habitual Rate condition	.97	.96	.97
Rapid Rate condition	.98	.95	.96

TABLE 14

Mean and standard deviation values for ratings by six judges of three speech attributes in two rate conditions.

Group	Nasality		Articulation		Intelligibility	
	Habitual	Rapid	Habitual	Rapid	Habitual	Rapid
Noncleft						
$\overline{X}$	1.5	1.7	1.5	1.9	1.3	1.7
SD	.55	.62	.32	.72	.31	.67
Cleft						
$\overline{X}$	5.2	5.2	3.9	4.2	3.6	3.9
SD	1.4	1.5	1.5	1.5	1.5	1.6

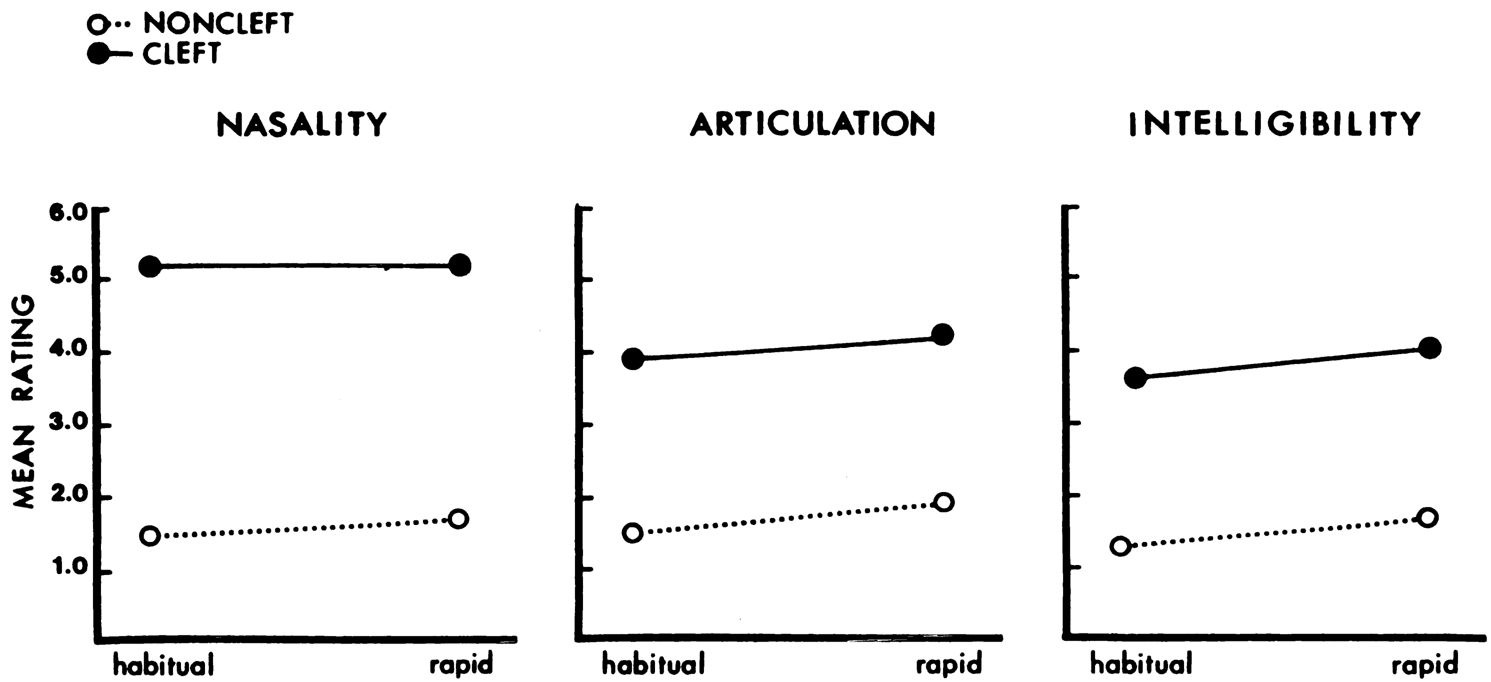

FIGURE 2. Mean speech attribute ratings for cleft and noncleft groups in the habitual and rapid rate conditions. (Higher numbers represent poorer ratings.)

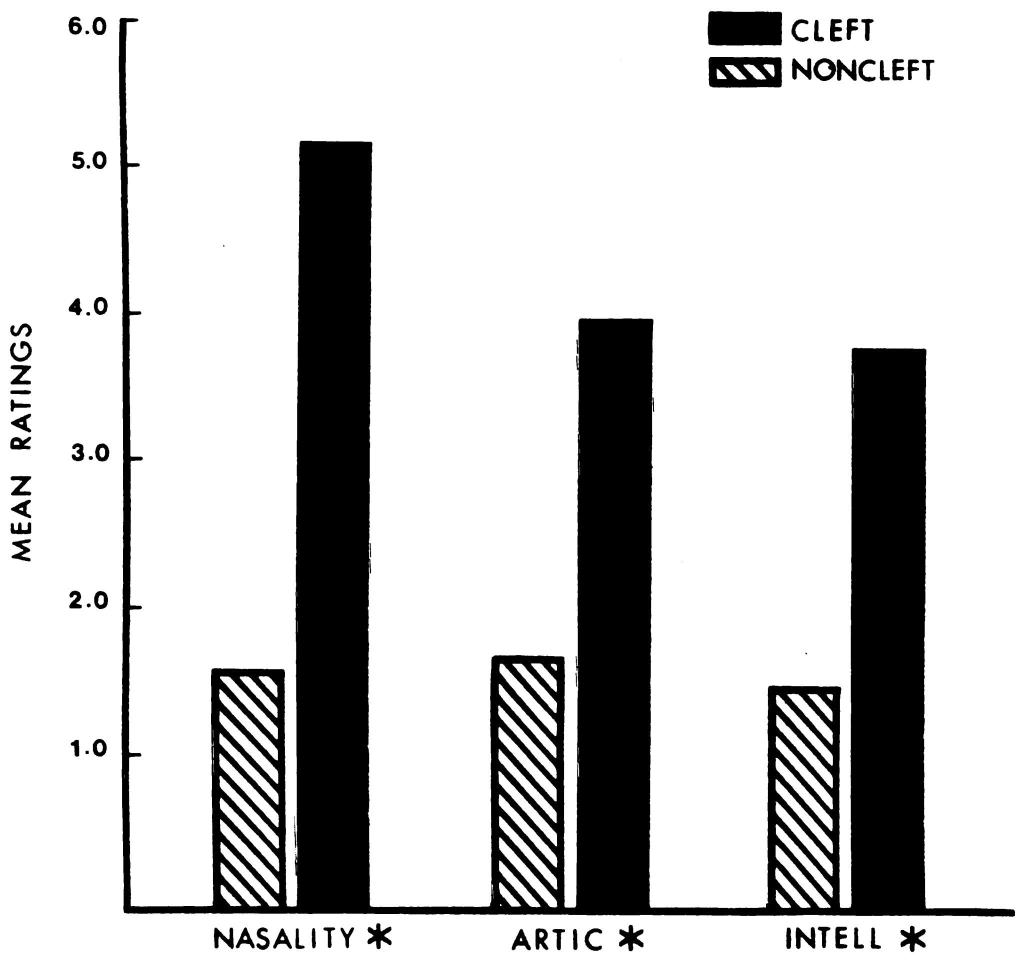

FIGURE 3. Comparison of mean speech attribute ratings between cleft and noncleft groups: habitual and rapid rate conditions combined. (Higher numbers represent poorer ratings.)

* Significant at the .01 level

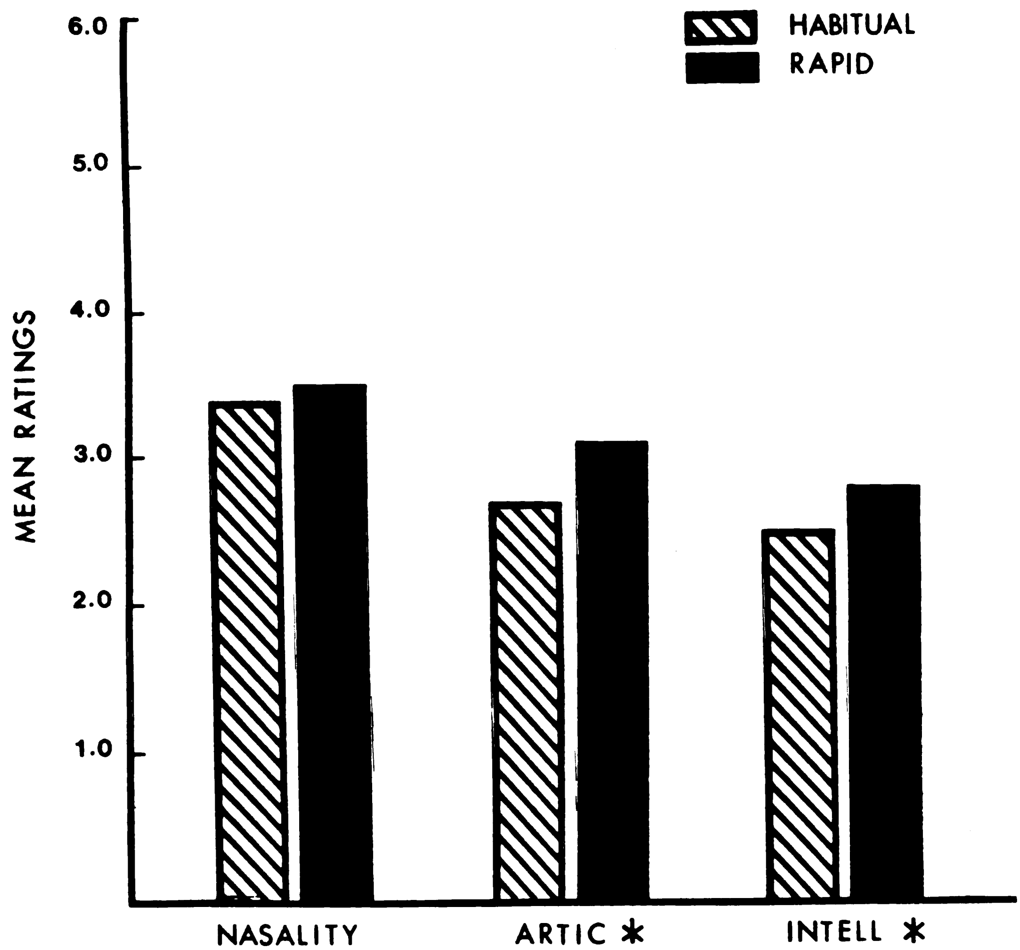

FIGURE 4. Comparison of mean speech attribute ratings between habitual and rapid rate conditions: cleft and noncleft groups combined. (Higher numbers represent poorer ratings.)

* Significant at the .01 level

TABLE 15

Summary of anaylsis of variance for
mean ratings of nasality.

	df	F	Significance
Between Groups	1	52.997	.0000
Between Rate Conditions	1	.686	.4226
Group X rate Interaction	1	.247	.6280

TABLE 16

Summary of analysis of variance
for mean ratings of articulation.

	df	F	Significance
Between Groups	1	22.340	.0002
Between Rate Conditions	1	11.390	.0033
Group X rate Interaction	1	.055	.8178

TABLE 17

Summary of analysis of variance

for mean ratings of intelligibility.

	df	F	Significance
Between Groups	1	20.118	.0003
Between Rate Conditions	1	9.428	.0065
Group X rate Interaction	1	.018	.8960

TABLE 18

Condition relation matrix for mean ratings, duration and speaking rate for the noncleft group.

		Habitual Condition			Rapid Condition			Duration		Speaking Rate	
								Habitual Condition	Rapid Condition	Habitual Condition	Rapid Condition
		Nasal.	Artic.	Intell.	Nasal.	Artic.	Intell.				
Habitual Condition	Nasal.		.57	**.78	***.93	.09	.18	.10	.02	-.12	-.05
	Artic.			***.91	.59	*.74	*.69	.18	.50	-.15	-.50
	Intell.				**.78	.62	*.65	.03	.38	-.05	-.39
Rapid Condition	Nasal.					.22	.28	-.01	.07	-.01	-.08
	Artic.						***.97	-.40	.30	.38	-.26
	Intell.							-.28	-.14	-.26	.11

*Significant at the .05 level or greater

**Significant at the .01 level or greater

***Significant at the .001 level or greater

TABLE 19

Correlation matrix for mean ratings, duration and speaking rate for the cleft group.

		Habitual Condition			Rapid Condition			Duration		Speaking Rate	
								Habitual Condition	Rapid Condition	Habitual Condition	Rapid Condition
		Nasal	Artic.	Intell.	Nasal	Artic.	Intell.				
Habitual Condition	Nasal		***.86	***.89	***.92	***.92	***.91	*.72	.58	*-.70	-.53
	Artic.			***.99	**.86	***.96	***.93	**.81	**.86	**-.82	**-.84
	Intell.				***.86	***.97	***.93	**.81	**.82	**-.81	**-.80
Rapid Condition	Nasal					***.88	**.81	*.72	*.66	**-.74	*-.65
	Artic.						***.95	**.82	**.75	**-.82	*-.73
	Intell.							**.82	**.75	**-.79	*-.68

*Significant at the .05 level or greater

**Significant at the .01 level or greater

***Significant at the .001 level or greater

TABLE 20

Correlation between intelligibility ratings and nasality/articulation ratings.

Group/Condition	Nasality		Articulation	
	r=	p=	r=	p=
Noncleft				
Habitual	.77	.008	.90	.0003
Rapid	.27	.440	.96	.0001
Cleft				
Habitual	.88	.006	.99	.0001
Rapid	.81	.004	.95	.0001

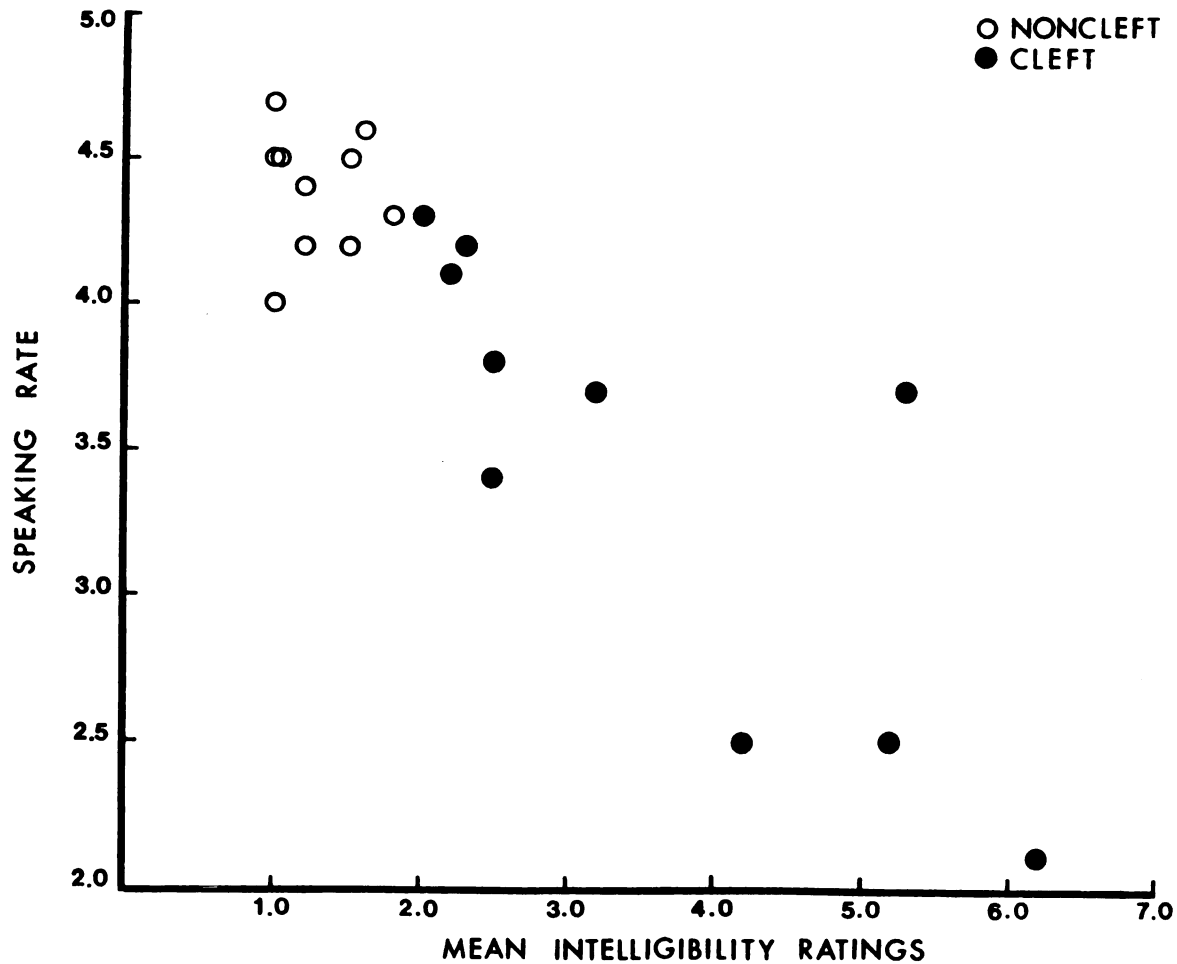

FIGURE 5. Scatter plot of mean intelligibility ratings as a function of speaking rate for individual cleft and noncleft subjects in the habitual rate condition.

Discussion

The data obtained in Experiment 1 revealed several findings pertaining to the two specific questions which were addressed:

1. What are the effects of increased speaking rate on listener ratings of nasality, articulation and intelligibility?

2. Are speech ratings for individuals with cleft palate affected more by increased speaking rate than speech ratings for individuals without cleft palate?

Prior to discussing the effects of increased speaking rate on ratings of speech, it is necessary to describe the rate characteristics of the cleft and noncleft groups.

Data from the present experiment indicate that the cleft group spoke more slowly than the noncleft group in the habitual condition; however, there was less difference between the groups in the rapid condition. That is, cleft speakers altered their speaking rate more than noncleft speakers. This finding may be accounted for, in part, by implications present in the instructions to the subjects. In the habitual condition, the instructions were simply to "read the passage." The implied goal was to produce intelligible speech which would communicate the contents of the passage. In the rapid condition, however, the instructions were to "speak as rapidly as possible". The implication in this situation was that increased rate was the goal, and communication effectiveness was secondary. Regardless of the assumptions of the subjects, the finding implies that reduced speaking rate for the cleft group in the habitual condition was not simply due to passive mechanical restraints on the speech production system as some investigators might suggest. Because the cleft group increased speaking rate more than the noncleft group and was able to achieve rates approximating those of the normal group, reduced rate in the habitual condition appears to have been an active strategy. This interpretation of the data supports the hypothesis that individuals with cleft palate decrease speaking rate in an attempt to improve intelligibility.

Further support for this hypothesis may be gained from an analysis of the listener ratings which indicates that increased rate does result in poorer articulation and intelligibility for both cleft and noncleft speakers. Somewhat surprisingly, however, the results indicate that increased rate has no effect on nasality ratings for either group. This finding was expected for the noncleft subjects. However, for individuals with cleft palate, it was believed that increased speaking rate would lead to increased nasality. This result may be better understood by considering the nasality ratings for individual subjects as opposed to the mean values for the groups.

Four subjects in the cleft group showed poorer nasality ratings in the rapid condition and one subject showed no change. Of these five subjects three obtained the maximum nasality rating (7.0) in the rapid condition. It is possible that these three subjects would have obtained even higher nasality ratings if the scale had been expanded resulting in a higher mean value. (The highest nasality rating for a noncleft subject was 2.7; therefore, an increased upper limit on the rating scale would not have affected the mean nasality value for the noncleft group.) If the mean value for nasality ratings was increased for the cleft group in the rapid condition, the prediction that increased rate results in increased nasality might have been substantiated.

A second factor which undoubtedly contributed to the lack of significant change in nasality ratings in the rapid condition is the "direction of change." In the noncleft group, two of the ten subjects showed an average decrease in nasality ratings, (0.2) rather than an increase as expected. On the other hand, five of the ten cleft subjects showed an average decrease in nasality ratings (0.4 - ranging from 0.2 to 0.7).

Therefore, while half of the cleft subjects actually showed an improvement in nasality ratings in the rapid condition the other half of the cleft subjects demonstrated increased nasality which may have been numerically underestimated. Therefore, the group as a whole, represented by the mean value, appeared to be unaffected by increased rate. From this discussion it is understandable why increased rate had no effect on nasality ratings for the cleft group. However, the question that remains is: Why did nasality ratings for half of the cleft subjects improve with increased rate?

One possible explanation for this finding may be derived from a study of perceived nasality in the speech of the deaf. Colton and Cooker (1968) demonstrated that normal speakers are perceived as more nasal when they speak at a slower-than-normal rate. Based on their findings, the authors suggest that perceived nasality in the speech of the deaf may be the direct result of the slow speaking rates common to deaf speech rather than the result of abnormal velopharyngeal function. The authors further suggest that therapeutic techniques aimed at increasing speaking rate may result in a concomitant reduction in perceived nasality in deaf speakers. The current data suggest that this hypothesis is true for some speakers with cleft palate.

It was expected that ratings of speech for the cleft group would be more adversely affected by increased rate than ratings for the noncleft group. This prediction was strengthened by the finding that the cleft group showed a greater relative increase in speaking rate from the habitual to the rapid rate condition than the noncleft group. It was believed that this disproportionate increase in rate would result in a greater demand on an already stressed speech production mechanism. This theory cannot be substantiated by the present data.

However, while it is true that the changes in ratings from the habitual to the rapid condition were not statistically different between groups, the changes may in fact have had distinctly different perceptual consequences. We cannot be certain that the rating scale which was used is linear. That is, the difference between 1.3 and 1.7 (intelligibility ratings for the noncleft group in the habitual and rapid conditions) and 3.6 to 3.9 (ratings for the cleft group in both conditions) may be mathematically equal but may be perceptually quite different. Therefore it is not clear from the present data that increased rate truly had equal effects on speech ratings for both the noncleft and cleft groups.

The current findings indicate that the cleft group speaks more slowly than the noncleft group in the habitual condition and that increased speaking rate results in poorer articulation and intelligibility ratings for both groups. Furthermore, it has been hypothesized that the reduced speaking rate observed in the cleft group may be an active strategy rather than the result of passive mechanical restraints. However, it must be cautioned that it cannot be inferred from these results that a decrease in rate will uniformly lead to improved speech quality. It is likely that there is an optimal range of speaking rate. Values at either extreme of this range will probably result in reduced intelligibility. In fact, results of the correlation analyses indicate there is a significant relationship between duration/speaking rate and speech ratings within a given rate condition for the cleft group, suggesting that slower speech is poorer. It is important to note, however, that this is a between subject (not a within subject) relationship. Therefore, while samples with the longest durations/slowest speaking rates elicited the poorest ratings, it is possible that the slowest speakers obtained the poorest ratings for reasons other than, or only partially related to, speaking rate *per se*. That is, the more anatomically involved speaker may also be the slower speaker; in turn, the slow speaking rate and reduced speech quality may both be results of the nature and extent of the anatomic limitations.

This finding, in conjunction with the finding that nasality ratings for half of the cleft subjects improved with increased rate, suggests that the relationship between utterance duration/speaking rate and speech quality remains unclear. Further study of the rate characteristics of speakers with cleft palate appears to be warranted.

IV Experiment 2: Comparison of acoustically defined segment durations in cleft and noncleft speech

Introduction

The results of Experiment 1 confirm the findings of previous studies indicating that speakers with cleft palate generally speak more slowly than individuals without clefts. The findings of Lass and Noll (1970), Tarlow and Saxman (1970), and Rolnick and Hoops (1971) suggest that cleft speakers spend more time in phonation and articulation than noncleft speakers when producing the same utterances. However, no investigations have addressed the issue of how this increase in phonation and articulation time manifests itself at the phonetic level. That is, is the overall increase in duration reflected in a linear, horizontal expansion of the signal, or are some phonetic intervals more affected than others?

In the only study of durations of phonetic intervals in cleft speech, Rolnick and Hoops (1971) observed increases in plosive phoneme durations in the speech of individuals with cleft palate and suggested that these increases were the result of palato-pharyngeal inadequacy. These results were derived from measurements of voiceless plosives in word initial position only. The authors did not compare the results with measurements of voiced plosives nor did they consider contextual effects on consonant duration. Furthermore, they made no duration measurements of vocalic segments to determine whether both consonant and vowel segments were elongated in cleft speech.

Nevertheless, the preceding studies do suggest that there are differences in the overall timing characteristics of cleft palate speech when compared with noncleft speech. Lass and Noll (1970) addressed the effects of rate alteration on the timing differences between these two groups at a macroscopic level of analysis. They found that at the sentence level, noncleft and cleft speakers employed the same strategies to decrease speaking rate but used slightly different strategies when asked to increase rate. No studies have addressed the effects of rate alteration at the more microscopic levels of cleft speech as compared with noncleft speech. Specifically, there are no data pertaining to the effects of rate alteration on durations of phonetic intervals in the speech of individuals with cleft palate.

Specific Questions

Experiment 2 explores five specific questions which have not been experimentally addressed in the literature on cleft palate speech:

1. Do cleft speakers spend more time phonating/articulating than noncleft speakers when producing the same utterance?

2. Are some segments in cleft speech more prolonged than others?

3. Are segment durations more variable in cleft than noncleft speech?

4. When speaking rate is increased by either group, do segment durations become more or less variable?

5. When cleft speakers increase speaking rate, are segment durations altered in the same manner as for noncleft speakers?

Subjects

Nine subjects were selected from Experiment 1 to participate in the present experiment. Table 21 lists the subjects with the mean intelligibility ratings and speaking rates in the habitual rate condition obtained in Experiment 1. Three noncleft subjects were chosen randomly from the noncleft group in Experiment 1. Selection of the six cleft subjects was based on intelligibility ratings and speaking rate. The cleft subjects PV, JL, and MH obtained high intelligibility ratings and relatively rapid speaking rates, while the subjects JD, OL, and CD demonstrated both the lowest intelligibility ratings and among the slowest speaking rates for the cleft group. (Appendices A and B contain additional information regarding these subjects).

Table 21

Mean intelligibility rating and speaking rate in the habitual rate condition for nine subjects from Experiment 1 who served as subjects in Experiment 2.

Group/Subject	Intelligibility rating	Speaking rate
Noncleft		
LB	1.0	4.0
BM	1.0	4.5
MR	1.2	4.2
Cleft		
PV	2.3	4.2
JL	2.2	4.1
MH	2.5	3.8
JD	4.2	2.5
OL	6.2	2.1
CD	5.3	2.7

Methods

Speech sample. To obtain duration measurements it was first necessary to acquire appropriate speech samples from the subjects. In the speech samples it was important to include both vowels and consonants which represented different articulatory/acoustic contrasts. For the consonants, it was also important to select phonemes with relatively recognizable onsets and offsets and to combine the consonants and vowels in such a way that would facilitate measurement procedures. Furthermore, it was desirable that the phonemes be produced in connected speech to be as natural as possible. To meet these needs, four vowels and three consonants were selected.

Vowels

/i/ high front vowel (heat)

/ae/ low front vowel (hat)

/u/ high back vowel (hoot)

/a/ low back vowel (hot)

Consonants

/p/ bilabial, voiceless stop

/b/ bilabial, voiced stop

/d/ lingual, alveolar, voiced stop

The selected phonemes were combined to form consonant-vowel-consonant nonsense syllables (CVC) in which V was one of the four vowels /i, ae, u, a/ and C_1 and C_2 were one of the three consonants (i.e., in a given CVC, C_1 and C_2 were the same phoneme. Therefore, four vowels X three consonants = 12 CVC syllable "types"). Each CVC syllable was produced within the carrier phrase "Say a --- a again", (e.g., /se əpipə əgɪn/.

Recording. Each speaker in the experiment was recorded individually in a sound-treated room. Utilizing a voice microphone (TEAC Electret condenser microphone, Model ME -120) the speech samples were recorded on magnetic audio tape via one channel of a four channel A.M. tape recorder (TEAC Model A3440). Appropriate equipment adjustments were made at the beginning of each recording session (i.e., microphone placement and recording levels).

The experiementer familiarized the speaker with the four vowels and three consonants that would comprise the CVC syllables by producing spoken models of the component phonemes. The speaker was instructed to produce the carrier phrase with a given CVC five times on a single breath stream at the habitual speaking rate. There was a pause, and the speaker was then instructed to repeat the same procedure, this time at a rapid speaking rate. This pattern was followed until all CVC syllable types had been produced at both the habitual and rapid speaking rates (12 syllable types x 5 repetitions or "tokens" x 2 speaking rates = 120 samples per subject).

Occasionally, a subject's approximation of his habitual rate was markedly faster than his conversational rate, or his productions of a given vowel were in error. When this occurred, the recording was stopped, the subject was reinstructed by the experimenter, and the recording was resumed. Likewise, some of the subjects paused for breath between tokens. When this occurred and was observed by the experimenter, the speaker was asked to begin again and to produce all five tokens on the same breath.

Equipment. The time waveforms of the speech samples for the nine subjects in Experiment 2 were digitized, displayed, and segmented employing an interactive, timesharing, computer system. Figure 6 displays a functional block diagram of the computer hardware which was utilized.

The system consisted of a Data General computer (Eclipse S130) with 384 K bytes of memory, with disk drive and magnetic tape units, operating under the Advanced Operating System ®(AOS, Data General Inc.) The system also included peripheral devices necessary for digital signal processing:

1. TEAC 3440, 4-channel, reel-to-reel tape recorder with built-in preamplification.

2. Low-pass anti-aliasing filter (5K Hz. low pass, -50dB at 5.3K Hz.).

3. Custom built 12 bit A/D-D/A converter.

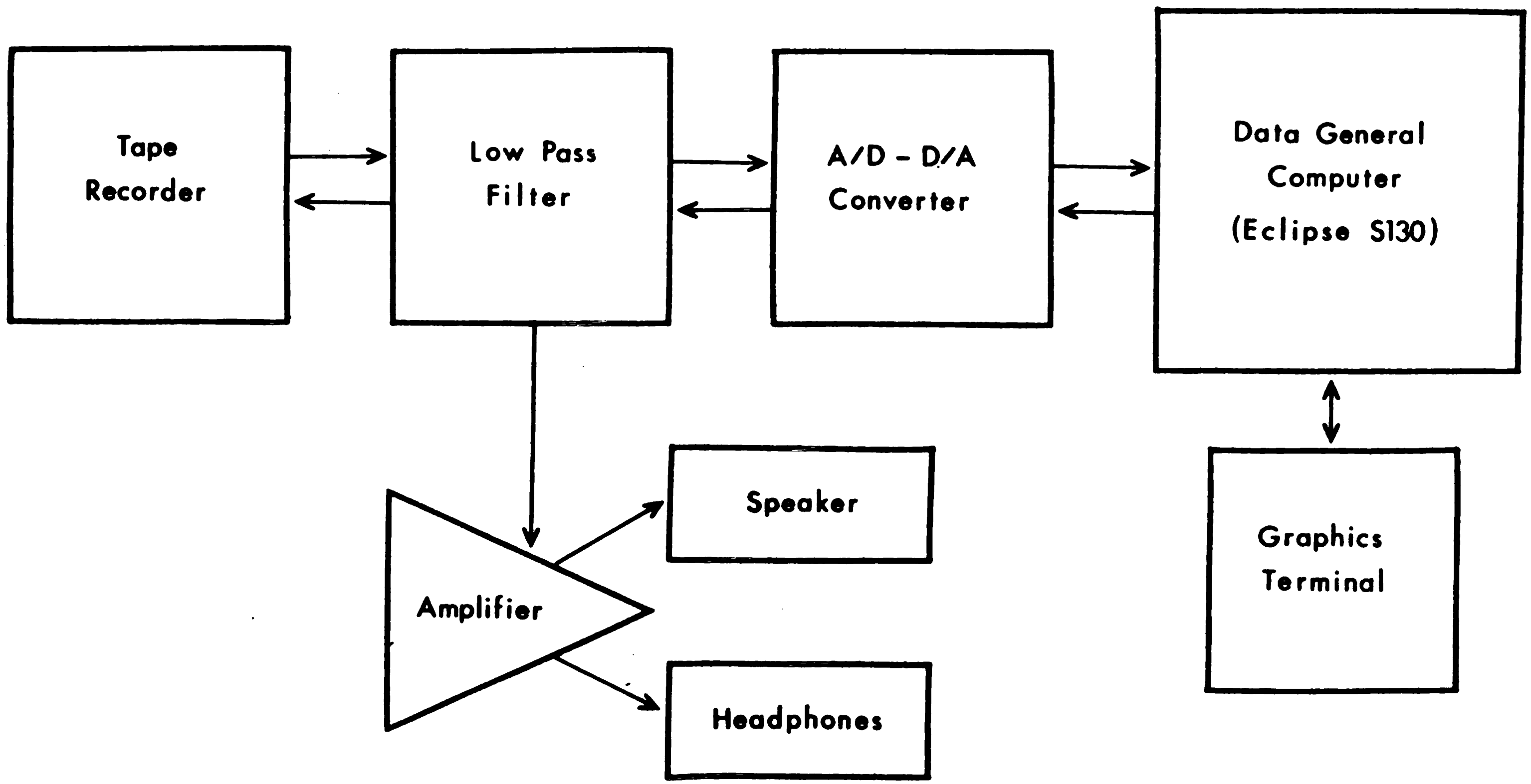

FIGURE 6. Functional block diagram of the computer hardware utilized for digital speech processing.

4. Tektronix 4010 compatible graphics terminal with built-in, X-Y coordinant input device.

5. Amplifier with external gain control with loud speaker and head phones.

The analog speech signal from the audio tape was converted to digital representation and input to the computer, employing a custom built analog-to-digital (A/D) converter. The signal was digitized at a sampling rate of 10K Hz. (10,000 samples per second). Each sample was quantized to 12 bits.

The resulting digital signals were stored in files on disk and magnetic tape. Processing of the signals was accomplished employing program modules from a commercially available software package for interactive digital signal processing (Interactive Laboratory System ® "ILS", Version 3.0, Signal Technology, Inc.).

Segmentation procedures. One of the parameters of the signal processing software allowed the user to determine the amount of time represented by arbitrary units called "frames". For the present experiment, this value was set so that each frame represented one millisecond. When a signal was displayed, a "cursor" command allowed demarcation of one or more points in a file and an accompanying, automatic display of the number of frames from one cursor to the next. In this case, since a frame equaled one millisecond, the number of frames between cursors equaled time in milliseconds. Therefore, the time waveform of the speech signal could be segmented from left to right, and duration measures were automatically calculated and transcribed from the terminal screen.

Each computer file consisted of five repetitions of one CVC type at one speaking rate by an individual subject. Segmentation of the waveform occurred in a series of approximations. First, the five repetitions were separated from one another visually, and segmentations were verified auditorially by playing back specified segments, which were heard through a speaker or headphones. Figure 7 shows an example of an entire file (five repetitions of the utterance "Say a peep a again") at the habitual speaking rate produced by the noncleft subject LB. Each repetition of the carrier phrase is windowed by cursor lines. Notice that there are two rows of numbers under each cursor line. The top row displays the "frame number" while the bottom row displays the number of frames from the last cursor. Once individual repetitions were identified they were expanded and displayed in isolation. Figure 8 shows an expanded display of the second token of the utterance seen in Figure 7. This process of windowing and expansion continued until the necessary visual resolution was achieved.

<u>Segmentation criteria</u>. As discussed in Chapter II, modern views of linguistics generally accept that the

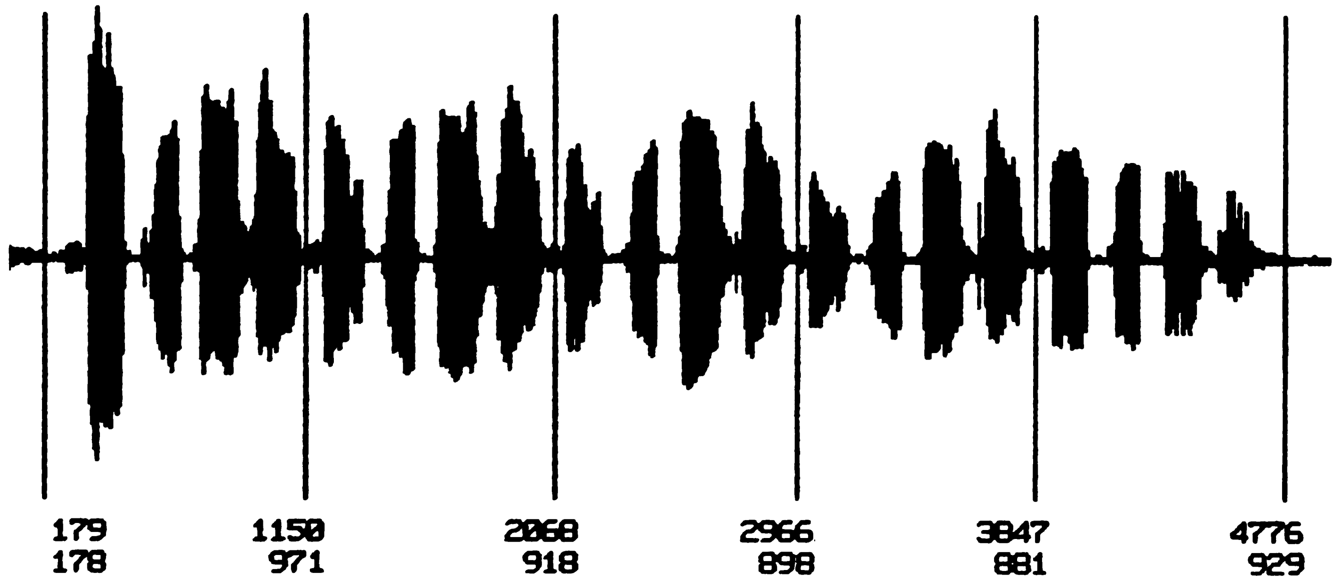

FIGURE 7. Sample acoustic waveform of five repetitions of the utterance "Say a peep a again", produced by the noncleft subject LB in the habitual rate condition.

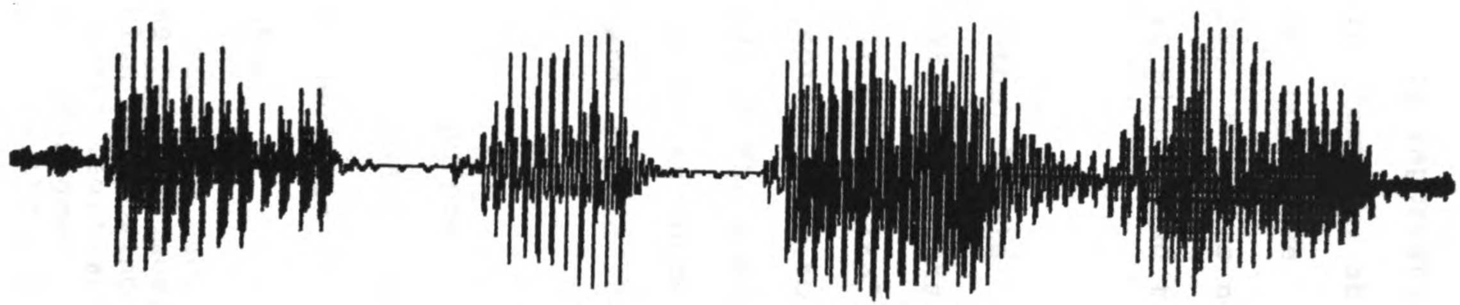

FIGURE 8. Windowed and expanded display of Token 2 of the utterance "Say a peep a again" produced by the noncleft subject LB in the habitual rate condition.

phonetic units of speech overlap and carry information pertaining to surrounding segments. Furthermore, while linguistic segments are important concepts for describing language, they are complex, abstract units which are primarily the result of cognitive processes applied by the listener. That is, there is no one-to-one correspondence between the acoustic signal and the perceptual, phonemic units of speech.

In a paper on the levels of description in speech research, Repp (1981) suggests that "perceptual-cognitive (phonetic-linguistic) categories", such as consonant, vowel, syllable, should not be used to refer to measurements made from graphic displays of the acoustic waveform. Repp points out that these measurements concern the visual correlates of acoustic segments and should be described primarily in acoustic terms.

Therefore, for the purposes of this experiment, the term "segment" will be used to refer to acoustically defined intervals which are specified in physical terms. However, as Repp also suggests,

> "Definition of acoustic segments in purely physical terms can be cumbersome, e.g., 'the periodic portion following the fricative noise.' It is quite legitimate, therefore, to name the linguistic segment for which a given acoustic segment is the primary cue, as long as the main term is physical in nature, e.g., 'the u periodic portion', 'the p silence', or 'the s noise'" (p 1464).

The intervals of interest in the present experiment are described below along with their shorter more convenient terms which will be employed throughout the text in keeping with the suggestions made by Repp. These intervals are graphically displayed in Figure 9 which shows the segmentation of the CVC /pip/ (peep) previously displayed in Figures 7 and 8.

1. Initial stop silence - the silent interval from termination of periodicity for the preceding schwa to the onset of the burst for /p,b,d/

2. Initial stop burst - the interval from the release of stop closure (seen in the burst spike) to onset of periodicity for the following vowel /i,ae,u,a/.

3. Vowel periodicity - the interval from the onset of periodicity for /i,ae,u,a/ following stop closure and burst to termination of periodicity.

4. Final stop silence + burst - the interval from termination of periodicity for /i,ae,u,a/ to the onset of periodicity for the following schwa.

5. Total sentence - the interval from the onset of periodicity for /e/ in /se/ (say) to the termination of periodicity for /n/ in /əgIn/ (again).

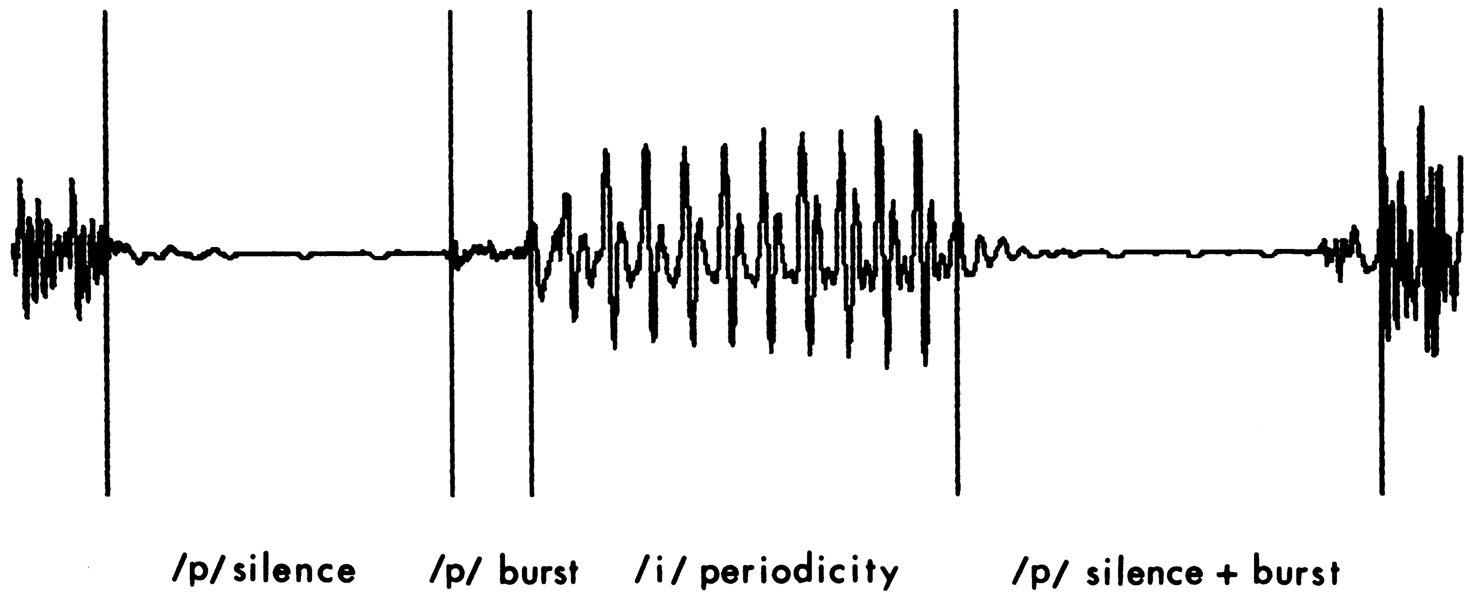

FIGURE 9. Illustration of segmentation criteria for four acoustically defined intervals for the CVC /pip/.

Results

All speech samples for the nine subjects were digitized and interactively displayed and analyzed. The CVCs comprised of the consonant /p/ (/p/ data) were segmented, measured and statistically analyzed. The CVCs comprised of /b/ or /d/ (/b/ or /d/ data) were segmented and measured; however, segmentation was often difficult (especially for the cleft subjects) and the results were extremely variable. Therefore, the results of Experiment 2 are grouped into two broadly defined and sometimes overlapping categories:

1. quantitative and statistical analysis of duration measures for the /p/ data, and

2. qualitative descriptions of timing made from observations of the /p/, /b/, and /d/ data.

Reliability. Informal reliability measures of the experimenter's segmentation procedures were made. Four speech samples were selected to represent examples of least and most difficult waveforms for segmentation. The CVC types chosen were /pip/ in the habitual rate condition, produced by a noncleft and a cleft speaker, and /bab/ in the habitual and rapid rate condition, produced by a cleft speaker. Repeat measurements were made approximately three months after the initial segmentation. The discrepancy between the two sets of measurements for the /p/ data ranged from 2 msec. to 6.6 msec. and for the /b/ data from .4 to

13.4 msec. With the exception of the one discrepancy of 13.4 msec. (for final /b/ silence + burst produced by a cleft speaker in the rapid condition) all measurement discrepancies were under 9 msec. Therefore, the majority of repeat measurements fell within ± one glottal period. Furthermore, the range of discrepancy values for the /p/ data was narrower than for the /b/ data, with the majority of repeat measurements falling within ± one half of a glottal period.

Quantitative duration measures. As discussed earlier, only the /p/ data were analyzed in a quantitative, statistical manner. The results of these analyses are reported in this section. For the present discussion, the nine subjects have been divided into three groups: noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC). Eight values were calculated for quantification and analysis of the /p/ data:

1. Mean segment duration - the average duration of segment measurements of five tokens of one CVC type.

2. Sample S.D. of segment durations - the sample standard deviation of the five token duration measurements.

3. Group mean segment duration - the average of the mean segment durations across 4 vowel types for 3 subjects within a group.

4. Sample S.D. of the group mean segment durations - the

sample standard deviation of the mean segment duration values for a group. (That is, the 12 mean duration values for each group [3 subjects x 4 CVC types = 12] were averaged together and the standard deviation of the new mean was calculated.)

5. Mean of the sample S.D. (MSD) - the average of the sample standard deviation values across 12 duration measures for each group (3 subjects x 4 CVC types = 12). (That is, the standard deviation values for the 5 repetitions of one CVC type in one rate condition for one subject were averaged together across the 4 CVC types x 3 subjects.

6. Sample S.D. of the MSD values - the sample standard deviation of the MSD values.

7. Normalized MSD values - a ratio value resulting from the calculation, MSD/Group mean segment duration.

8. Normalized sample S.D. of the MSD - a ratio value resulting from the calculation, MSD ± sample SD of the MSD/Group mean segment duration.

Table 22 presents the group mean segment durations and sample S.D. values for the segment durations for the three groups in two rate conditions. Mean segment durations and standard deviation values for individual subjects are provided in Appendicies C and D.

The group mean segment duration data are displayed in

Figures 10 through 17. The data indicate that, on the average, segments produced by the cleft groups are generally longer than segments produced by the noncleft group. Furthermore, segments produced by the low intelligiblity cleft group are longer than segments produced by the high intelligibility cleft group. This rank ordering is most noticeable in the habitual rate condition. In the rapid rate condition, the duration differences between the groups are reduced. An exception to the rank order pattern between the groups is seen in the /p/ burst and vowel periodicity segments (Figures 12 and 13). However, when these two intervals are added together (as they commonly are by many investigators), the rank order function follows the same general pattern as with the other segments (Figure 15).

The data were further analyzed through application of an analysis of variance for each segment. Detailed results of the analyses are provided in Appendix E. Table 23 provides a summary of the levels of statistical differences between the segments in the form of P values derived from the analyses of variance. The results indicate that all group mean segment durations are significantly longer in the habitual rate condition than in the rapid rate condition. Furthermore, the duration differences between the groups are statistically significant for the /p/ burst and the /p/ burst + silence intervals, and approach significance for the total sentence duration. The difference between the groups for the /p/ silence and vowel periodicity segments was not

Table 22

Group mean segment duration values and S.D. values for three groups in two rate conditions.

		Habitual Rate			Rapid Rate		
		NC	HC	LC	NC	HC	LC
Total Sentence	$\bar{X}$	879	1046	1079	697	714	814
	SD	83	86	109	56	120	50
/p/ Silence	$\bar{X}$	76	84	90	64	60	72
	SD	7	7	14	9	8	9
/p/ Burst	$\bar{X}$	38	55	50	27	39	44
	SD	10	15	8	7	9	9
Vowel Periodicity	$\bar{X}$	93	87	94	84	67	86
	SD	22	23	21	21	25	15
/p/ Silence + Burst	$\bar{X}$	94	110	128	80	92	111
	SD	3	14	20	7	14	20

NC = Noncleft

HC = High Intelligibility Cleft

LC = Low Intelligibility Cleft

Table 23

Summary of P values derived from analysis of variance for group mean duration values.

	Between Rates Habitual/ Rapid	Between 2 Groups Noncleft & Cleft	Between 3 Groups Noncleft Hi Intell. Cleft Lo Intell. Cleft	Group X Rate Interaction	Between Vowels	Rate X Vowel Interaction
Total Sentence	.0001	.08	.14	.15	.92	.36
/p/ Silence	.001	.20	.14	.37	.29	.53
/p/ Burst	.002	.01	.04	.19	.32	.37
Vowel Periodicity	.005	.58	.44	.26	.0005	.23
/p/ Silence + Burst	.001	.04	.05	.87	.25	.75

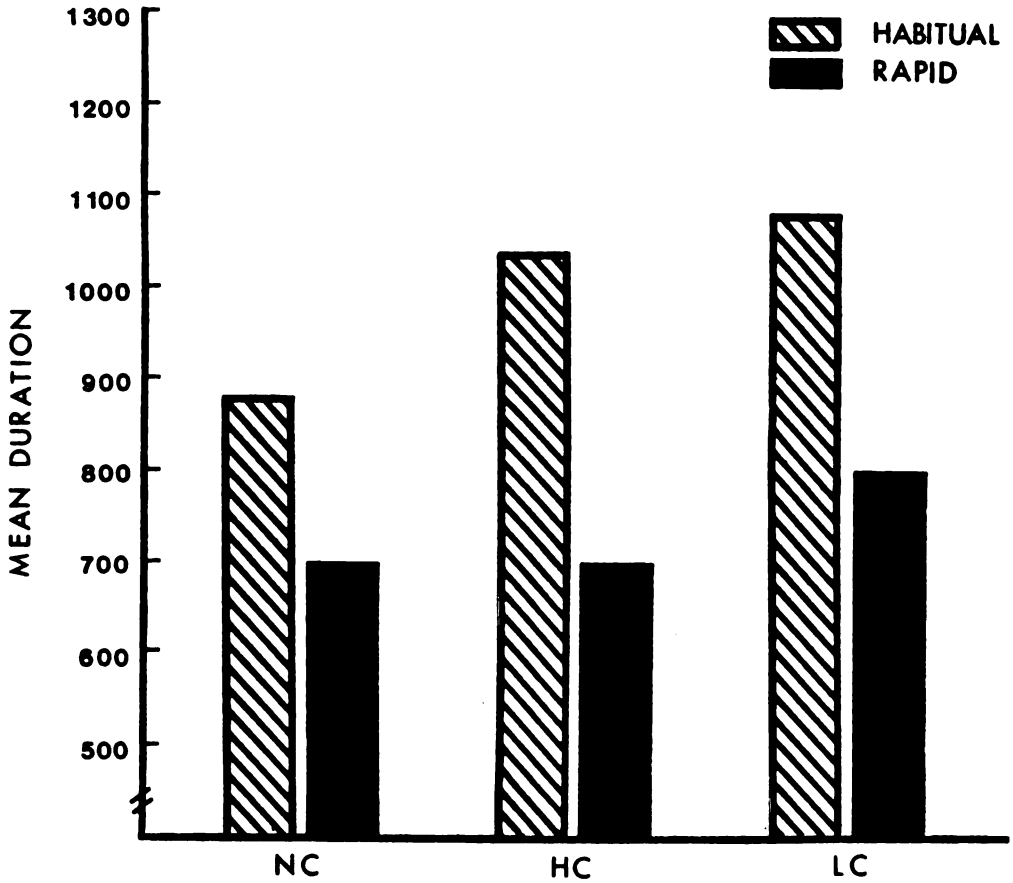

FIGURE 10. Mean duration values in msec. for "total sentence" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

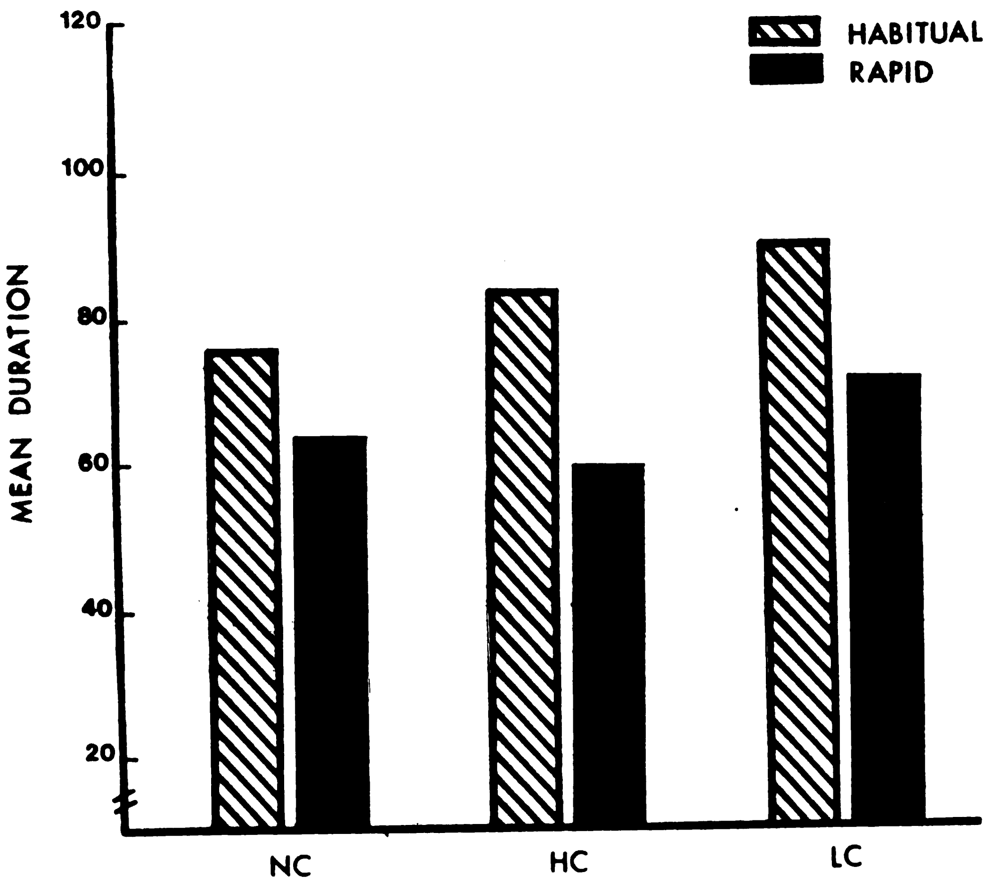

FIGURE 11. Mean duration values in msec. for "/p/ silence" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

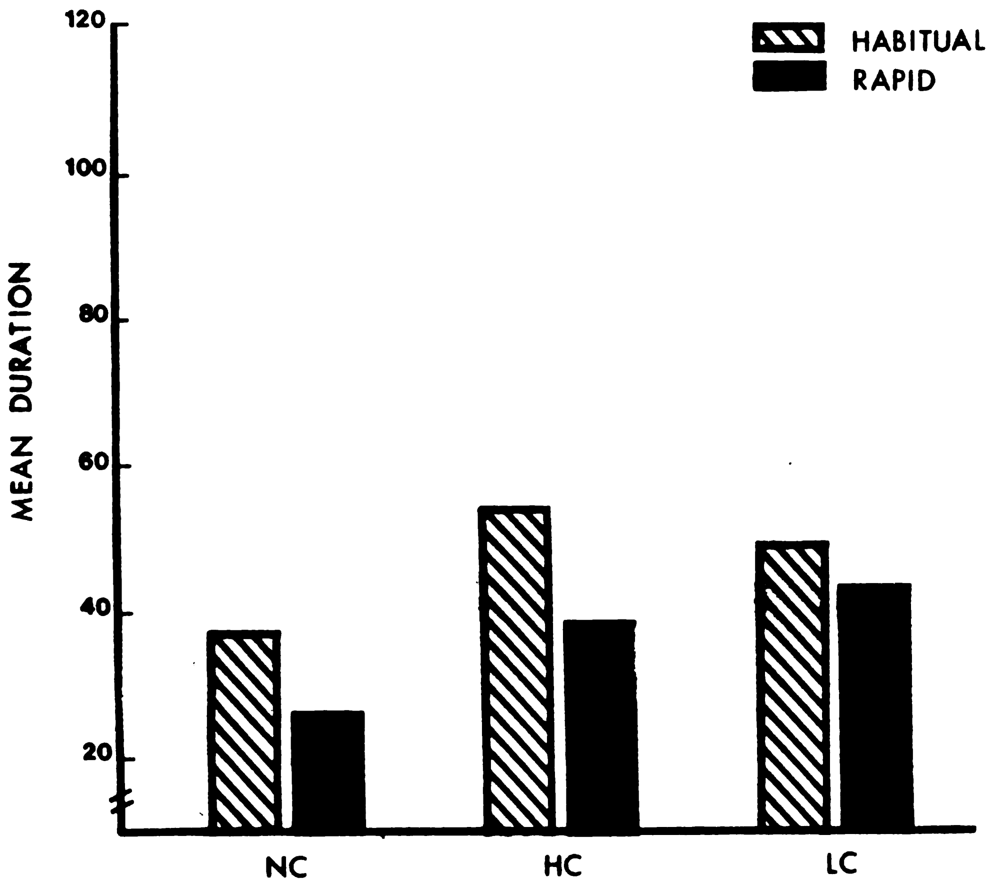

FIGURE 12. Mean duration values in msec. for "/p/ burst" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

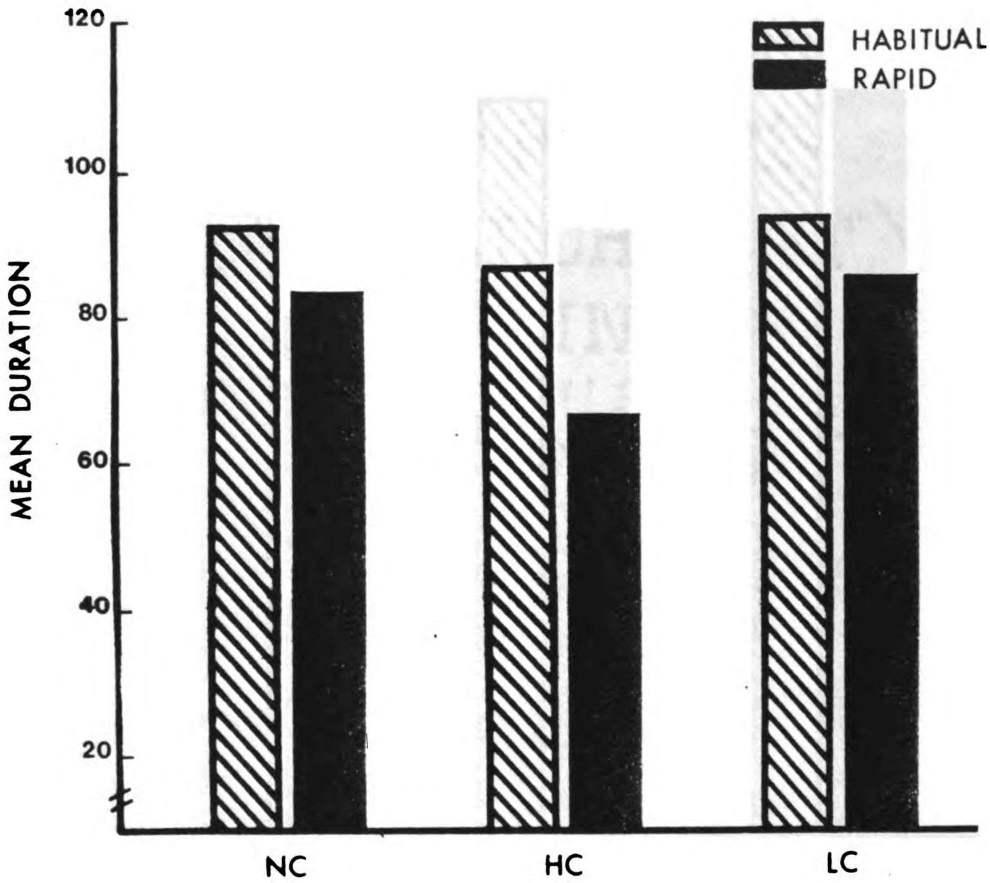

FIGURE 13. Mean duration values in msec. for "vowel periodictiy" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

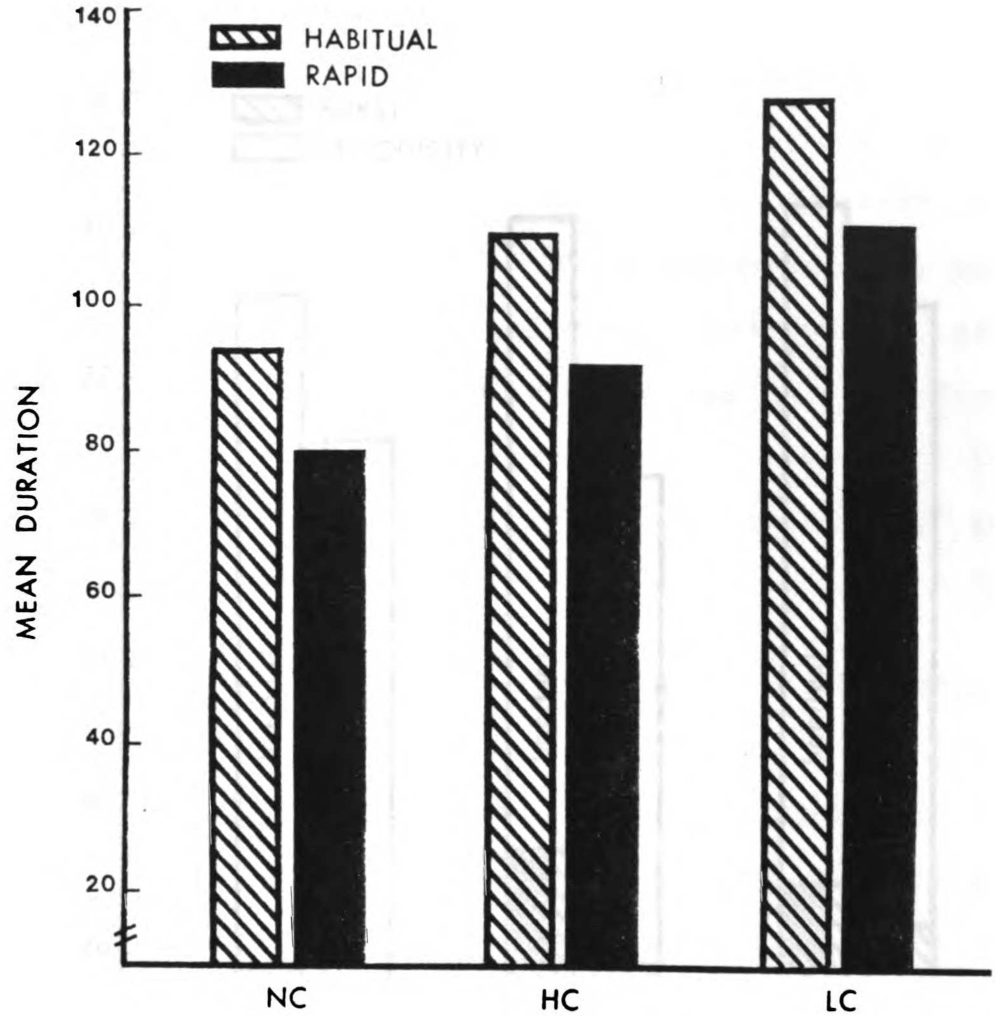

FIGURE 14. Mean duration values in msec. for "/p/ silence + burst" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

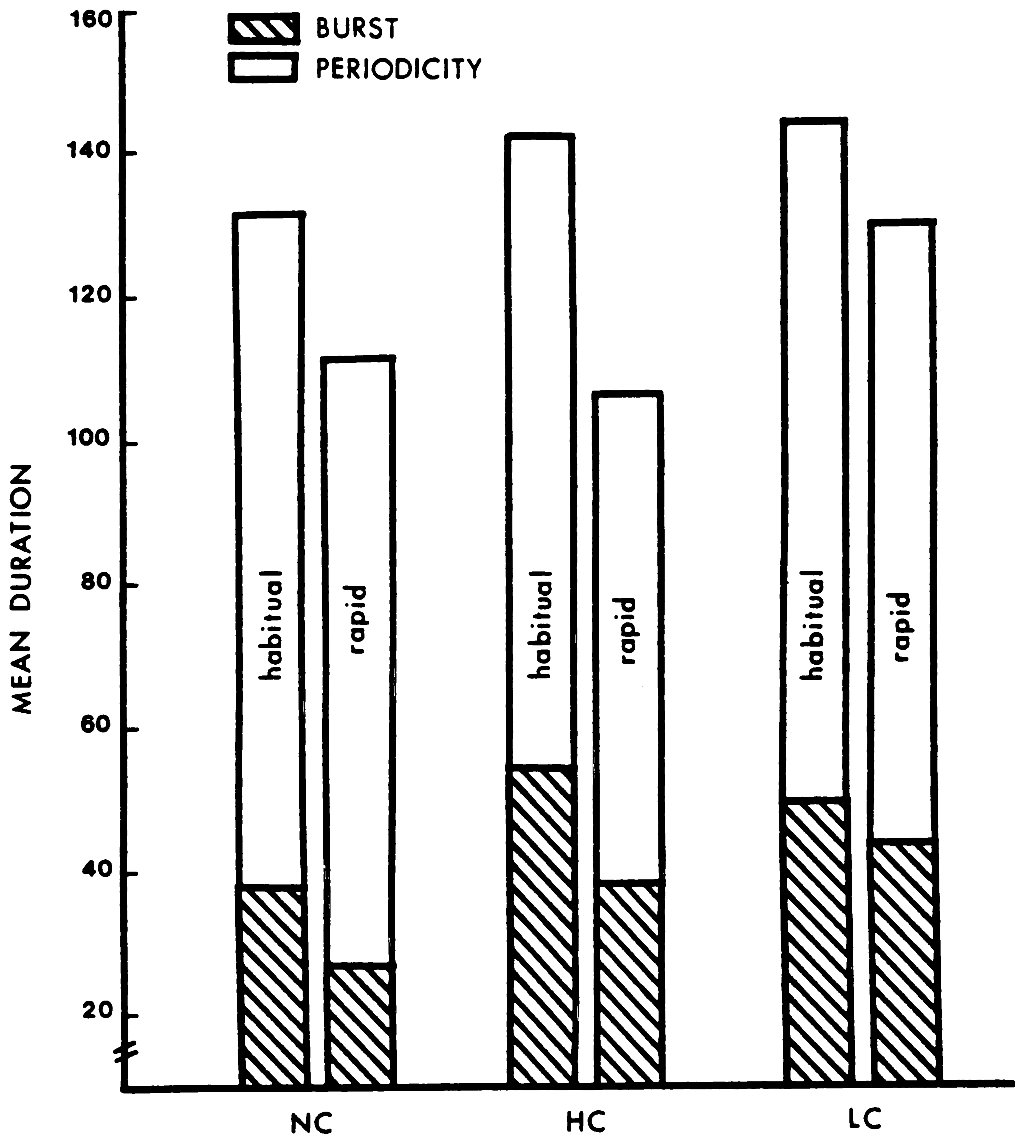

FIGURE 15. Mean duration values in msec. for "/p/ burst" and "vowel periodicity" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

statistically significant.

As expected, the results of the analyses of variance for group mean segment durations further indicate that vowel identity has a significant effect on the duration of the vowel periodicity segments. The group mean vowel periodicity durations for the four individual vowels are provided in Table 24 and plotted in Figures 16 and 17. The data show that the vowels /i/ and /u/ are associated with shorter periodicity durations than the vowels /a/ and /ae/ for all groups in both rate conditions.

As indicated by the previous finding, vowel periodicity duration is known to vary as a result of vowel identity. This interval also varies with consonant context. Therefore, vowel periodicity was measured for vowels produced in the /b/ data as well as in the /p/ data. Figure 18 illustrates the effects of the voiced /voiceless stop environment on the durations of vowel periodicity. Both noncleft and cleft groups produce longer periodicity durations in the voiced stop (/b/) context than in the voiceless stop (/p/) context.

In order to obtain an estimate of the variability among segments and groups, the mean of the sample standard deviation value (MSD) was calculated for each segment. (Recall that the standard deviations of the segment durations are averaged together and treated as mean values themselves, referred to as the MSD values.) Table 25 presents the MSD

Table 24

Group mean vowel periodicity durations for individual vowels for three groups in two rate conditions.

		Habitual Rate			Rapid Rate		
		NC	HC	LC	NC	HC	LC
Vowel Periodicity	a	112	94	106	94	74	94
	ae	113	108	117	105	82	100
	i	79	69	74	71	55	71
	u	69	77	79	66	56	78
Burst	a	37	64	44	25	34	46
	ae	37	49	50	22	33	40
	i	37	56	55	28	44	48
	u	41	53	50	34	44	44
Burst + Periodicity	a	149	158	150	119	108	140
	ae	150	157	167	127	115	140
	i	116	125	129	99	99	119
	u	110	130	129	100	100	122

NC = Noncleft

HC = High Intelligibility Cleft

LC = Low Intelligibility Cleft

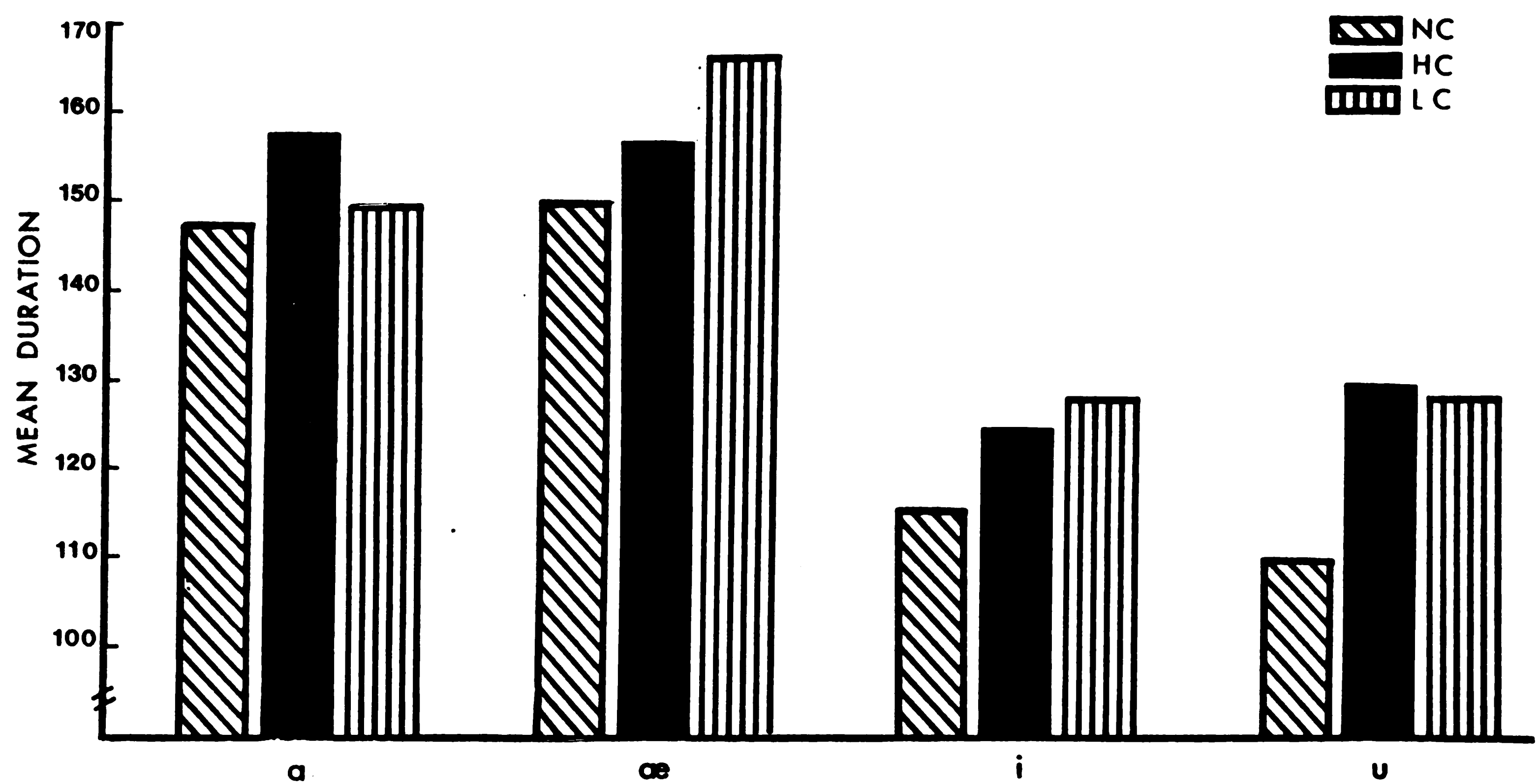

FIGURE 16. Mean duration values in msec. for "/p/ burst" + "vowel periodicity" segments for individual vowel types produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in the habitual rate condition.

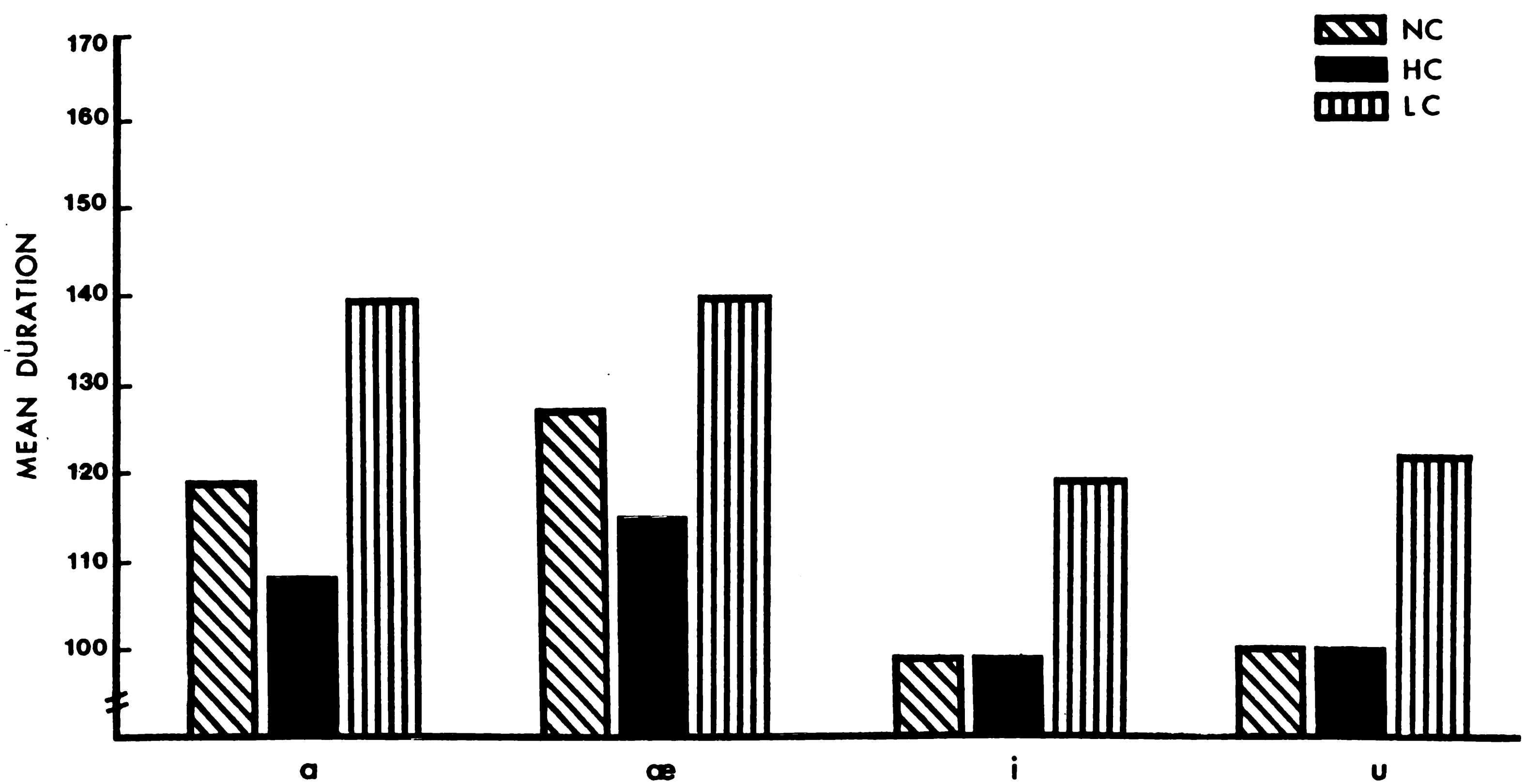

FIGURE 17. Mean duration values in msec. for "/p/ burst" + "vowel periodicity" segments for individual vowel types produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in the rapid rate condition.

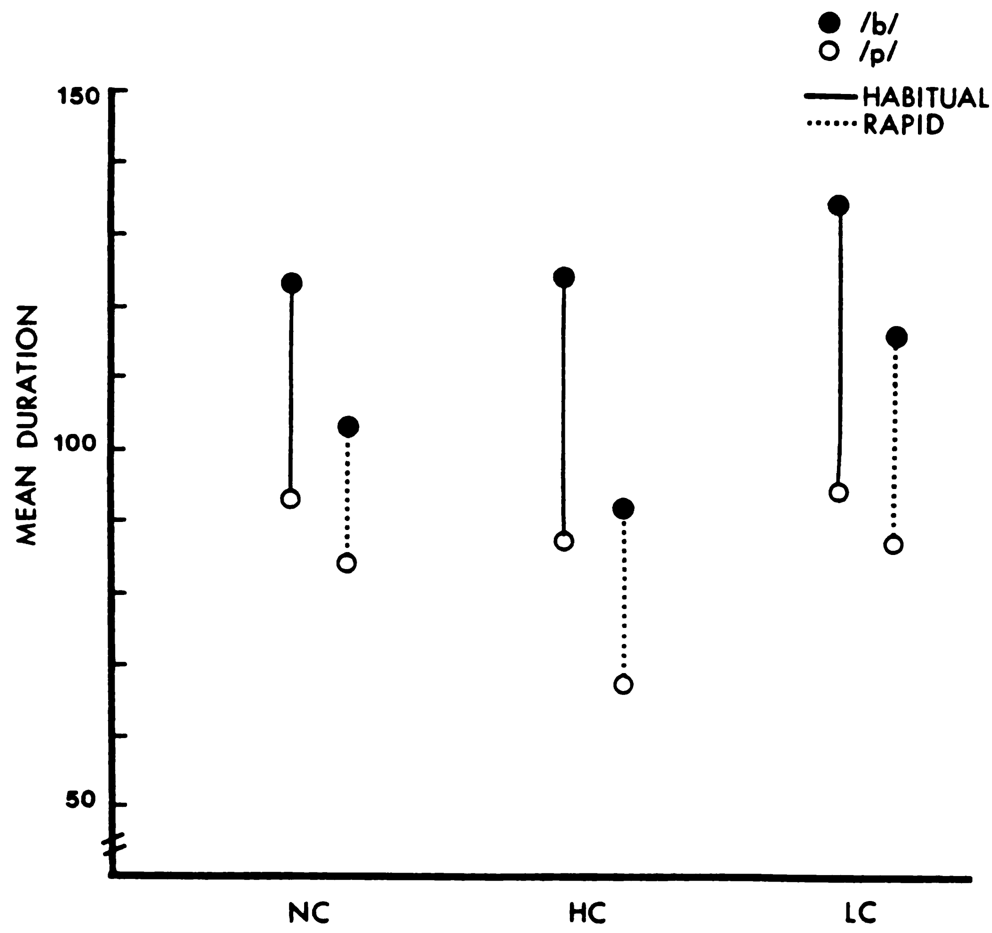

FIGURE 18. Mean duration values in msec. for "vowel periodicity" segments in /p/ and /b/ consonant environments, produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

values and the sample SD of the MSD values for the three groups in two rate conditions.

Analyses of variance were calculated for the MSD values for each segment. Detailed results of the analyses are provided in Appendix F. Table 26 shows a summary of the levels of statistical differences among the MSD values derived from the analyses of variance. The MSD values for the segments that showed significant differences are plotted in Figures 19, 20, and 21.

The results indicate that for the total sentence interval there is a significant difference in MSD values between the two rate conditions and the three groups. MSD values in the habitual rate condition are higher than MSD values in the rapid condition, and values are lowest for the noncleft group and highest for the low intelligibility cleft group. For the /p/ burst segment, MSD values are significantly higher for the two cleft groups than for the noncleft group. Finally, for the vowel periodicity segment there is a significant group-by-rate interaction. That is, the MSD values were equal in the habitual and rapid rate conditions for the noncleft group but decreased in the rapid rate condition for both cleft groups.

While absolute MSD values provide insights into variability they may be misleading because standard deviation values tend to covary with the size of the mean. Therefore, an additional measure of variability was obtained to control

for the effects of duration on the standard deviation. Normalized MSD values were obtained by calculating the ratio of the MSD divided by the group mean segment duration. The normalized MSD values, together with the normalized standard deviations of the normalized MSD values, are plotted in Figures 22 through 26 and summarized in Figure 27.

The results of the normalized mean standard deviation data for the total sentence interval agree with the results of the unnormalized data. That is, mean standard deviation values in the habitual rate condition are higher than mean standard deviation values in the rapid condition. Additionally, values are lowest for the noncleft group and highest for the low intelligibility cleft group. The magnitude of the differences between groups and rate conditions, however, is greatly minimized in the normalized data.

The normalized mean standard deviation data for the four CVC segments show some different trends from the unnormalized data. The results may be grouped as they relate to three principal comparisons:

1. Between segments - Figures 22 through 26 indicate that the total sentence interval shows the lowest mean standard deviation values while the /p/ burst segment shows the highest. There is little difference between mean standard deviation values for the remaining segments: /p/ silence, periodicity, and /p/ silence + burst.

Table 25

MSD values and

S.D. of the MSD values

for three groups in two rate conditions.

		Habitual Rate			Rapid Rate		
		NC	HC	LC	NC	HC	LC
Total Sentence	$\overline{X}$	43.7	69.7	89.5	28.1	41.9	55.1
	SD	16.4	28.9	32.4	7.7	17.9	30.3
/p/ Silence	$\overline{X}$	5.3	9.0	11.6	8.1	7.7	8.7
	SD	1.8	4.6	5.8	4.8	3.1	3.6
/p/ Burst	$\overline{X}$	7.0	8.4	6.4	3.7	8.7	8.6
	SD	3.2	2.9	2.4	1.6	3.7	5.3
Vowel Periodicity	$\overline{X}$	8.5	9.3	10.6	9.4	8.1	7.6
	SD	3.5	5.3	6.1	3.4	3.0	3.4
/p/ Silence + Burst	$\overline{X}$	7.3	10.2	12.2	8.4	12.3	11.2
	SD	2.5	6.0	5.1	3.8	3.7	5.2

NC = Noncleft

HC = High Intelligibility Cleft

LC = Low Intelligibility Cleft

Table 26

Summary of P values derived from Analysis of variance for standard deviation values.

	Between Rates Habitual/ Rapid	Between 2 Groups Noncleft & Cleft	Between 3 Groups Noncleft Hi Intell. Cleft Lo Intell. Cleft	Group X Rate Interaction	Between Vowels	Rate X Vowel Interaction
Total Sentence	.02	.006	.01	.66	.68	.24
/p/ Silence	.59	.12	.19	.09	.47	.46
/p/ Burst	.77	.03	.06	.10	.46	.27
Vowel Peridicity	.07	.97	.97	.05	.26	.27
/p/ Silence + Burst	.56	.13	.29	.60	.15	.23

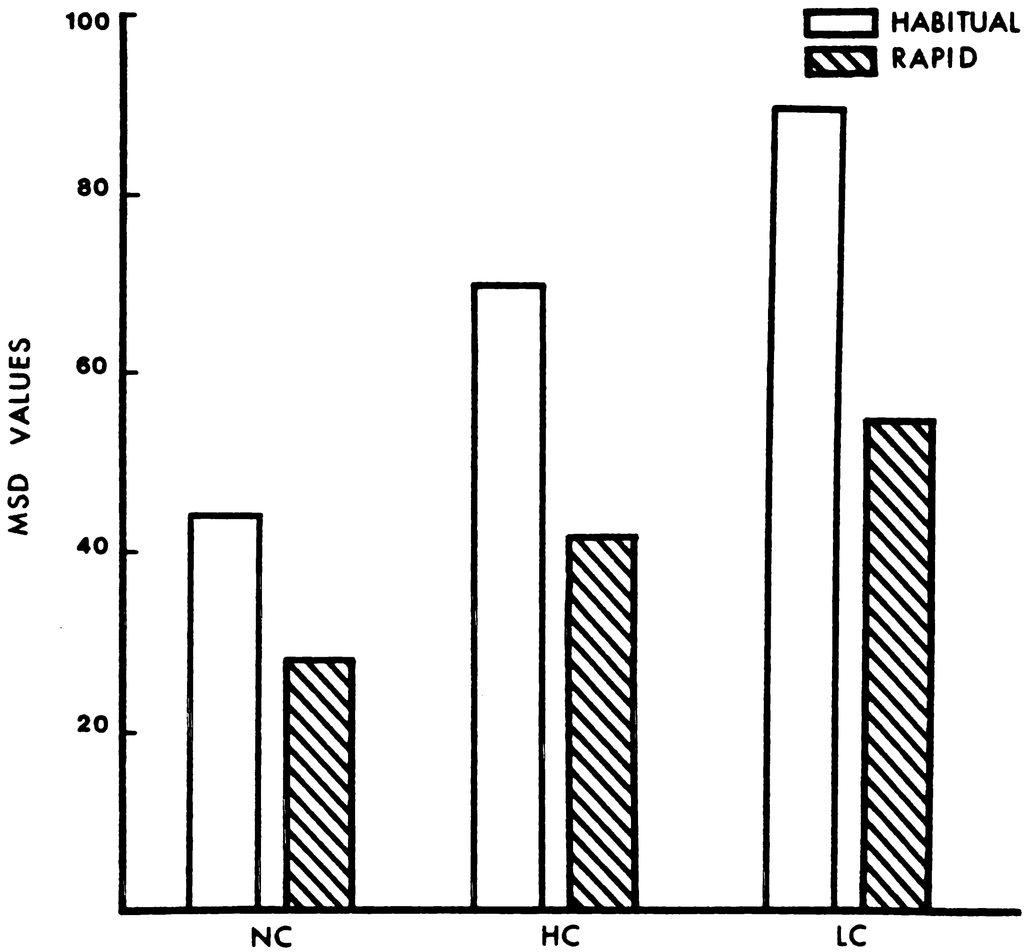

FIGURE 19. Mean standard deviation values for "total sentence" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

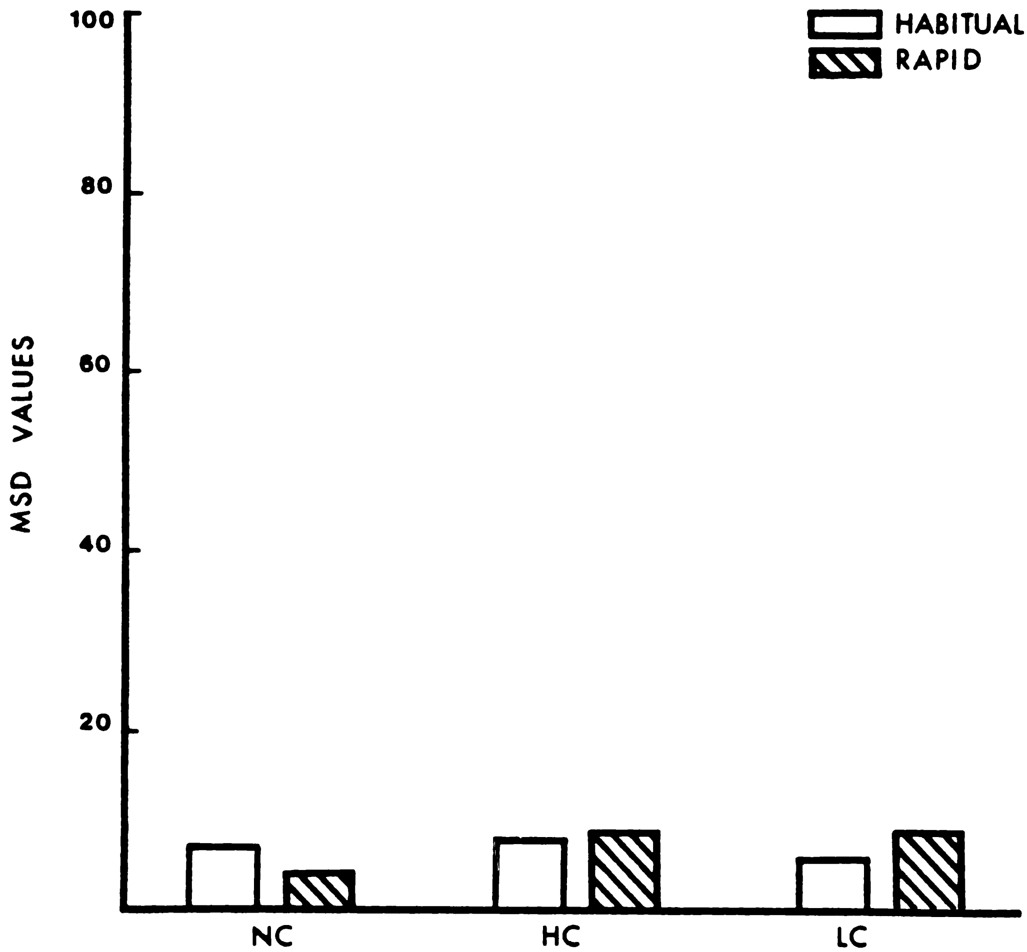

FIGURE 20. Mean standard deviation values for "/p/ burst" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

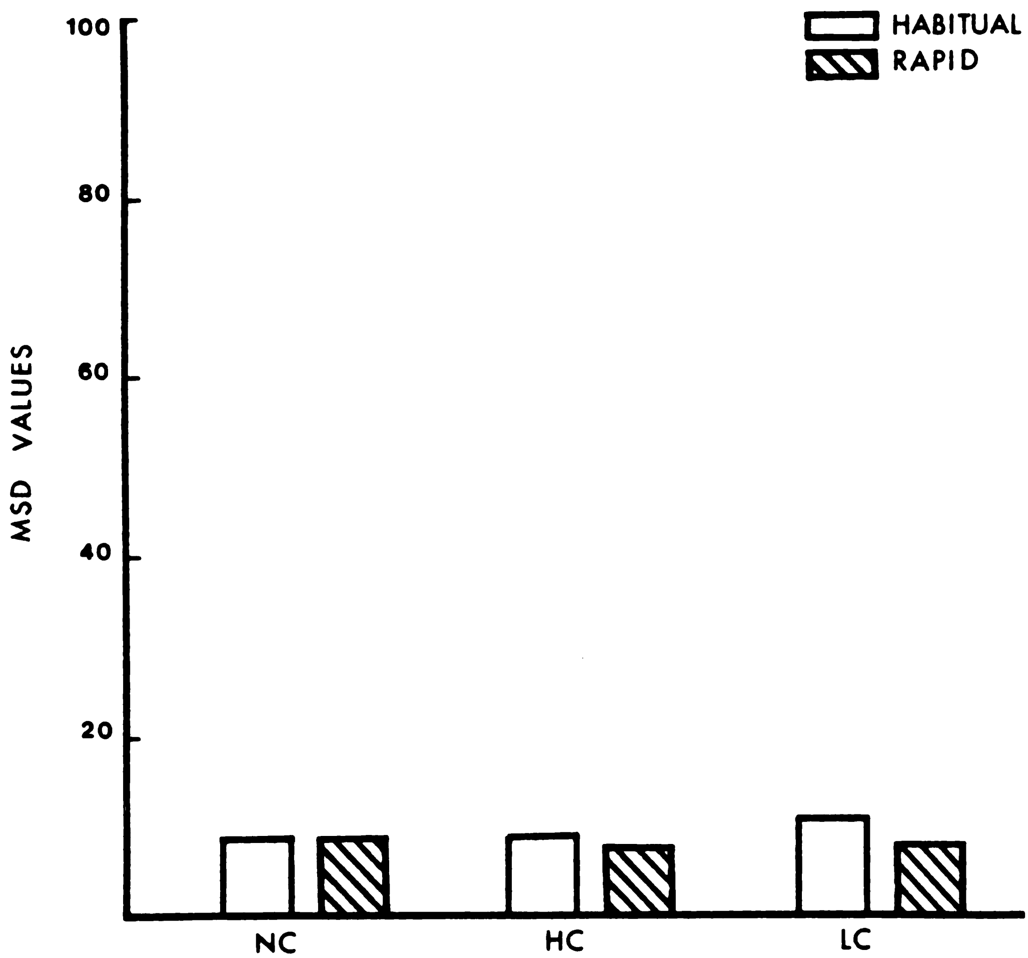

FIGURE 21. Mean standard deviation values for "vowel periodicity" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

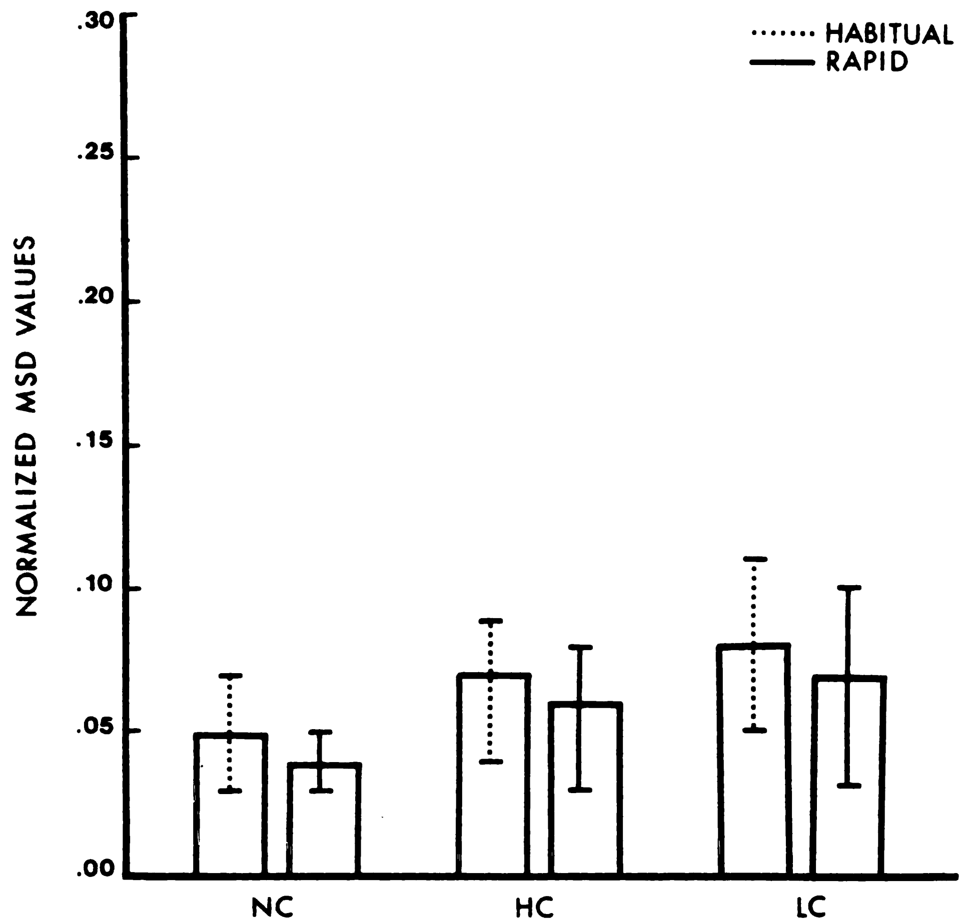

FIGURE 22. Normalized Mean Standard Deviation (MSD) values for "total sentence" segments produced by non-cleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

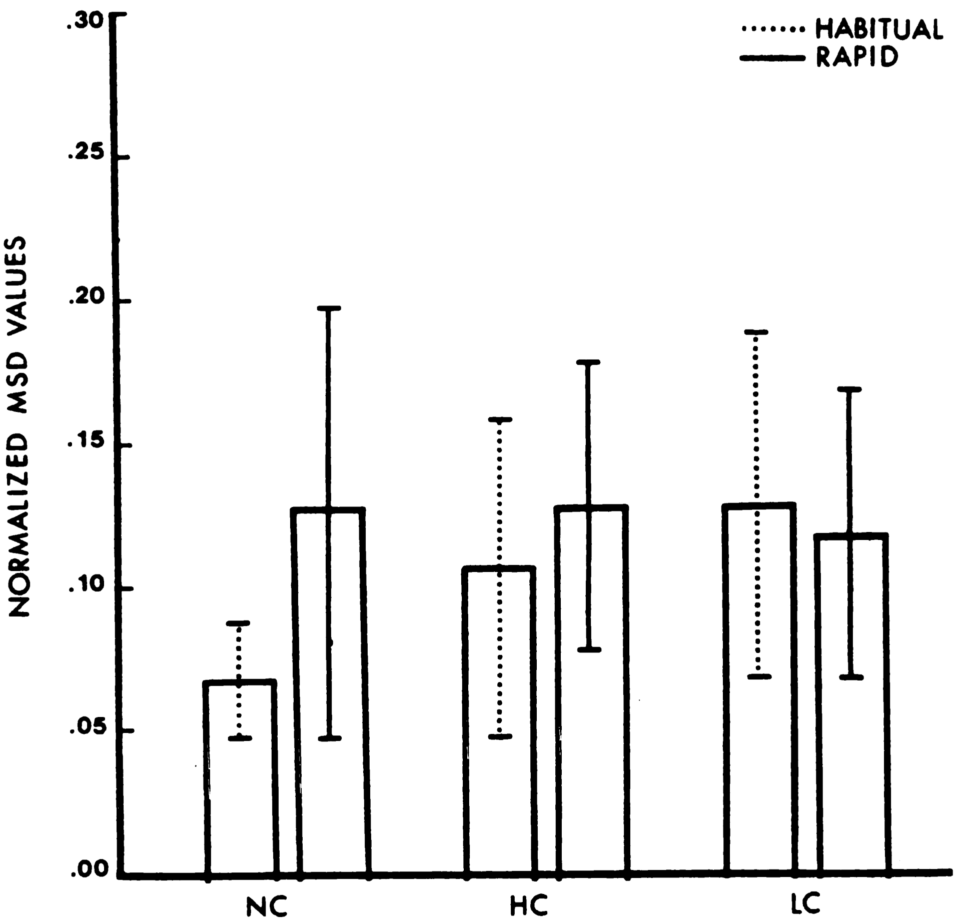

FIGURE 23. Normalized Mean Standard Deviation (MSD) values for "/p/ silence" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

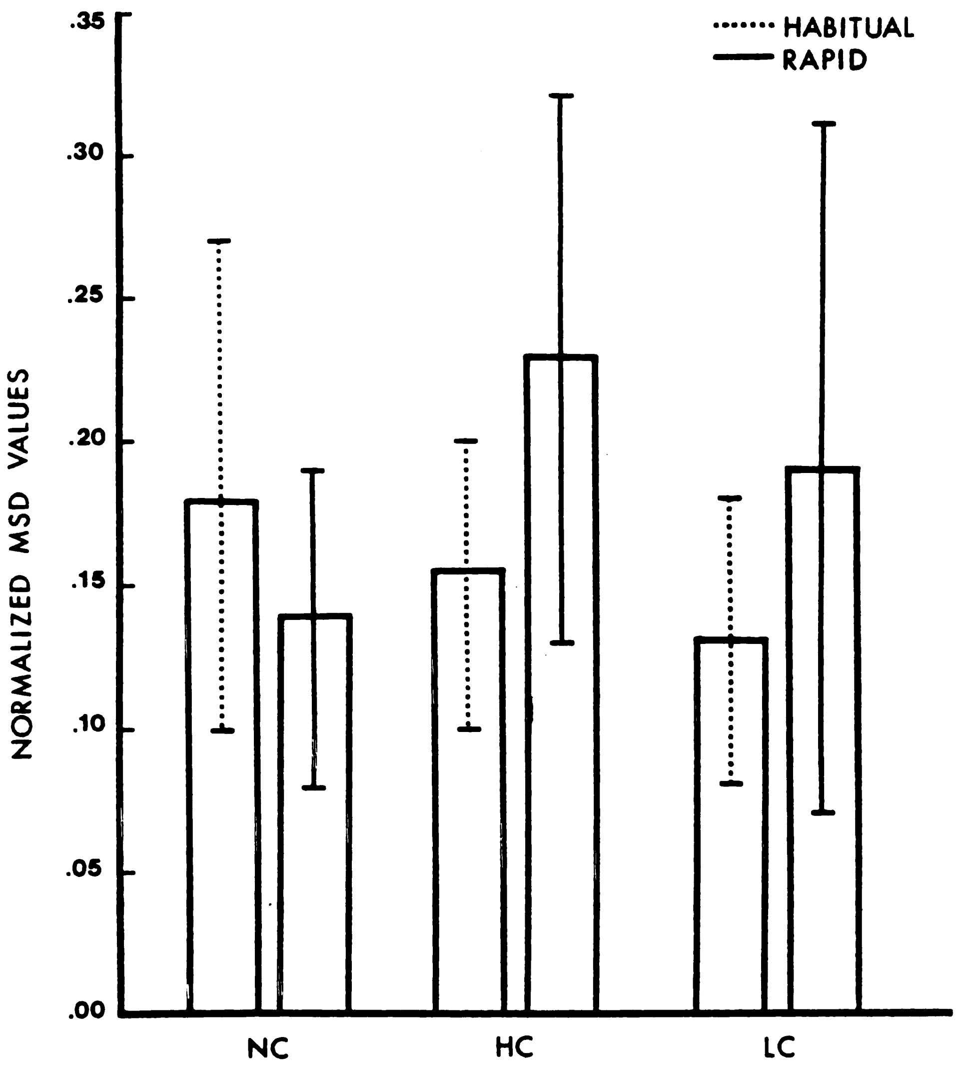

FIGURE 24. Normalized Mean Standard Deviation (MSD) values for "/p/ burst" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

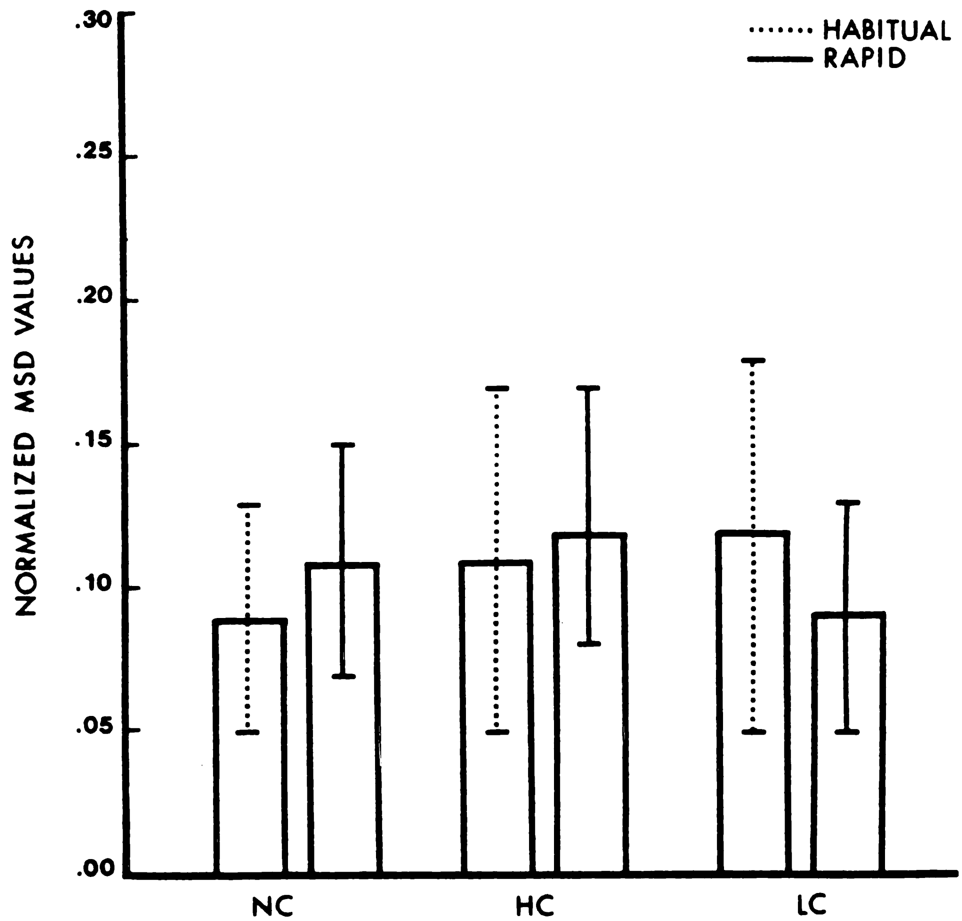

FIGURE 25. Normalized Mean Standard Deviation (MSD) values for "vowel periodicity" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

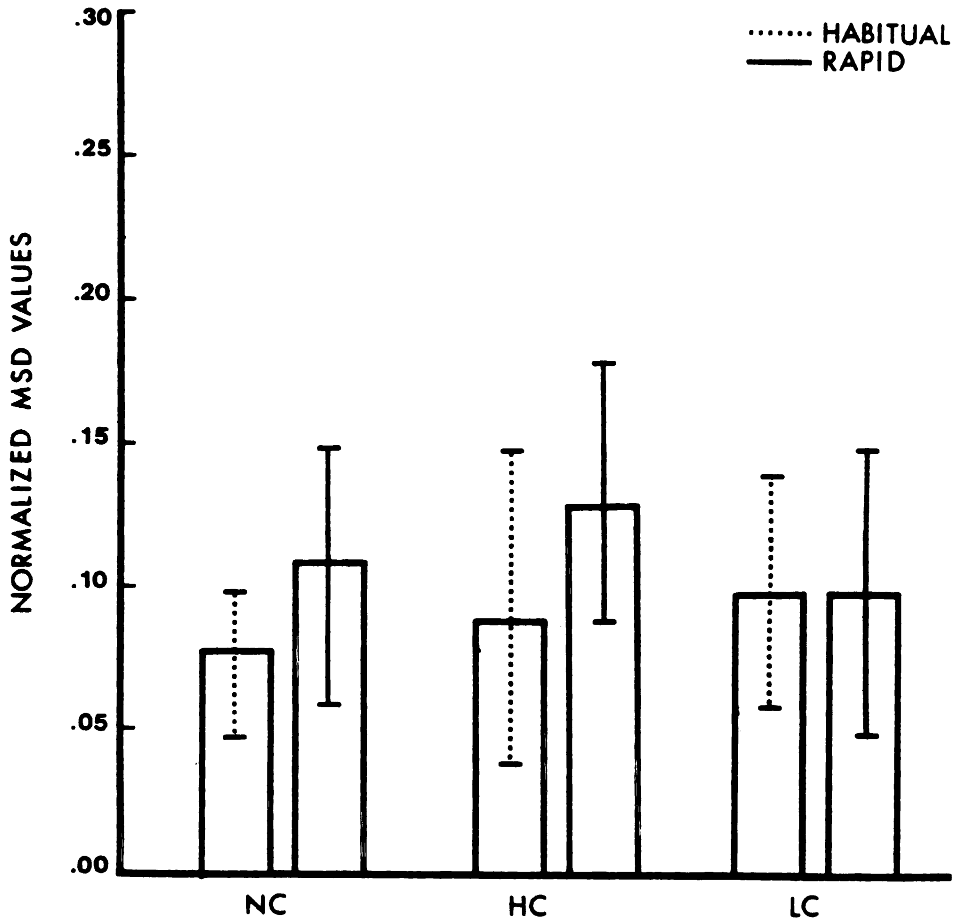

FIGURE 26. Normalized Mean Standard Deviation (MSD) values for "/p/ silence + burst" segments produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

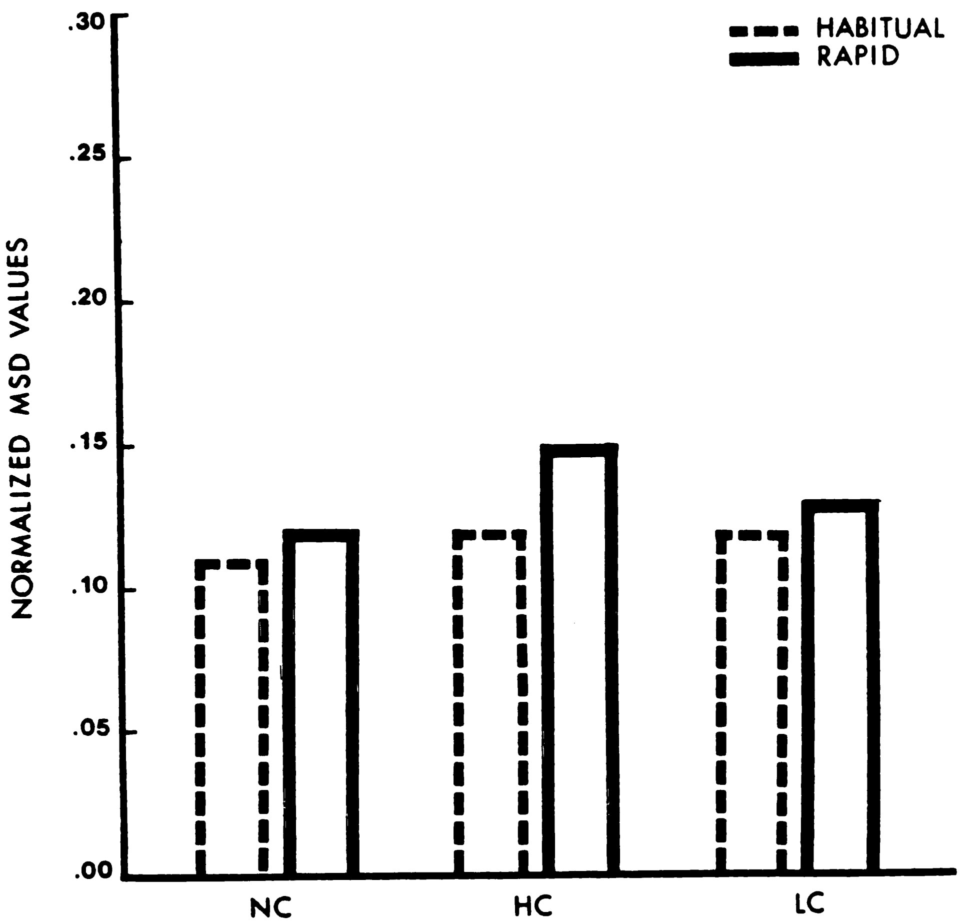

FIGURE 27. Normalized Mean Standard Deviation (MSD) values averaged across four segments (/p/ silence, /p/ burst, vowel periodicity, and /p/ silence + burst) produced by noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups in two rate conditions.

2. Between groups - Figure 27 illustrates the normalized mean standard deviation values averaged across the four segment types. There is no apparent difference between groups in the habitual condition and only a small difference between groups in the rapid condition. In the rapid rate condition both cleft groups show slightly higher MSD values than the noncleft group, with the high intelligibility cleft group demonstrating the highest MSD values.

3. Between rates - Figure 27 also indicates that the rapid rate condition is associated with higher MSD values than the habitual rate condition.

The effects of increased rate on segment durations are summarized in Figures 28 and 29. The data suggest that an increase in speaking rate from the habitual to the rapid rate condition affects segment durations unequally. Figure 28 shows that the noncleft and high intelligibility cleft groups reduce the burst + periodicity interval substantially more than the /p/ silence and /p/ silence + burst intervals. The low intelligibility cleft group, on the other hand, reduces the /p/ silence and /p/ silence + burst segments more than the burst + periodicity interval.

In Figure 29 the burst + periodicity segments are plotted separately. The data indicate that the noncleft group reduces burst duration more than periodicity duration. However, both cleft groups reduce periodicity duration more than burst duration.

To this point the results that have been presented have focused on comparisons between groups. For the majority of these findings, data for individual subjects follow the group trend. However, there are some instances where the group data do not accurately describe the individual speakers. In these events, the differences between subjects should be addressed. For example, Figures 30 and 31 illustrate the effects of increased rate on segment durations for individual speakers. Note that one of the noncleft speakers (LB) reduces the /p/ silence + burst segment more than the burst + periodicity or the /p/ silence intervals and thus deviates slightly from the group trend. Similarly, in the low intelligibility cleft group, speaker CD shows a reduction pattern consistent with the noncleft and high intelligibility cleft groups rather than the low intelligibilty cleft group. These findings will be addressed in more detail in the discussion section. Figure 31 plots the effects of increased rate on the burst and periodicity segments for individual subjects. Note that all but two speakers (LB and PV) reduce the duration of the periodicity segment more than the burst segment.

Additional differences between subjects which are not represented by group values may be seen in the data pertaining to the effects of vowel context on /p/ segment durations in the habitual rate condition. These data are illustrated in Figures 32, 33 and 34.

Figure 32 plots the mean duration of /p/ silence segments as a function of following vowel context. The greatest context effects for /p/ silence segments occur for the low intelligibility cleft speaker JD. For this speaker /p/ silence segments are markedly shorter when followed by the vowel /i/ than when followed by /a, ae, u/. The remaining two low intelligibility cleft speakers demonstrate shorter /p/ silence durations when followed by /a,ae/ than when followed by /i, u/. On the other hand, two of the high intelligibility cleft subjects produce the longest /p/ silence durations when followed by /a, u/. Figure 33 shows the mean duration of /p/ burst segments for individual subjects. Recall that measurements of this segment type showed the greatest variability, as indicated by standard deviation values. This pattern of variability may also be seen in the effects of vowel context on /p/ burst duration where there are large individual differences in segment durations between subjects and vowel contexts.

The greatest differences in contextual effects between cleft and noncleft groups are seen in the durations of final /p/ silence + burst segments when plotted as a function of preceding vowel context. Figure 34 illustrates these data. Note that the noncleft subjects show little difference in final /p/ silence + burst duration between vowel contexts; furthermore, there is little difference between the individual subjects. For both cleft groups, however, there are large differences between subjects as well as differences

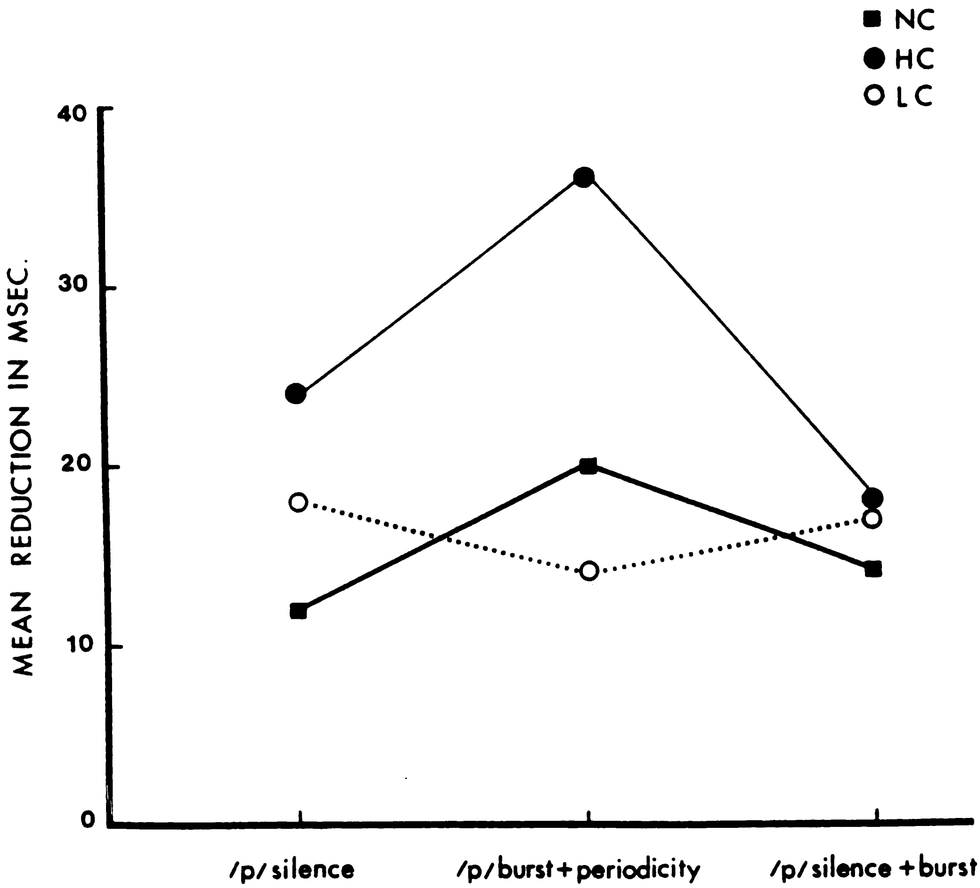

FIGURE 28. Mean reduction in msec. from the habitual to the rapid rate condition for "/p/ silence", "/p/ burst" + "periodicity" and "/p/ silence + burst" segments for the noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups.

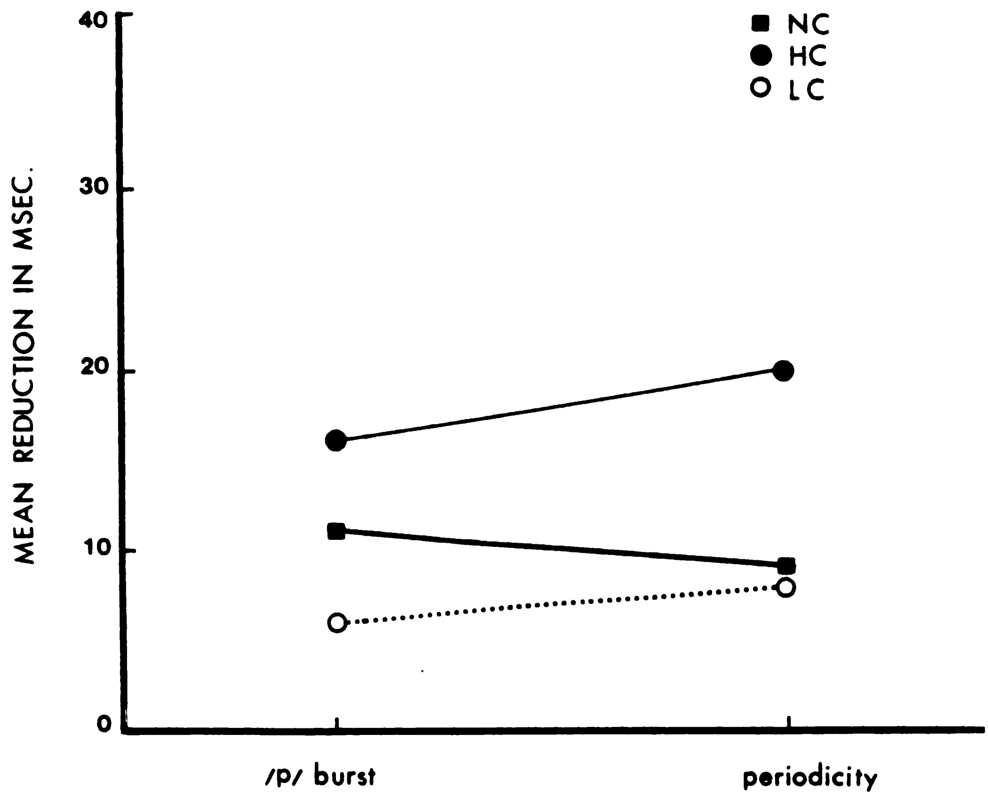

FIGURE 29. Mean reduction in msec. from the habitual to the rapid rate condition for "/p/ burst" and "vowel periodicity" segments for the noncleft (NC), high intelligibility cleft (HC), and low intelligibility cleft (LC) groups.

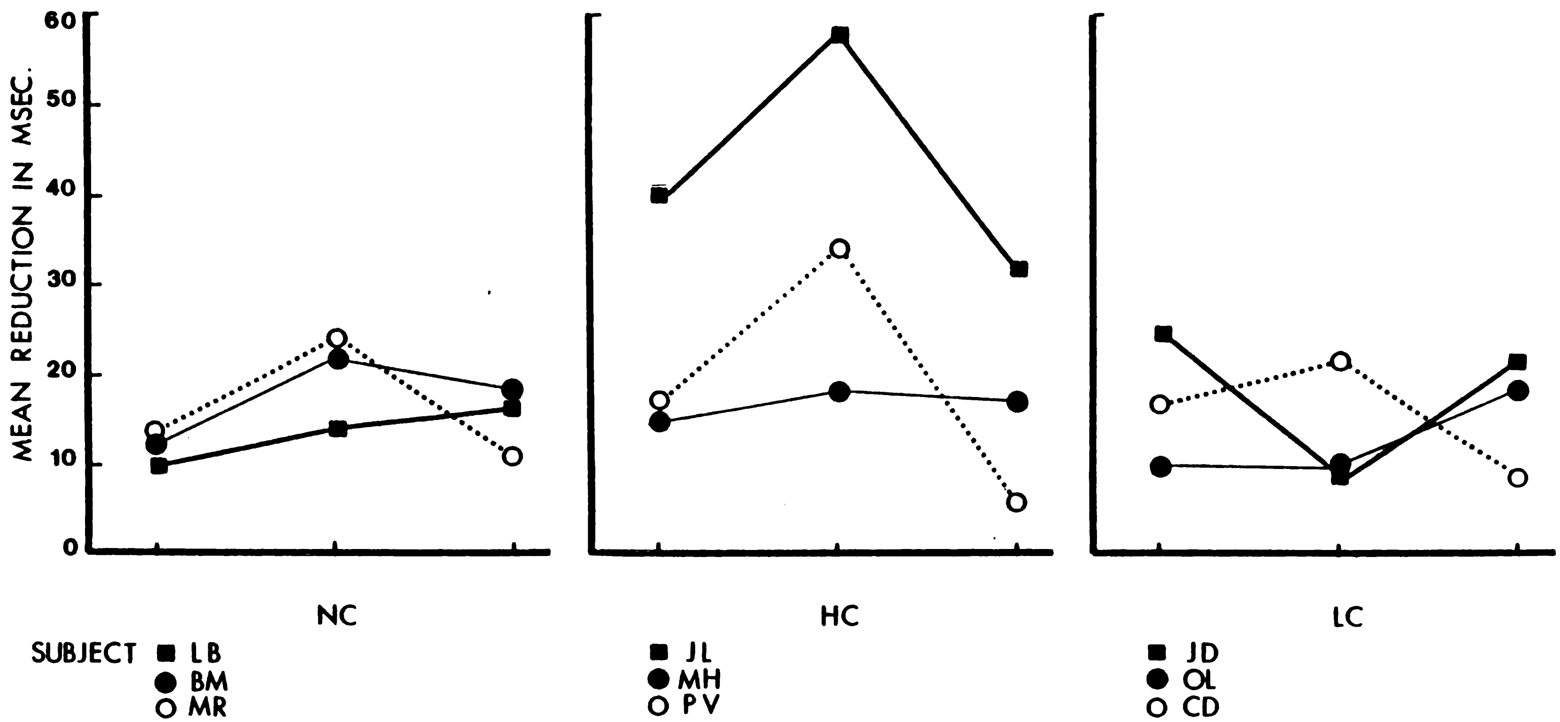

FIGURE 30. Mean reduction in msec. from the habitual to the rapid rate condition for "/p/ silence", "/p/ burst" + ""periodicity" and "/p/ silence + burst" segments for individual subjects in three groups.

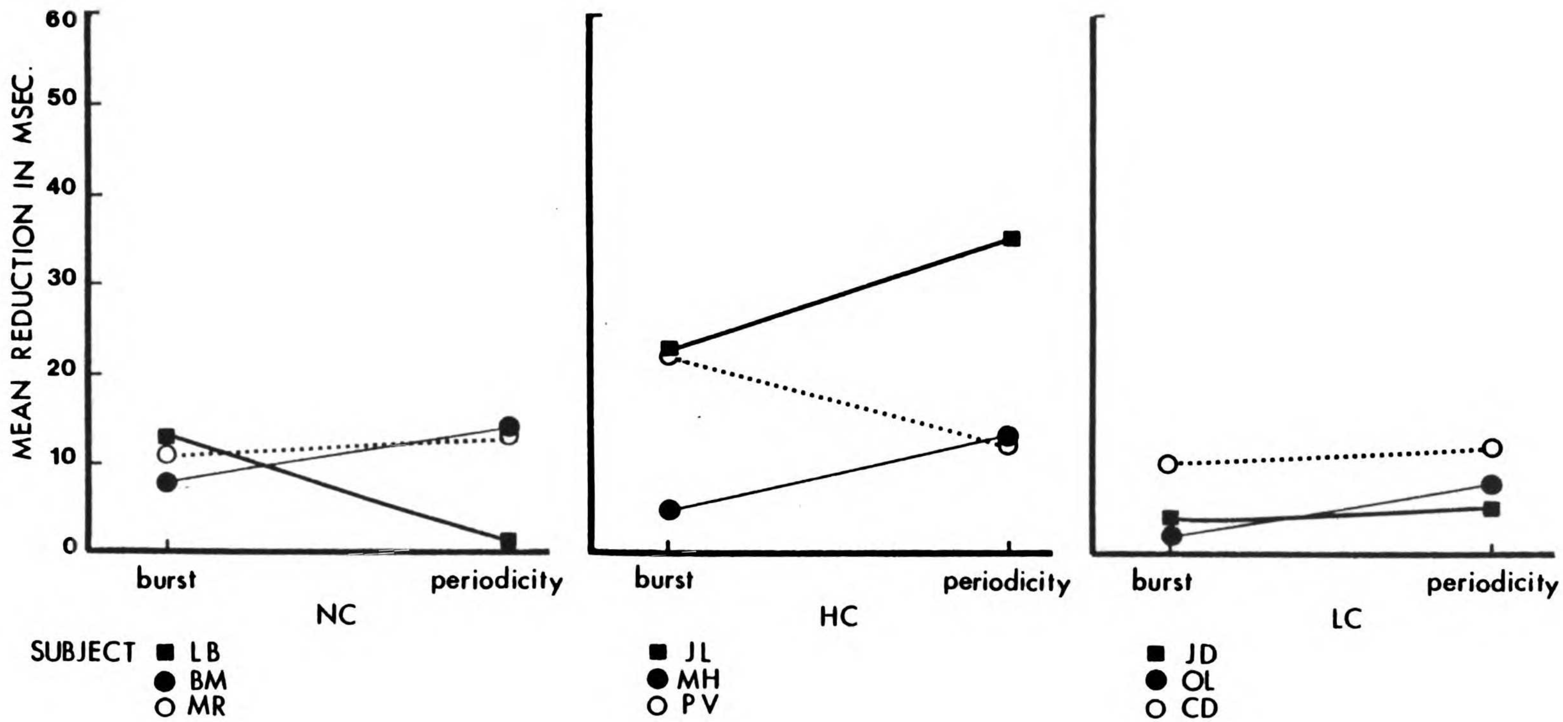

FIGURE 31. Mean reduction in msec. from the habitual to the rapid rate condition for "/p/ burst" and "vowel periodicity" segments for individual subjects in three groups.

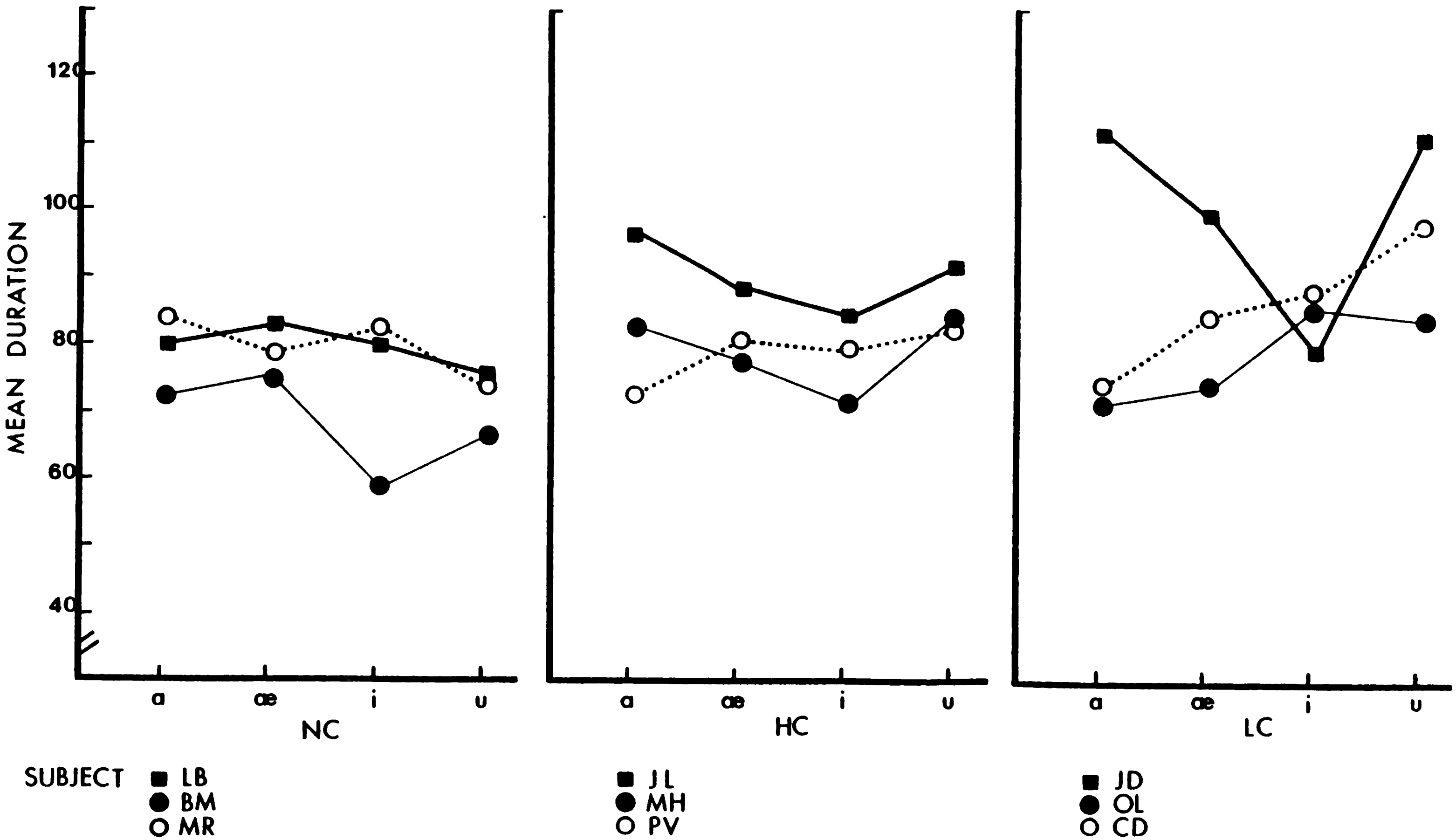

FIGURE 32. Mean duration values for "/p/ silence" segments as a function of following vowel environment for individual subjects in three groups.

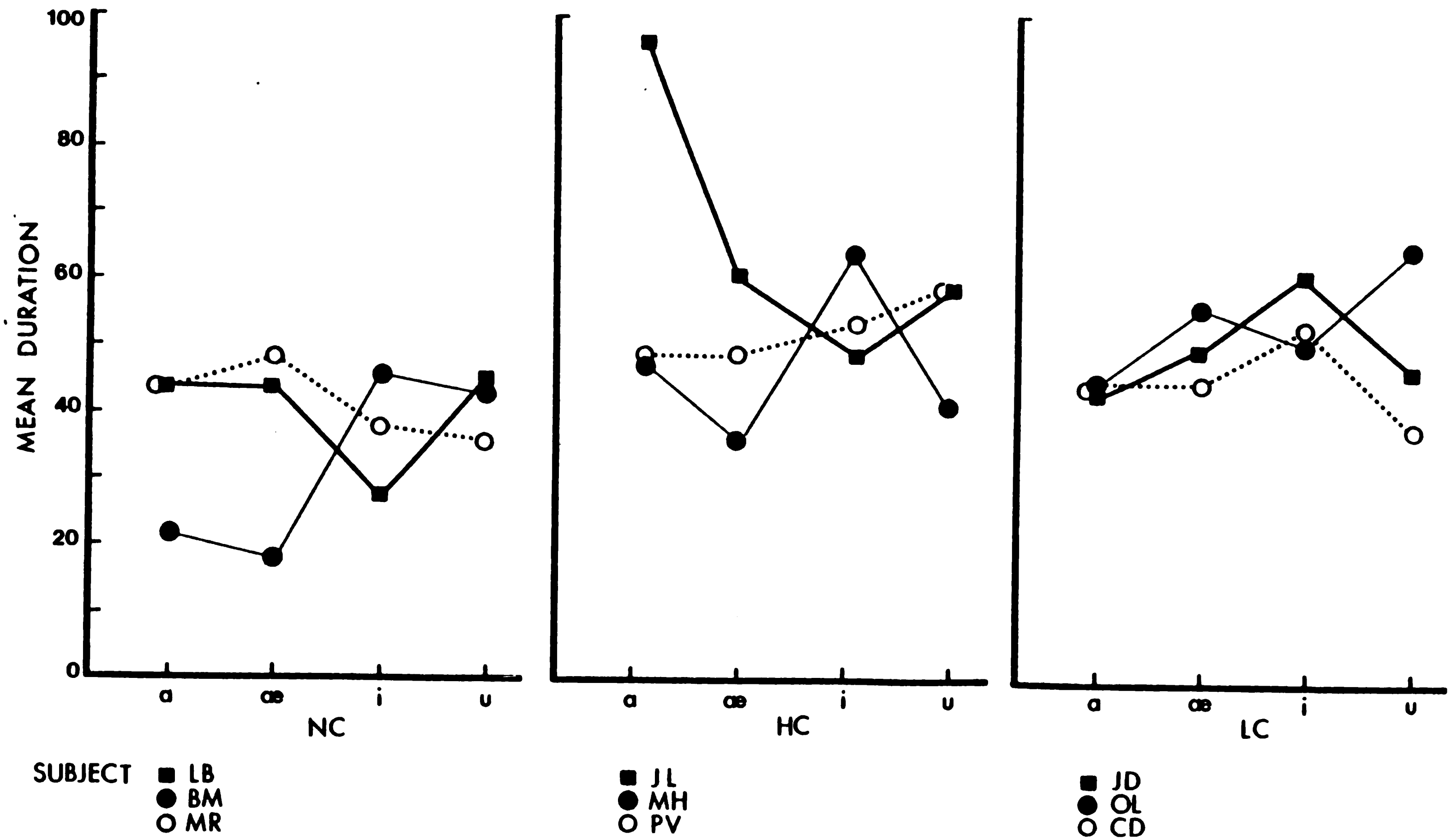

FIGURE 33. Mean duration values for "/p/ burst" segments as a function of following vowel environment for individual subjects in three groups.

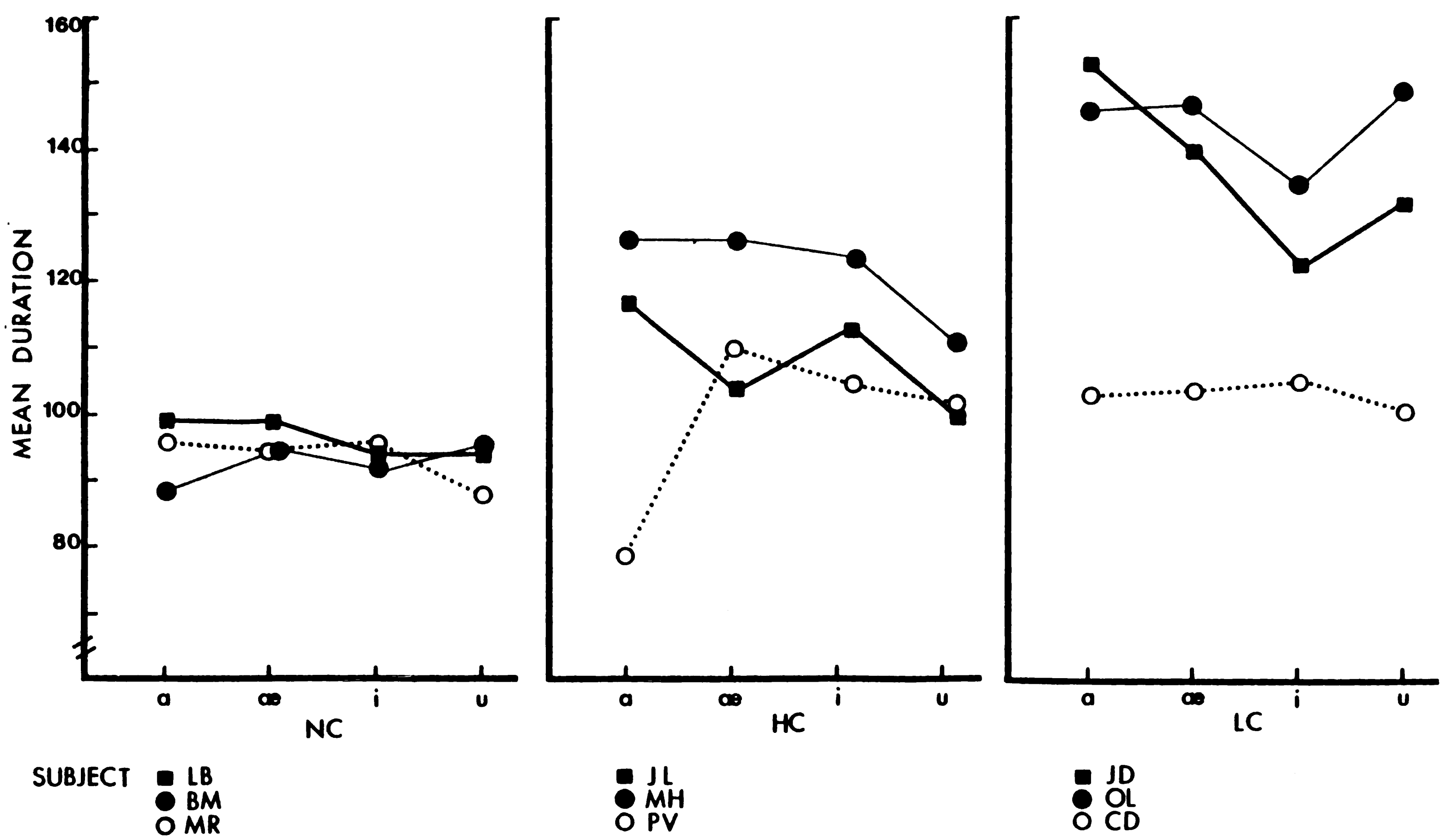

FIGURE 34. Mean duration values for "/p/ silence + burst" segments as a function of preceding vowel environment for individual subjects in three groups.

between durations in the four vowel contexts. For the two low intelligibility cleft speakers JL and OL /p/ silence durations were shortest following the vowel /i/. For speaker JL the longest /p/ silence segments followed the vowels /a, ae/, and for speaker OL the longest durations were associated with /a, ae/ equally as well as /u/. Confirming the observation that vowel context has variable effects on surrounding segment durations, the high intelligibility speaker PV shows a reverse pattern from the other cleft speakers, whose final /p/ silence + burst duration is shortest following the vowel /a/ than the vowels /ae, i, u/.

The results displayed in Figure 34 are of additional interest for their contribution to the discussion of variability. on variability within subjects. It was always expected that there would be large differences between subjects (particularly between cleft subjects) due to the differences in the individual speakers' articulatory systems resulting from varying degrees of anatomic involvement. Figure 34 shows that for the production of the final /p/ silence + burst segment there were particularly large differences between speakers in the cleft and noncleft groups and between individual cleft speakers. Note that the durations of the final /p/ silence + burst segment fall tightly together for noncleft speakers. There is little variability between subjects and vowel contexts. Both cleft groups, on the other hand, show wide differences between subjects and vowel contexts. This finding, in conjunction with observations from the qualitative data indicate that for cleft subjects, compared with the noncleft subjects, production of the final stop silence + burst interval showed the greatest variability between subjects and contexts.

Qualitative observations. During the process of segmentation and measurement of acoustic waveforms, several observations were made which were not quantified. In fact, oftentimes, characteristics of the speech of some of the cleft speakers actually prevented quantification of the data. These observations, however, provided important insights into the speech productions of cleft speakers in general and information concerning timing patterns in particular which enhanced the quantitative data. In this section, several of these observations will be presented and illustrated.

Once again, a note on terminology is warranted. In the following section, several speech waveforms will be presented and described as they relate to the acoustically defined segments of interest in this experiment. However, terminology which is slightly different from that employed in the description of the quantitative data will be used to describe the intervals associated with the stop consonants. "Initial stop constriction" and "final stop constriction" will be used, particularly when referring to the /b/ and /d/ data. This change is brought about by two observations. First, the acoustic waveform characteristic of the stop consonants /b/ and /d/ is not typically associated with "silence" intervals like those associated with /p/. Second, some "stop" productions by cleft speakers did not show signs of stop closure at any point and more closely resembled the acoustic description of fricatives even though they were auditorially perceived as stops. For these items, the fricative constriction was measured.

1. Voiced/voiceless stop productions. Figure 35 provides examples of the speech waveform for two "total sentence" segments produced by the noncleft subject LB, comprised of the CVCs /pip/ and /bib/. Figure 36 shows windowed and expanded displays of each CVC. As expected, the voiceless stop consonant /p/ is associated with complete silence (evidenced by the relatively flat line in the time waveform), while the voiced stop /b/ is associated with low amplitude voicing throughout closure. This voiceless/voiced pattern was present in the waveforms of all the noncleft speakers and most of the cleft speakers.

Figure 37 shows examples of the speech waveform for two sentences produced by the low intelligibility cleft speaker OL containing the CVCs /pip/ and /bib/. Notice that the utterance containing the CVC /pip/ shows well defined constriction associated with both initial and final /p/. However, the CVC is barely identifiable in the sentence containing /bib/. In the windowed and expanded views of the two CVC regions (Figure 38) it is evident that this speaker produces a clear "silent" interval for both initial and final /p/ but produces only slight evidence of constriction for initial /b/ and no evidence of constriction for final /b/. There is a strong distinction between the voiced and voiceless cognates /p/ and /b/ in this subject's productions. These examples are representative of all tokens produced by the subject OL, similar patterns were observed for one of the other low intelligibility cleft speakers.

For example, Figure 39 illustrates a windowed and expanded display of the waveform for /did/ produced by the low intelligibility cleft speaker JD. This speaker routinely produced silent intervals associated with initial and final /p/. In the CVCs containing /b/ however, a recognizable constriction interval was always associated with initial /b/ but often difficult to discern for final /b/. This same pattern was true for /d/ (as illustrated in Figure 39); however, final /d/ constriction was rarely recognizable.

2. Variability in constriction within one utterance type and rate. As suggested by the previous observations, many of the cleft speakers demonstrated great variability in the productions of the stop consonants. This variability occurred both between and within subjects. There was virtually always recognizable "constriction" intervals for initial stops in the CVCs. Final stops in the CVCs, on the other hand, varied from complete to no recognizable constriction. Likewise, the duration of final stop constric-

tion was variable even within a given utterance type and rate condition.

Figures 40 and 41 provide examples of the waveform for the windowed CVCs /bib/ in the habitual and rapid rate conditions produced by the low intelligibility cleft speaker JD. The top waveforms in both Figures show tokens where final /b/ constriction was minimal and constriction duration was relatively short. The bottom waveforms illustrate tokens where the degree of final /b/ constriction was greater and constriction duration was longer. These examples illustrate that within a given utterance type and rate condition final consonant constriction varied in both degree and duration. Furthermore, there appears to be a negative relationship between these two variables, i.e., the greater the degree of constriction, the longer the constriction.

3. Variability in constriction between rates. Quantitative analysis of the /p/ data showed that increased speaking rate results in reduced segment durations for all segments measured. This pattern is not present for all segments in the /b/ data, however. Figures 42 and 45 provide examples of the waveforms for the windowed CVCs /bab/ and /bub/ in the habitual and rapid rate conditions for the high intelligibility cleft speaker PV.

In Figure 42 the final /b/ constriction for /bab/ in the habitual rate condition was 55 and 49 msec. in the two tokens. In Figure 43, the final /b/ constriction for /bab/

in the rapid rate condition for the two tokens was 79 and 82 msec., that is, final /b/ constriction was longer in the rapid rate condition than in the habitual rate condition. Figures 44 and 45 provide additional examples of this finding for the CVC /bub/. The numbers below the time waveform indicate the durations of the four segments which were measured. The number in the far right margin indicates the total duration of the CVC. Notice that the duration of the total CVC was always shorter in the rapid rate condition compared with the habitual rate condition in spite of the fact that final /b/ constriction increased in the rapid rate condition. This pattern was consistently present throughout the productions of the speaker PV and sporadically present for the other cleft speakers to varying degrees. This pattern never occurred for the noncleft speakers, however.

4. Inappropriate constriction duration and placement. All of the cleft speakers show some examples of excessive constriction or silence durations in seemingly inappropriate places. Two of the low intelligibility cleft speakers, however, showed grossly inappropriate and inconsistent constriction duration and placement throughout their speech productions. Figures 46 and 47 show the waveforms for the utterances /pap/ and /baeb/ produced by the speaker CD. This speaker routinely produced a silent interval between the schwa following the CVC and the schwa in again (say aCVCa * again).

Figure 48 illustrates the waveform for the utterance /bib/ produced by the speaker OL. There is an excessively long silence interval corresponding to the location of expected /b/ constriction. Auditorially this interval sounded like a stop closure.

Figures 49 and 50 illustrate the waveforms for the utterance /baeb/ in the habitual and rapid rate conditions produced by the speaker OL. Long silent intervals occur in both CVCs in different places in the waveform. In Figure 49 the silence is associated with production of the final /b/, while in Figure 50 it is associated with production of the initial /b/. This pattern of irregular silent interval elongation and placement never occurred for the noncleft speakers.

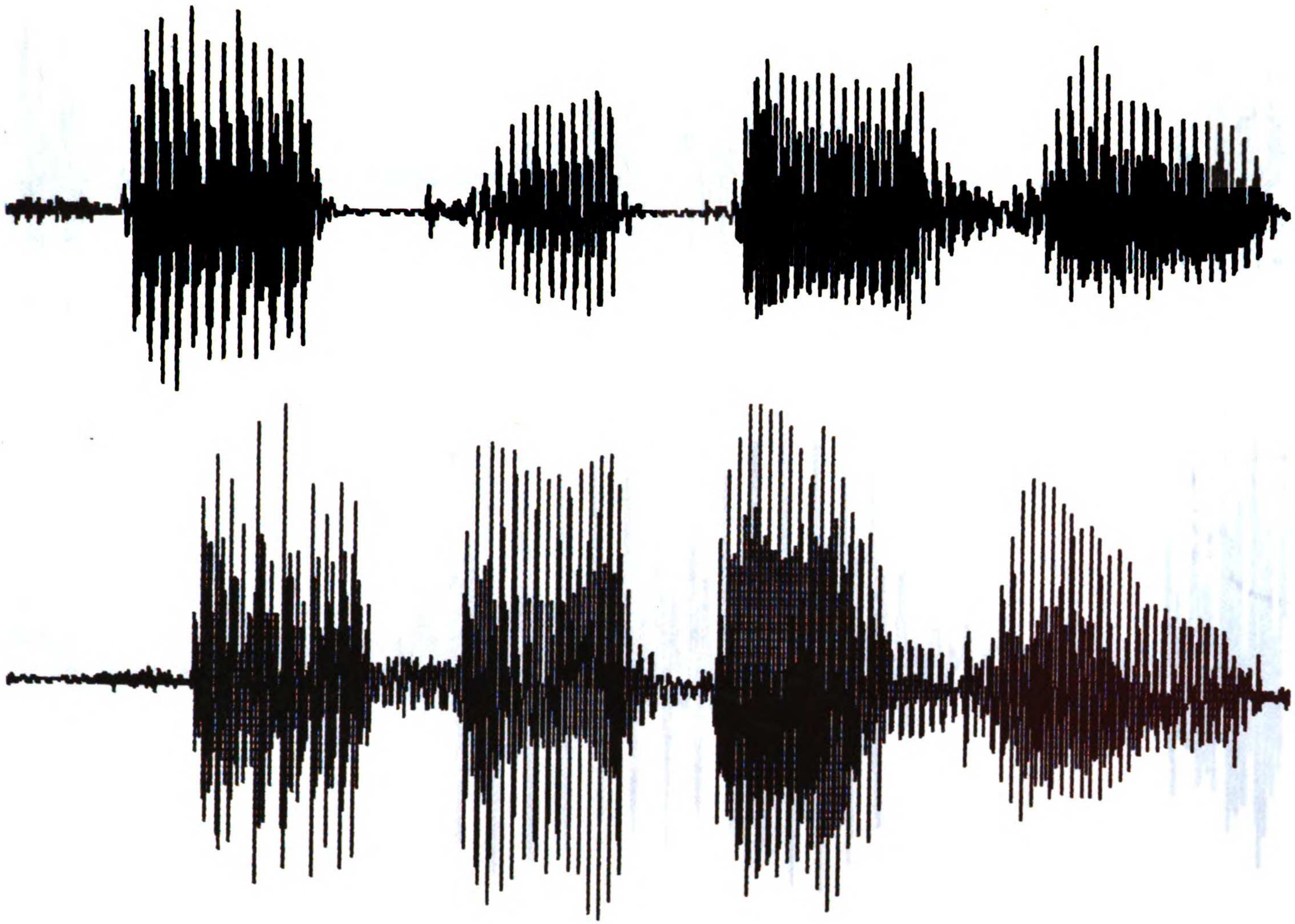

FIGURE 35. Acoustic waveform of two "total sentence" segments containing the CVCs /pip/ (TOP) and /bib/ (BOTTOM) produced by the non-cleft speaker LB in the habitual rate condition.

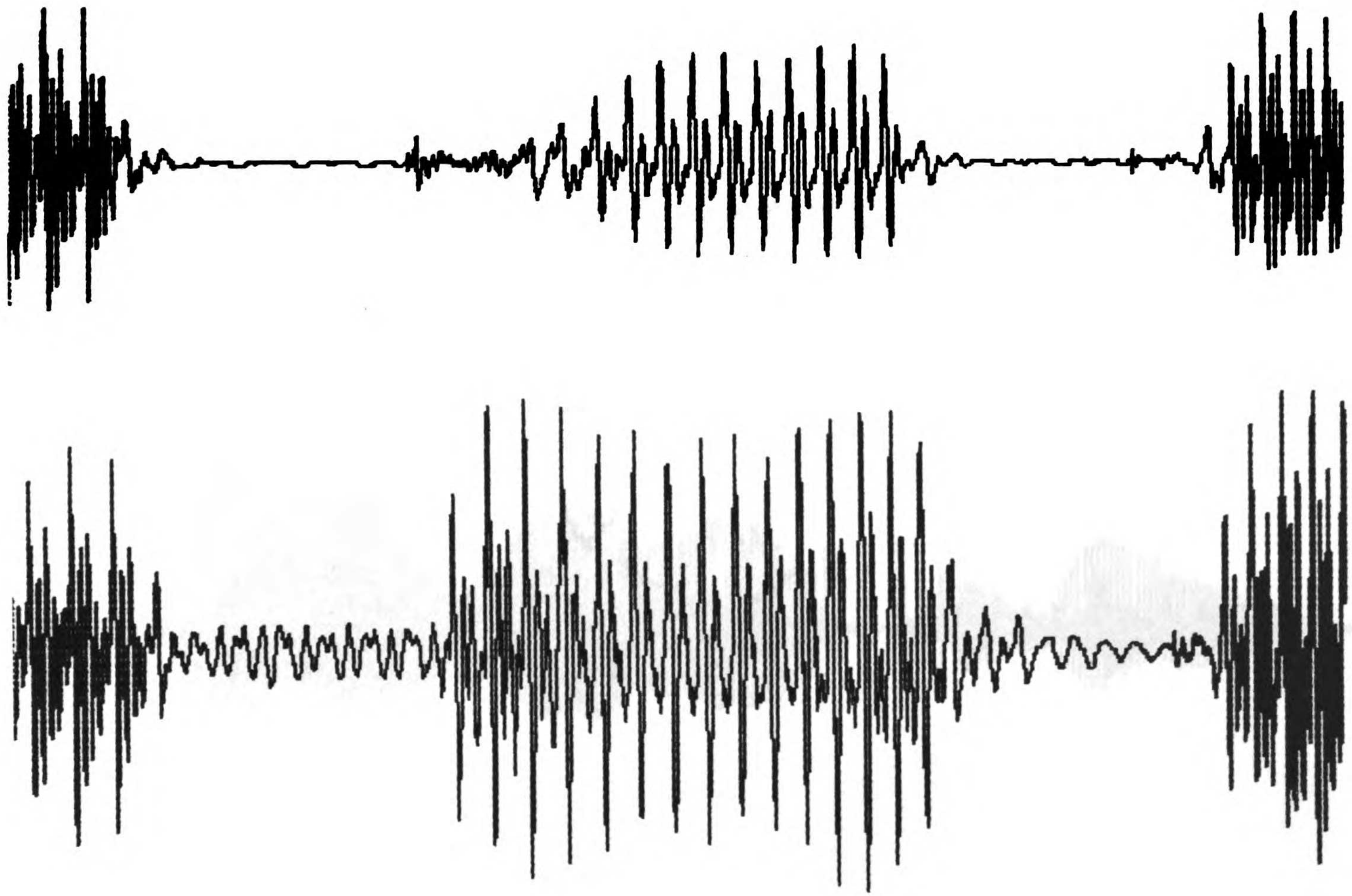

FIGURE 36. Windowed and expanded displays of the CVCs /pip/ (TOP) and /bib/ (BOTTOM) produced by the noncleft speaker LB in the habitual rate condition.

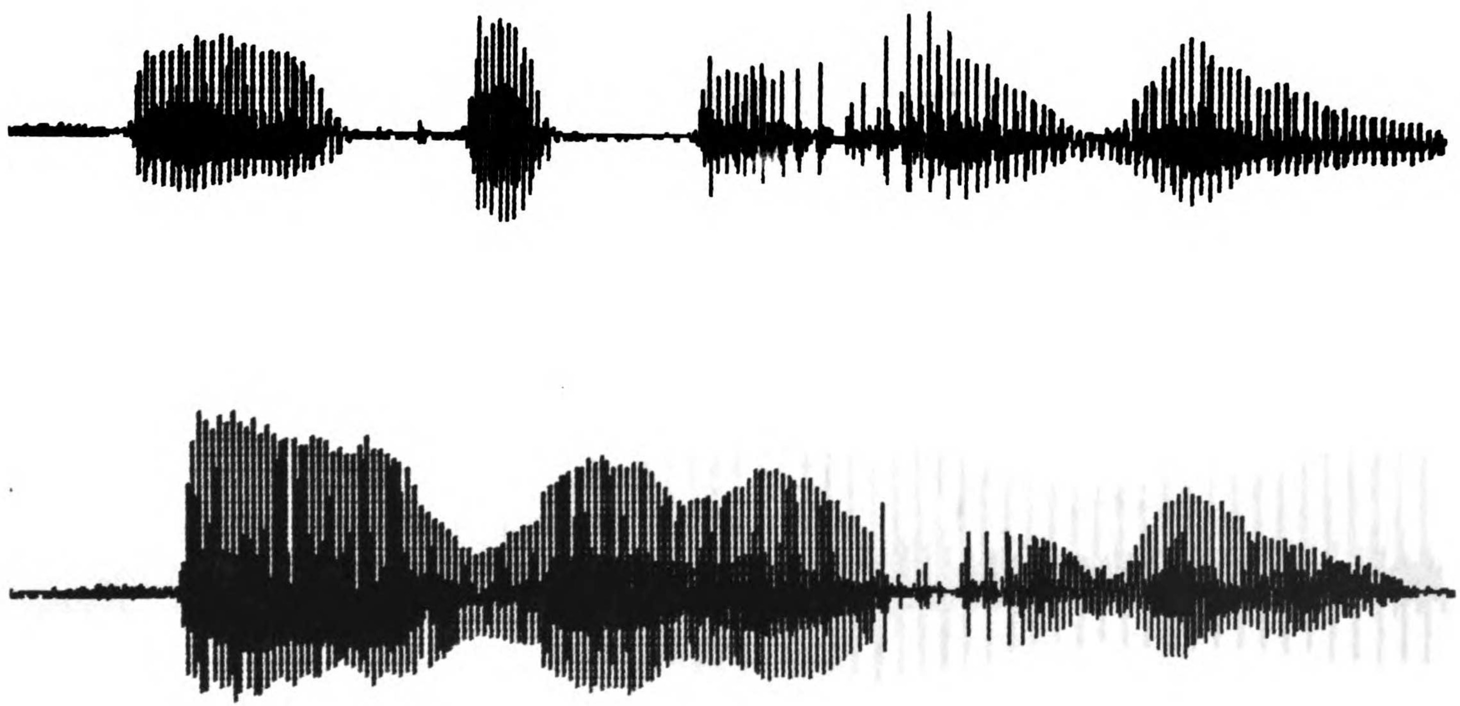

FIGURE 37. Acoustic waveform of two "total sentence" segments containing the CVCs /pip/ (TOP) and /bib/ (BOTTOM) produced by the low intelligibility cleft speaker OL in the habitual rate condition.

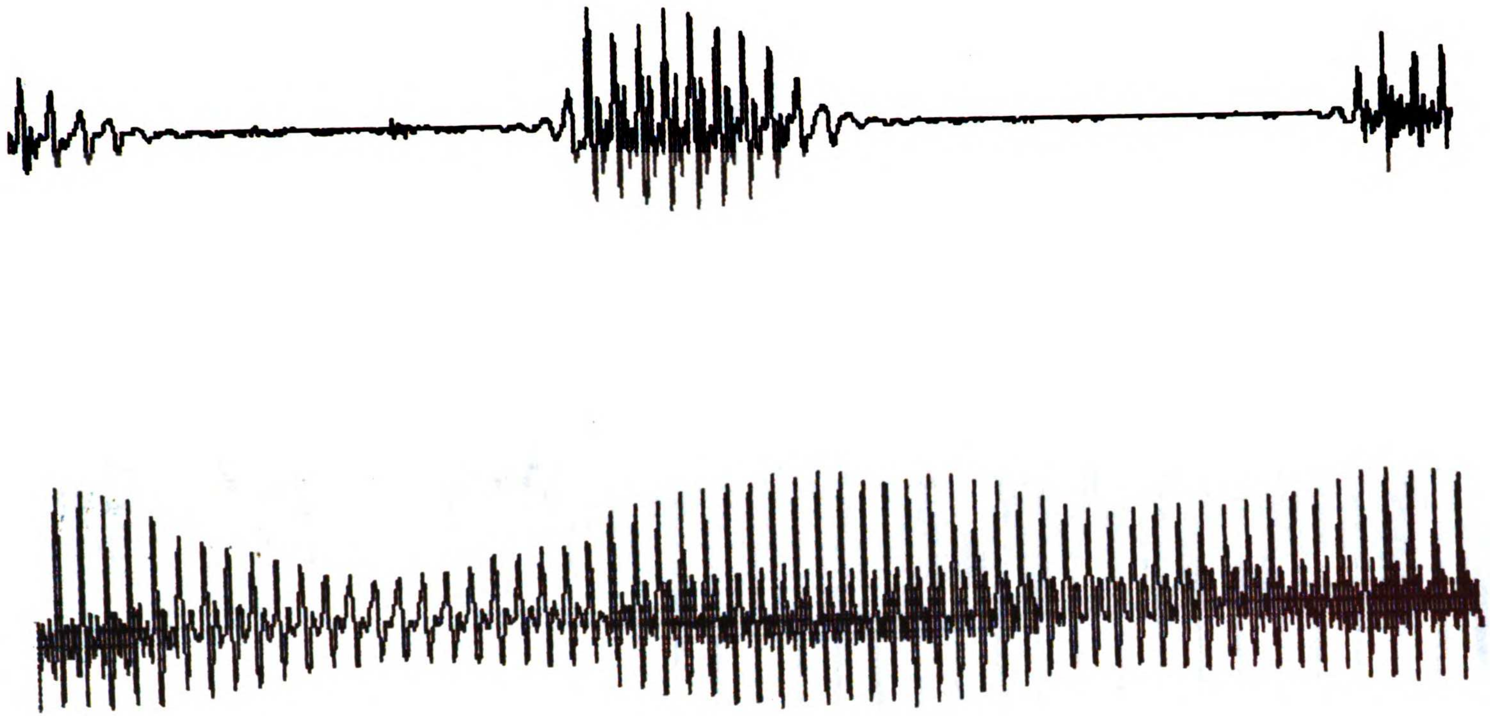

FIGURE 38. Windowed and expanded displays of the CVCs /pip/ (TOP) and /bib/ (BOTTOM) produced by the low intelligibility cleft speaker OL in the habitual rate condition.

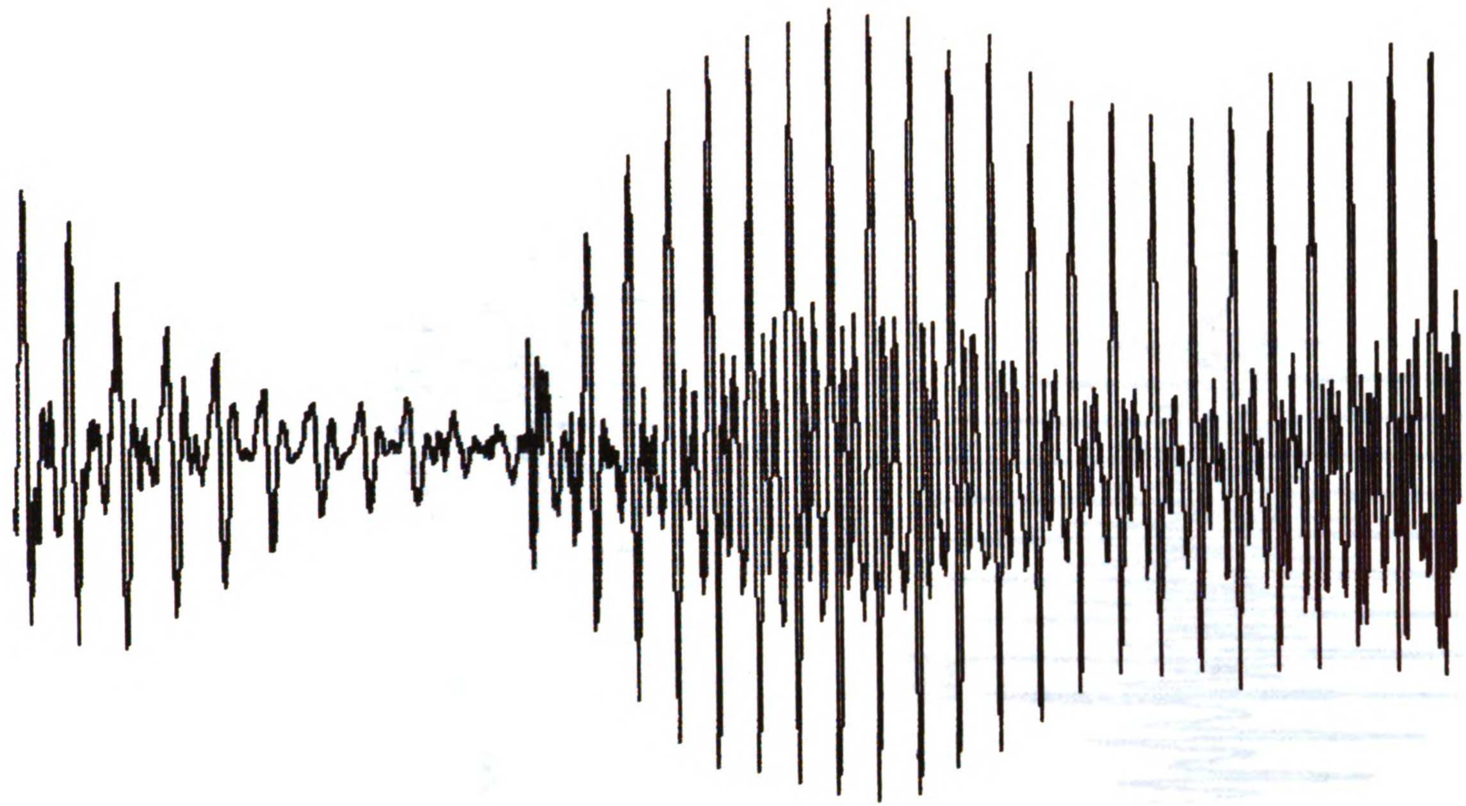

FIGURE 39. Acoustic waveform of the windowed CVC /did/ produced by the low intelligibility cleft speaker JD in the habitual rate condition.

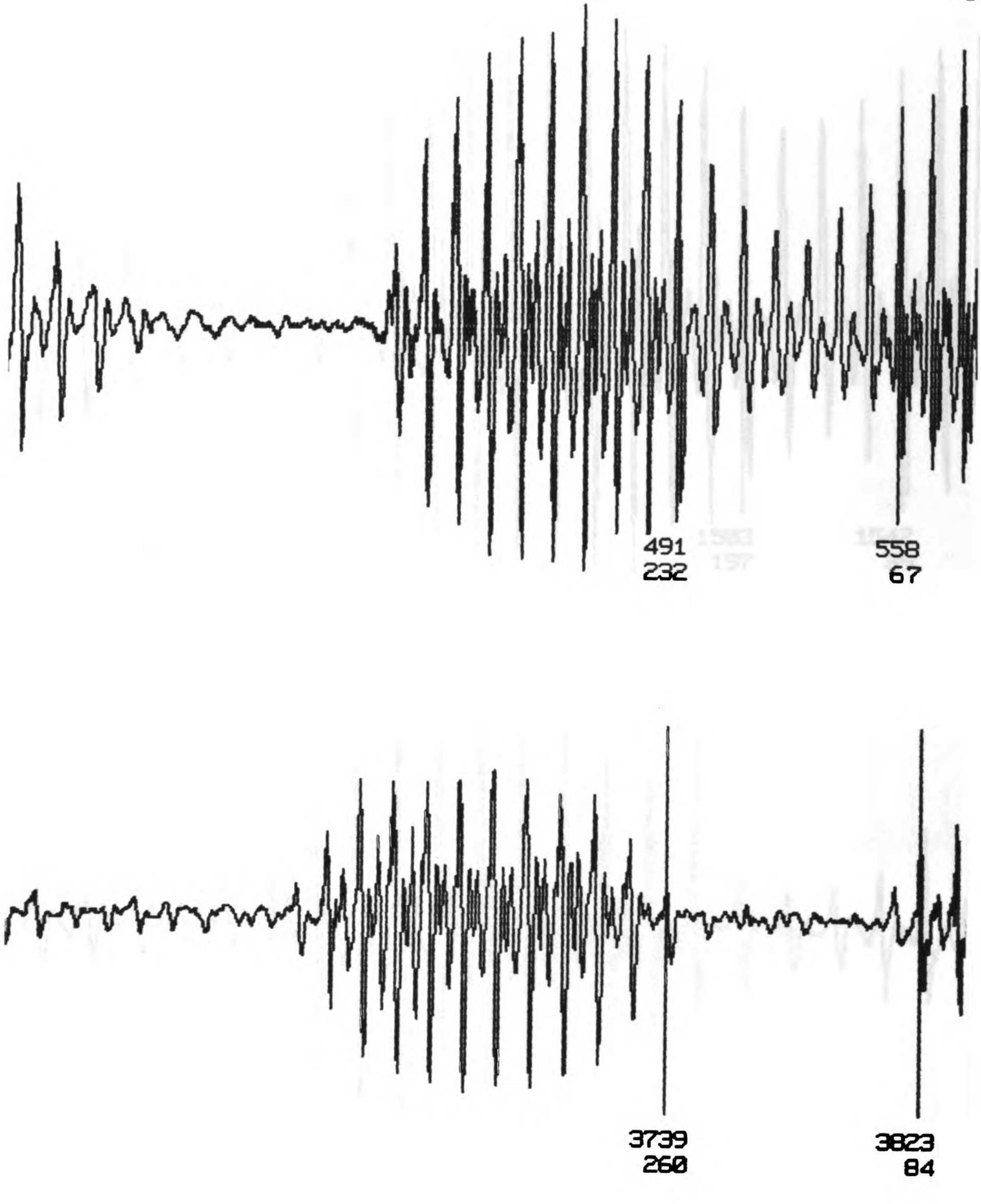

FIGURE 40. Acoustic waveform of two tokens of the CVC /bib/ produced by the low intelligibility cleft speaker JD in the habitual rate condition.

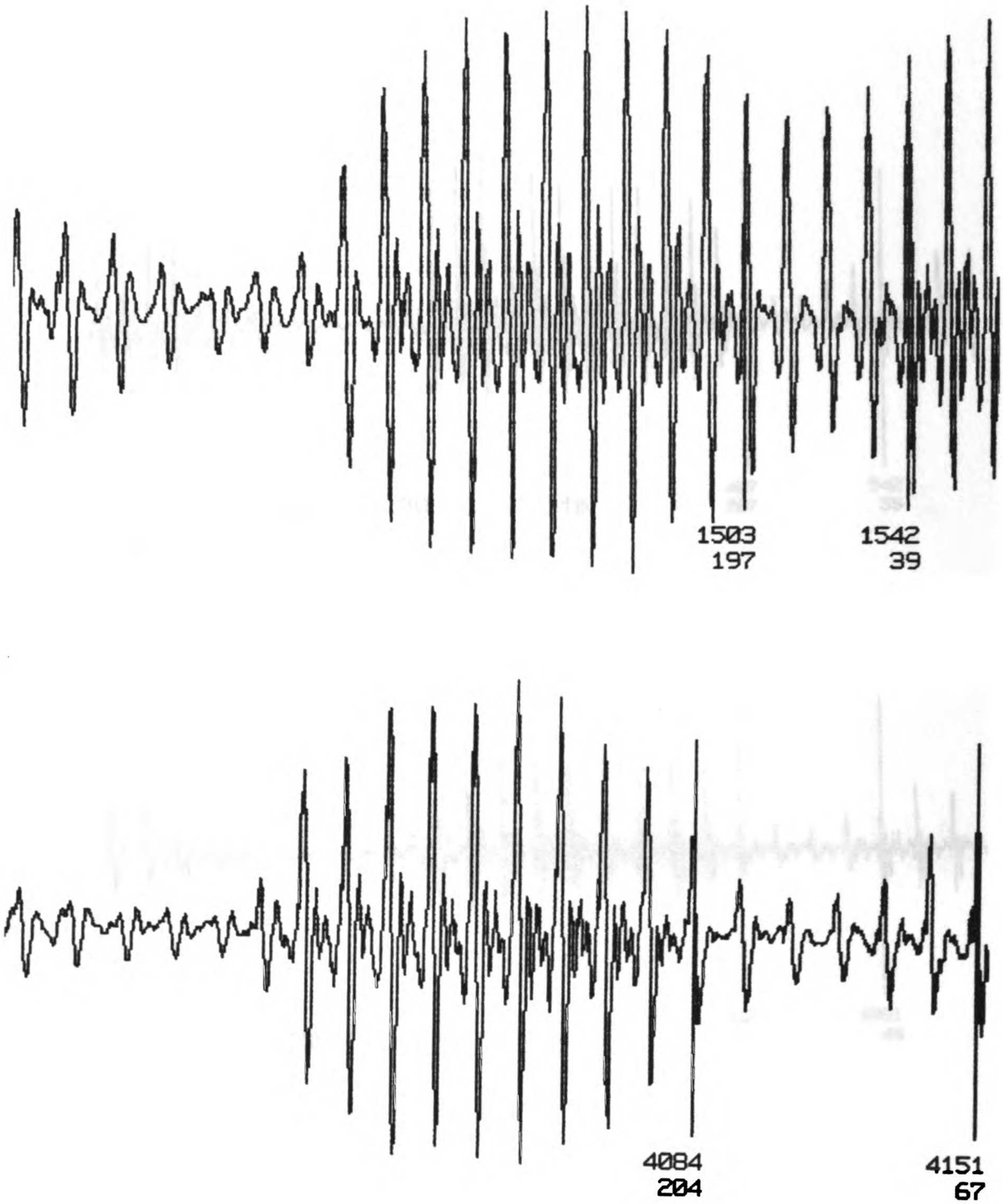

FIGURE 41. Acoustic waveform of two takens of the CVC /bib/ produced by the low intelligibility cleft speaker JD in the rapid rate condition.

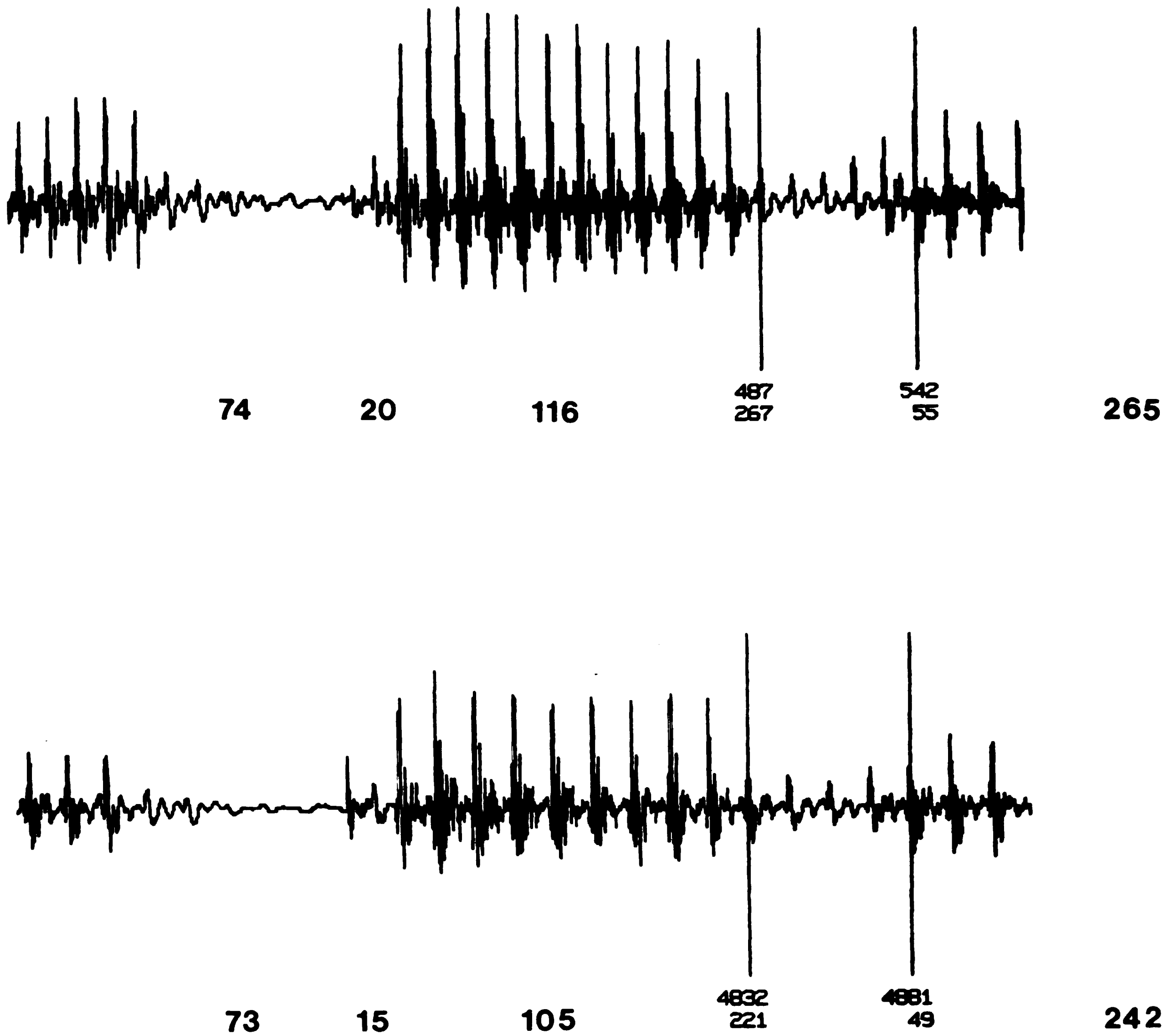

FIGURE 42. Acoustic waveform of two tokens of the CVC /bab/ produced by the high intelligibility cleft speaker PV in the habitual rate condition.

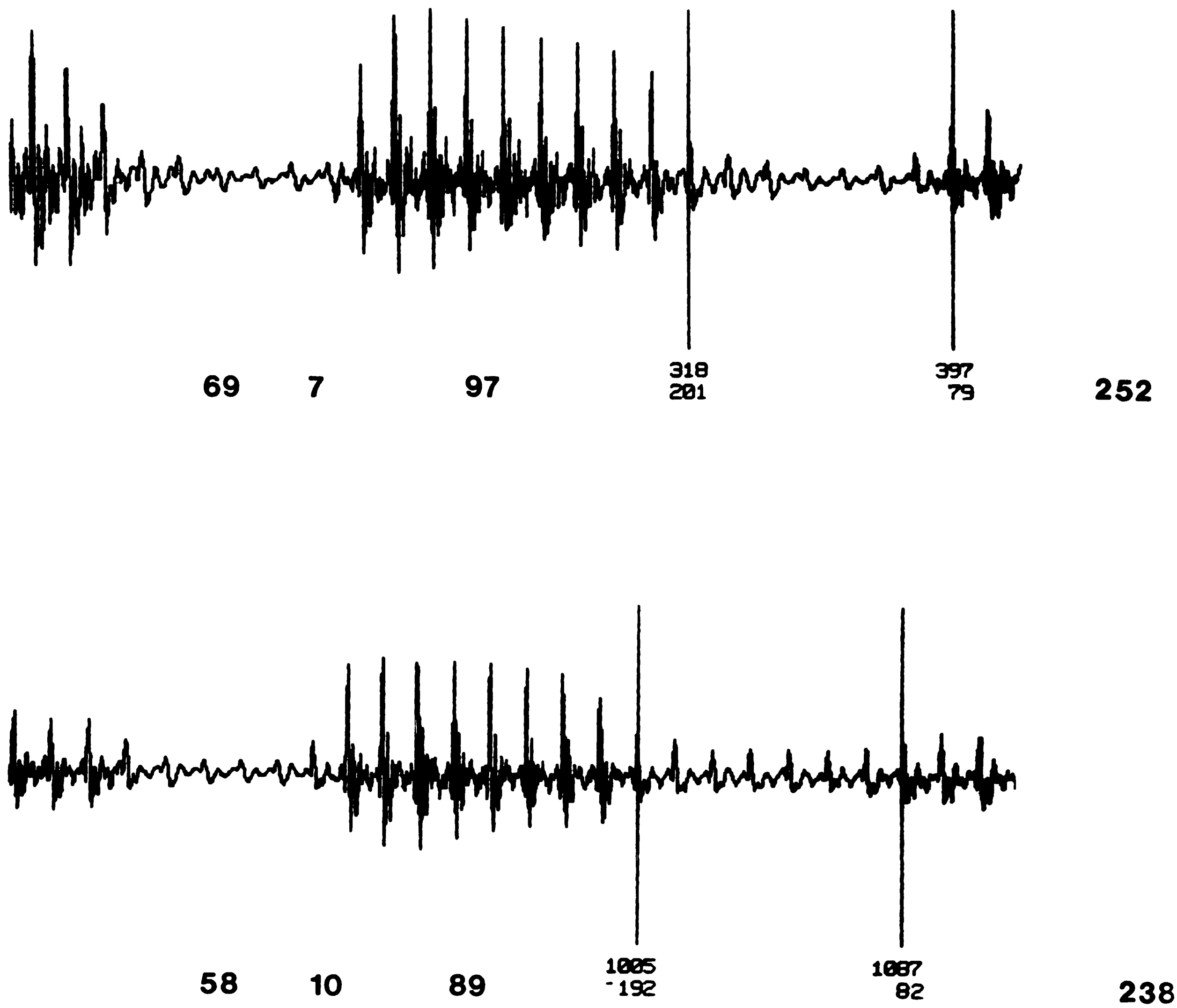

FIGURE 43. Acoustic waveform of two takens of the CVC /bab/ produced by the high intelligibility cleft speaker PV in the rapid rate condition.

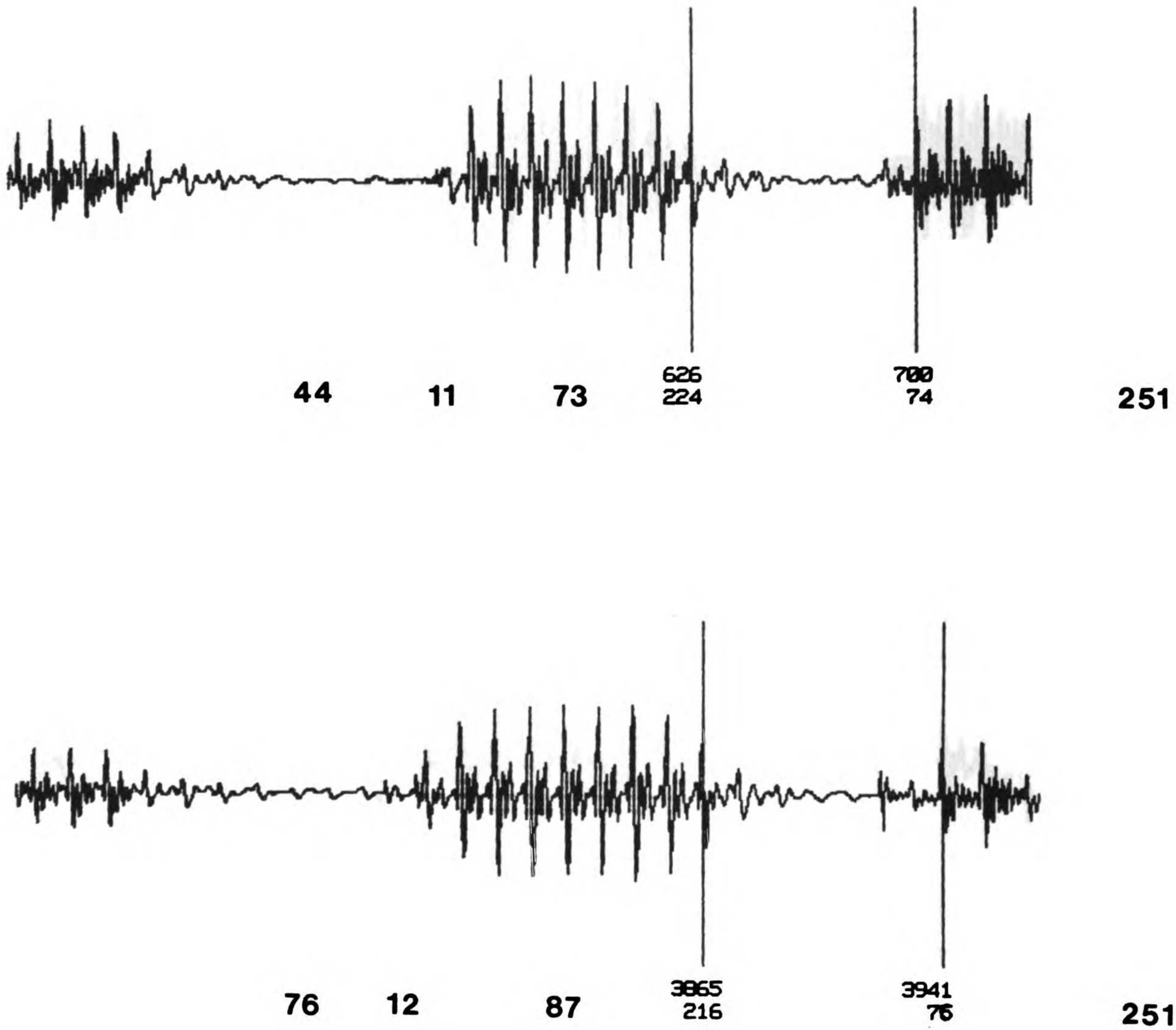

FIGURE 44. Acoustic waveform of two takens of the CVC /bub/ produced by the high intelligibility cleft speaker PV in the habitual rate condition.

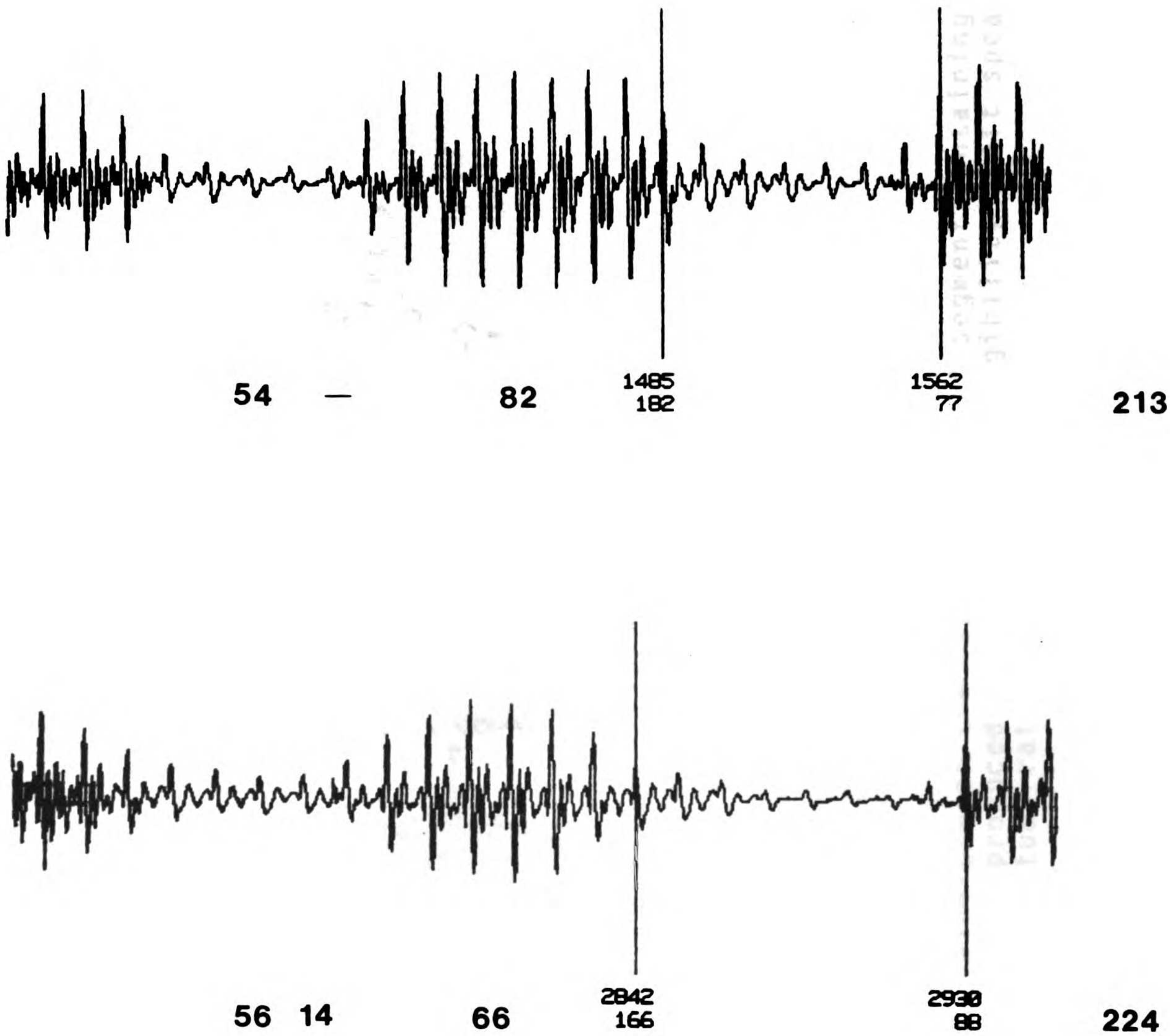

FIGURE 45. Acoustic waveform of two tokens of the CVC /bub/ produced by the high intelligibility cleft speaker PV in the rapid rate condition.

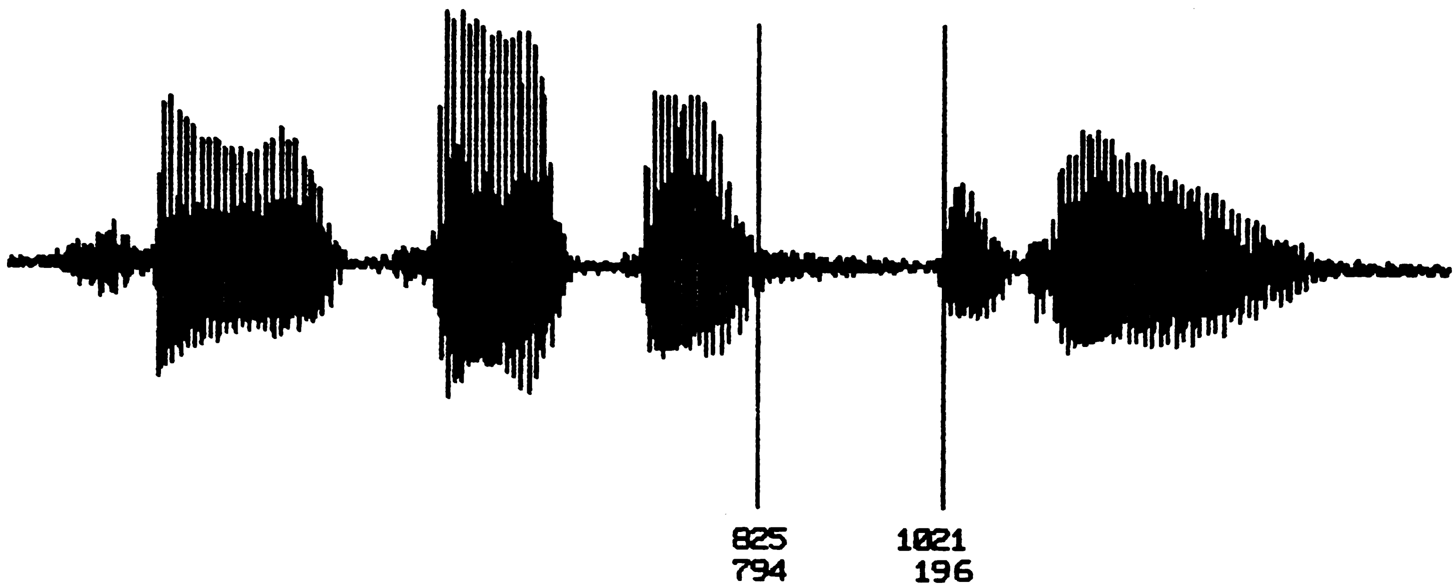

FIGURE 46. Acoustic waveform of the "total sentence" segment containing the CVC /pap/ produced by the low intelligibility cleft speaker CD in the habitual rate condition.

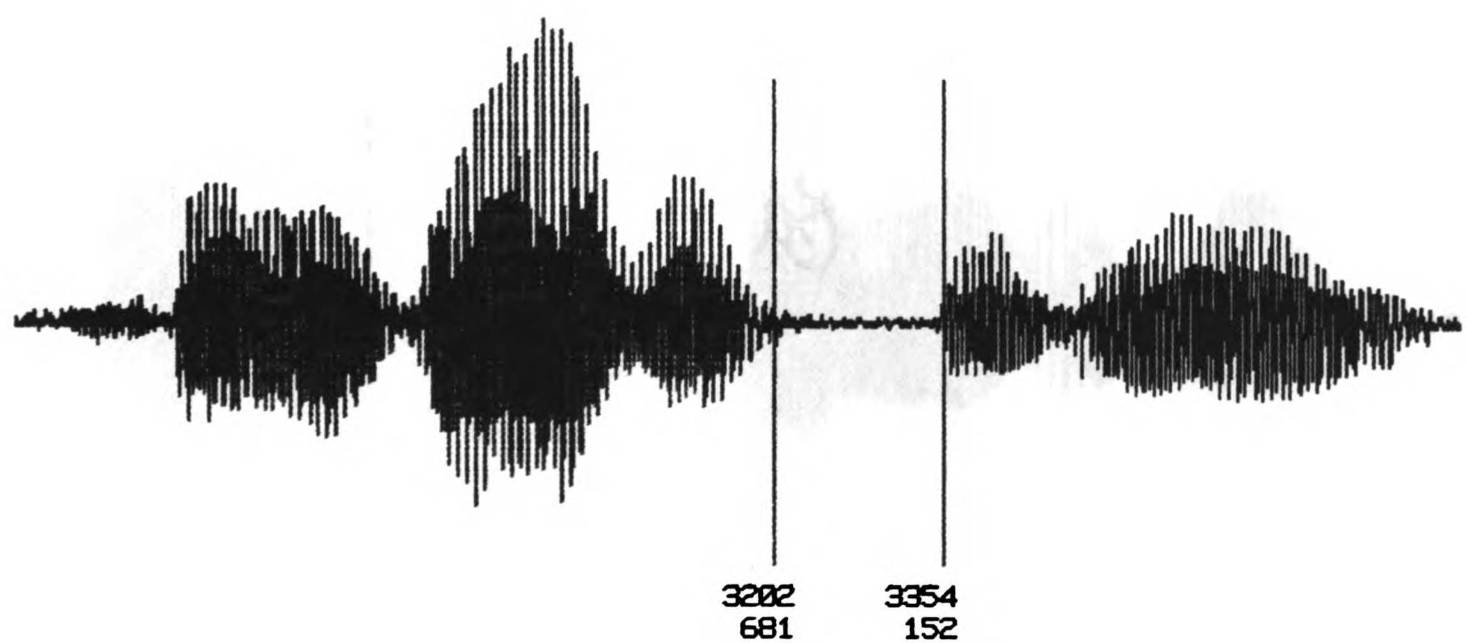

FIGURE 47. Acoustic waveform of the "total sentence" segment containing the CVC /bæb/ produced by the low intelligibility cleft speaker CD in the habitual rate condition.

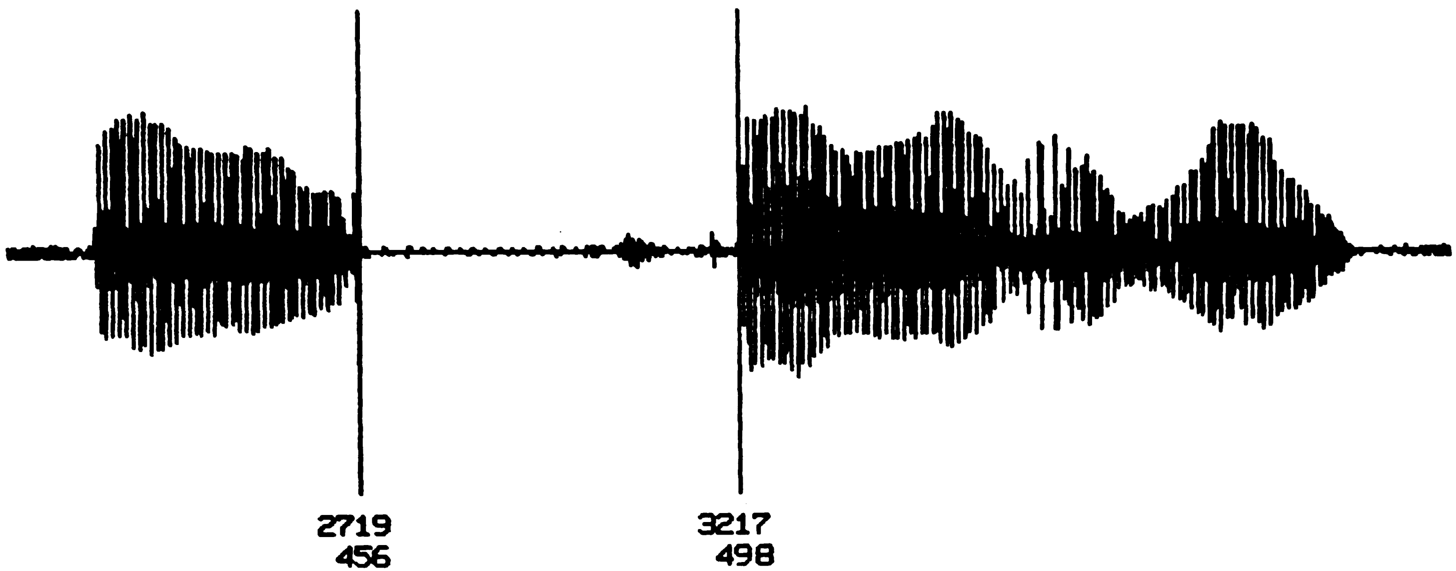

FIGURE 48. Acoustic waveform of the "total sentence" segment containing the CVC /bib/ produced by the low intelligibility cleft speaker OL in the rapid rate condition.

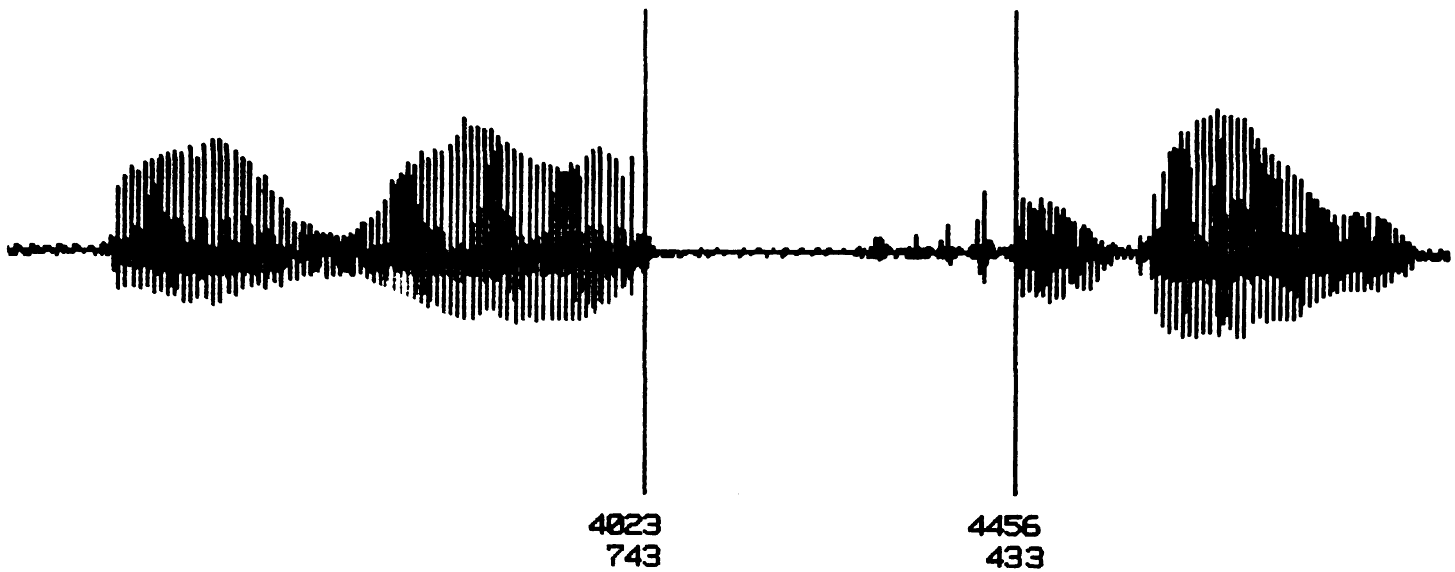

FIGURE 49. Acoustic waveform of the "total sentence" segment containing the CVC /bæb/ produced by the low intelligibility cleft speaker OL in the habitual rate condition.

FIGURE 50. Acoustic waveform of the "total sentence" segment containing the CVC /bæb/ produced by the low intelligibility cleft speaker OL in the rapid rate condition.

Discussion

The data obtained in Experiment 2 revealed several findings pertaining to the five specific questions which were addressed:

1. Do cleft speakers spend more time phonating/articulating than noncleft speakers when producing the same utterance?

2. Are some segments in cleft speech more prolonged than others?

3. Are segment durations more variable in cleft than noncleft speech?

4. When speaking rate is increased by either group, do segment durations become more or less variable?

5. When cleft speakers increase speaking rate, are segment durations altered in the same manner as for noncleft speakers?

The results of Experiment 2 indicate that cleft speakers generally spend more time in phonation and articulation than noncleft speakers. This finding demonstrates that the decrease in overall speaking rate previously observed for cleft speakers is not solely attributable to increased pause duration and frequency of occurence. The present results indicate that acoustically defined segments produced by cleft speakers were, on the average, longer than the same segments produced by noncleft speakers. Furthermore, segments produced by low intelligibility cleft speakers were generally longer than those produced by the high intelligibility cleft speakers. This pattern was most noticeable in the habitual rate condition.

In the rapid rate condition, however, the differences between groups diminished. The low intelligibility cleft group always produced longer segment durations than the noncleft and high intelligibility cleft groups in the rapid rate condition. The high intelligibility cleft group, however, displayed a more complex pattern. In the rapid rate condition, the total sentence segment durations for the high intelligibility cleft group equalled those produced by the noncleft group. Furthermore, durations of the /p/ silence and vowel periodicity segments produced by the high intelligibility cleft group in the rapid rate condition were actually shorter than those segments produced by the noncleft group. Therefore, it is apparent that the high intelligibility cleft speakers reduced some segment durations more than noncleft or low intelligibility cleft speakers. This finding is consistent with the results of Experiment 1 which indicated that the cleft group increased speaking rate more than the noncleft group when altering rate from the habitual to the rapid rate condition.

Because the high intelligibility cleft group reduced some segment durations more than the noncleft group it is likely that the greater durations apparent in the habitual rate condition were not exclusively the result of passive mechanical restraints. Rolnick and Hoops (1971) suggested that increased durations of word initial plosive phonemes were the result of palato-pharyngeal inadequacy. However, in the present experiment, while the high intelligibility cleft speakers produced initial /p/ silence intervals which were an average of 8 msec. longer than those produced by the noncleft group in the habitual condition they reduced the duration by an average of 24 msec. in the rapid rate condition. This was in comparison to an average 12 msec. reduction in the /p/ silence segment for the noncleft group. The large reduction accomplished by the high intelligibility cleft group resulted in a /p/ silence duration 4 msec. shorter than that produced by the noncleft group. Likewise, the high intelligibility cleft group reduced all other segment durations to a greater extent than did the noncleft group. (The effects of increased rate on segment durations will be discussed in greater detail later in this section).

The findings described above point out that some of the cleft speakers, (particularly the high intelligibility cleft speakers) were capable of producing shorter segment durations in the rapid rate condition than they produced in the habitual rate condition and shorter segment durations for some segments than noncleft speakers in either rate condition. These findings suggest that the factors influencing segment durations in the speech of individuals with cleft palate may be varied and complexly interrelated.

For example, the results of the present experiment demonstrate that some segments produced by cleft speakers are more prolonged than others. The /p/ burst and final /p/ silence + burst segments showed the greatest prolongation in the cleft groups followed by the initial /p/ silence segment. There was no apparent difference between durations for the vowel periodicity segments between cleft and noncleft groups.

It is known that the characteristics of vowel segments may have an affect on adjacent consonant production. For example, vowel height has been shown to effect both the rate and extent of velar elevation for obstruant production in normal speakers (Bell-Berti, et al., 1979). Additionally, high vowels have been associated with greater nasality ratings than low vowels in cleft speech (Moore and Sommers, 1973). Therefore, it was hypothesized that vowel context would have an effect on acoustically defined segment durations associated with the consonant /p/ for the cleft speakers in Experiment 2. An analysis of /p/ segment durations suggested that vowel environment generally had a greater effect on segment durations for /p/ silence and /p/ silence + burst intervals for the cleft speakers compared with the noncleft speakers. These effects were strongest for the /p/ silence + burst segments suggesting that vowel environment had stronger carryover effects than anticipatory effects on durations of adjacent segments in the speech of individuals with cleft palate. The nature of these effects was not consistent nor clear, as there were marked individual differences. It should be mentioned that the data pertaining to the effects of vowel environment on segment durations produced by individual subjects represents one CVC type repeated five times. Therefore, the number of repetitions may be too low to draw any conclusions. However, there does appear to be a tendency for vowel environment to affect surrounding consonant durations in cleft speech more than in noncleft speech. Further study of this aspect of timing in cleft speech seems warranted.

It was clearly evident in both the quantitative and qualitative data for cleft speakers that production of the final stop silence + burst segments showed the greatest variability between subjects. That is, final (post vocalic) stop closure was more elongated, more variable, and showed greater coarticulatory effects than initial (prevocalic) stop closure. Therefore, to the extent that consonant duration is related to velopharyngeal adequacy, the present results may be viewed as supporting the findings of Ushijima and Hirose (1974). They suggested that velar activity is not controlled by a simple on-off dichotomous mechanism and that there are different mechanisms for anticipatory and carryover effects of coarticulation at the level of the motor command governing velar activity.

Interpretation of the qualitative data in conjunction with the quantitative data indicated that the cleft subjects demonstrated greater difficulty producing acceptable voiced plosives (/b/ and /d/) than the voiceless plosive /p/. Furthermore, more temporal irregularities occurred in the final stop constriction + burst interval for voiced stops than for any other segment measured.

The preceding discussion suggests that there was a large amount of variability in segment durations both between and within subjects. Further analysis of the quantitative and qualitative data from Experiment 2 resulted in observations concerning additional temporal variability in the speech of individuals with cleft palate. First, the absolute (unnormalized) mean standard deviation data indicated that there were large differences between standard deviations of segment durations for the cleft and noncleft groups. This finding indicates that segment durations were more variable for cleft speakers than noncleft speakers. This difference between the groups was greatest for the total sentence and /p/ burst segments followed by /p/ silence and /p/ silence + burst segments. There was no difference in mean standard deviation values for the vowel periodicity segment durations. These findings suggest that the differences in variability in duration between cleft and noncleft groups are found in the "consonant" intervals not the "vocalic" intervals.

While these absolute differences in mean standard deviation values are informative, it is important to study the normalized data as well. As discussed in the results section, standard deviation values tend to covary with the size of the mean; therefore, it is important to address the normalized data to account for the influence of the size of the mean. Furthermore, it is likely that the perceptual system attends to both absolute and relative differences in variability during speech perception. The normalized standard deviation data showed that the total sentence segment was associated with the lowest standard deviation values, while the /p/ burst segment was associated with the highest. The variability in the durations of the /p/ burst segment may be due to two factors: measurement error, and variability in speaker strategies. The /p/ burst segment was generally the most difficult interval to confidently segment. The high standard deviation values may reflect inconsistencies in measurement. However, many of the subjects produced markedly different /p/ bust segments within a given utterance type, and these differences were reflected in the duration data. That is, /p/ burst segments were generally made up of two intervals: a strong transient and friction or aspiration. However, for many tokens the aspiration was omitted, resulting in an unaspirated /p/. When this occurred the /p/ burst segment was shorter than when aspiration was present. The omission of aspiration was an inconsistent occurrence; therefore, the standard deviation values were often high, reflecting this apparent inconsistency in /p/ burst duration.

It is a common clinical assumption that the speech of individuals with cleft palate is more variable than the speech of individuals without clefts. It was believed that this variability would be reflected in the temporal patterns of cleft speech. The quantitative analysis of the /p/ data suggests that segment durations in cleft speech were slightly more variable than segment durations in noncleft speech. It is also assumed by many clinicians that increased speaking rate results in increased variability in cleft speech. The present data suggest that segment durations commonly became more variable for both cleft and noncleft speakers when speaking rate was increased. However, the effects of rate alteration on variability appeared to be extremely complex, and the standard deviation data obtained in this experiment did not adequately address this issue.

Further valuable information concerning variability of segment durations was gained from interpretation of the qualitative data. For example, inspection of the /b/ data indicates that the cleft speakers showed the greatest variability in productions of the final /b/ constriction + burst segment. This variability was manifest both in the relative degree of constriction and its duration.

For instance, recall that the low intelligibility cleft speaker JD produced final /b/ constriction + burst segments that varied in amount and duration of constriction such that there appeared to be a negative relationship between these two variables, i.e., the greater the degree of constriction, the longer the constriction duration. This finding suggests that for the speaker JD the degree and duration of constriction were linked in such a manner that production of a constriction pattern which approximated that of noncleft speakers (i.e. relatively high degree of constriction with short duration) was not possible. The two variables seemed to be mutually exclusive. These observations raise numerous questions which remain unanswered. For example, are the two variables truly mutally exclusive in this subject's speech production? Are the two constriction patterns perceived as different? Does manipulation of the degree of constriction and/or duration alter the perceptual quality of the segment?

Questions relating to the temporal patterns present in cleft speech remain unanswered by the present experiment. Indeed, patterns of variability observed in the speech of another cleft subject serve to raise further questions. Recall the high intelligibility cleft subject PV, who consistently produced longer final /b/ constriction + burst segments in the rapid condition than in the habitual condition. This is an obvious timing error of unknown origin and unspecified effect on speech quality. Likewise the inappropriately placed and elongated silent intervals observed for the low intelligibility cleft subjects CD and OL (Figures 46-50) provide further evidence that there are abnormal timing properties in the speech of some individuals with cleft palate and that these patterns are highly variable both between and within subjects.

Perhaps the most interesting findings in Experiment 2 relate to how increased speaking rate was reflected in segment durations for cleft and noncleft speakers. Studies of normal speech production indicate that the most elastic portion of a syllable is the vowel nucleus (Kozhevnikova and Chistovich, 1965; Gay, 1978). That is, when speaking rate is increased, most of the total reduction in duration occurs in the vocalic segment rather than the consonant segments. The data from Experiment 2 indicated that this pattern was generally true for the noncleft and high intelligibility cleft groups but quite the reverse for the low intelligibility cleft group (Figures 28 and 29). Inspection of individual speaker patterns (Figures 30 and 31) indicated that, for two of the low intelligibility cleft speakers, reduction of the initial /p/ silence was equal to or greater than reduction of the burst + periodicity interval, and /p/ silence + burst reduction was greater than that for the burst + periodicity interval.

This finding is of particular interest. The duration data showed that the /p/ silence + burst interval was extremely elongated for the low intelligibility cleft group while the vowel periodicity interval duration approximated the noncleft group. Traditional explanations of this finding would suggest that the excessive duration of the final /p/ silence + burst segment was the direct result of inadequate velopharyngeal function. This explanation would draw support from the fact that these subjects showed some of the highest nasality ratings of all the cleft subjects. However, as the present data indicate, when asked to increase speaking rate, (i.e. to presumably shorten segment durations) two of these speakers reduced the interval which had been inappropriately elongated in the habitual rate condition. The one low intelligibility cleft speaker (CD) who showed a more "normal" timing pattern was different from the other cleft subjects in that he demonstrated high nasality ratings - he was the one cleft subject who had not undergone a pharyngeal flap procedure to reduce nasality. Therefore, it is possible that the differences between this subject and the other two low intelligibility cleft subjects may relate to the anatomical differences. Indeed, this subject's very inclusion in the low intelligibility cleft group may not have occurred if the assignment had been based on speech judgments made after a pharyngeal flap procedure had been completed.

Nevertheless, two of the low intelligibility cleft subjects were clearly capable of producing shorter final /p/ segments than they produced in the habitual rate condition. The prolongation of this interval may be related to velopharyngeal function but the relationship is obviously more complex than traditional theories might suggest. It is as if there were an articulatory reorganization in the rapid rate condition which took into account the abnormal temporal patterns present in the habitual rate condition. However, since the speakers were clearly able to produce shorter segments, why they did not do so in the habitual rate condition is not known. Further study of this phenomenon would be of particular interest to an understanding of cleft palate speech and to theories of articulatory organization in general.

While the origin of temporal abnormalities in cleft palate speech and their effects on speech quality remain unclear, we may speculate about both. It is reasonable to suggest that the timing errors evidenced by the cleft speakers may relate to velopharyngeal insufficiency. This relationship may be linked to attempts to build up adequate intraoral air pressure for stop plosive production. Or, the relationship may be more complex, involving inappropriate coordination and timing of velar movements with tongue, lip, and jaw activity as well as with voicing. Furthermore, some of the segment duration patterns observed for cleft speakers may reflect active compensatory strategies for speech production. This hypothesis is particularly supported by the findings of Experiment 2 with respect to rate alteration. Whatever the cause may be, it is reasonable to assume that the abnormal and inconsistent temporal properties observed in cleft speech do contribute to reduced speech quality. These timing patterns may result in actual phonemic errors, while other patterns (such as inconsistency of error occurence and duration) may result in reduced quality. On the other hand, some temporal patterns may represent active compensatory strategies on the part of the speaker to compensate for other speech abnormalities and may or may not result in reduced quality.

The data obtained in Experiment 2 showed that the low intelligibility cleft group generally produced longer segment durations with greater variability, and demonstrated more observable aberrant timing patterns than the high intelligibility cleft speakers. Interpretation of these findings suggests that for cleft speakers there is a relationship between the presence of temporal irregularities (such as those described above) and intelligibility. However, no causal relationship can be established from the present data.

The results of Experiment 2 clearly establish the existence of timing errors in the speech of some individuals with cleft palate, and suggest that there is a relationship between the presence of timing abnormalities and reduced intelligibility. Further research should be undertaken to address the effects of abnormal timing patterns on speech quality, and to attempt to account for their origin.

V. SUMMARY AND CONCLUSIONS

This chapter reviews and summarizes the major findings of the thesis. The results of the two individual experiments are discussed together with respect to information concerning speech timing in general, cleft palate speech in particular, and implications for treatment. Finally, the limitations of the present investigation are discussed along with directions for future research.

Review

The general objective of this thesis was to document some of the timing patterns in the speech of a sample of individuals with cleft palate in comparison with a group of noncleft speakers. The goal was to present data which revealed whether temporal patterns in cleft speech differed from noncleft speech.

Experiment 1 explored the effects of speaking rate on listener judgements of nasality, articulation, and intelligibility in cleft and noncleft speech. Ten cleft and ten noncleft adult, male speakers produced a speech sample at a habitual and a rapid speaking rate. Six judges rated the speech samples on a seven-point scale for perceived nasality, articulation and intelligiblity. Two specific questions were addressed:

1. What are the effects of increased speaking rate on

listener ratings of nasality, articulation and intelligibility?

2. Are speech ratings for individuals with cleft palate affected more by increased rate than speech ratings for individuals without cleft palate?

Experiment 2 employed a subset of the subjects from Experiment 1 to compare acoustically defined segment durations in the speech of three noncleft, three high intelligibility cleft and three low intelligibility cleft subjects. The speakers produced CVC nonsense syllables, within a carrier phrase, at a habitual and a rapid speaking rate. The acoustic waveform of the speech samples was interactively displayed, segmented, and measured employing digital computer hardware and software. Five specific questions were addressed:

1. Do cleft speakers spend more time phonating/articulating than noncleft speakers when producing the same utterance?

2. Are some segments in cleft speech more prolonged than others?

3. Are segment durations more variable in cleft than noncleft speech?

4. When speaking rate is increased by either group, do segment durations become more or less variable?

5. When cleft speakers increase speaking rate, are segment

durations altered in the same manner as for noncleft speakers?

The major findings of Experiment 1 were:

1. The cleft speakers spoke more slowly than the noncleft speakers in the habitual rate condition; however, there was less difference between the groups in the rapid condition. That is, cleft speakers altered their speaking rate more than noncleft speakers.

2. Increased speaking rate resulted in poorer articulation and intelligibility ratings for <u>both</u> groups but had a more complex effect on nasality ratings. Rate alteration had no effect on nasality ratings for noncleft speakers; however, an increase in rate resulted in poorer nasality ratings for half of the cleft subjects and improved nasality ratings for the other half.

3. For the cleft group there was a significant correlation between speech sample duration within a rate condition, and ratings of nasality, articulation and intelligibility; the longer the speech sample the poorer the speech ratings. Likewise for the cleft group, there was a significant negative correlation between speech attribute ratings and speaking rate within a rate condition. That is, the slower the speaking rate the poorer the speech rating.

4. Among the speech attributes, articulation ratings showed a stronger relationship with intelligibility ratings than

did nasality.

The findings of Experiment 2 were:

1. Acoustically defined segments produced by the cleft speakers were generally longer than the same segments produced by the noncleft speakers. Furthermore, segments produced by the low intelligibility cleft group were longer than those produced by the high intelligibility cleft group. Therefore, it appears that cleft speakers do spend more time phonating/articulating than noncleft speakers and that the decrease in overall speaking rate previously reported for cleft speakers is not solely attributable to increased pause duration and frequency of occurence.

2. Some segment types were more prolonged in cleft speech than others. The /p/ burst and final /p/ silence + burst segments showed the greatest prolongation in cleft speech followed by the initial /p/ silence segment. There was no apparent difference between durations for the vowel periodicity segments between cleft and noncleft groups.

3. Vowel environment appeared to have had a stronger effect on /p/ segment durations for cleft speakers than noncleft speakers. Furthermore, these effects were strongest for the /p/ silence + burst segments. This suggests that vowel environment had stronger carryover effects than anticipatory effects on durations of adjacent segments in the speech of individuals with cleft palate.

4. A conservative interpretation of the results of the quantitative analysis of the /p/ data indicated that segment durations in cleft speech were slightly more variable than segment durations in noncleft speech. Furthermore, segment durations commonly became more variable for both cleft and noncleft speakers when speaking rate was increased. Additionally, the final /p/ silence + burst interval showed the greatest variability in duration between subjects.

5. Information from a qualitative analysis of the /p/, /b/, and /d/ data revealed that on the average, the cleft speakers demonstrated substantially more variability in both degree of constriction and its duration than noncleft speakers. This variability was greatest for final voiced stop productions and was observed both between and within subjects. Furthermore, the cleft speakers commonly produced excessive constriction or silence durations, often in seemingly inappropriate locations in the acoustic waveform. This pattern of irregular silent interval elongation and placement never occurred for the noncleft speakers.

6. The effects of increased rate on segment durations were complex. On the average, the high intelligibility cleft speakers reduced segment durations more than noncleft or low intelligibility cleft speakers. Both the noncleft and high intelligibility cleft speakers reduced the vocalic interval (/p/ burst + vowel periodicity) more than the consonant intervals (/p/ silence and /p/ silence + burst). Two of the

low intelligibility cleft speakers, on the other hand, showed a reverse pattern, reducing the excessively long consonant intervals more than the vowel interval.

7. Finally, the results revealed that the low intelligibility cleft group generally produced longer segment durations with greater variability, and demonstrated more observable aberrant timing patterns than the high intelligibility cleft speakers. This suggested that for the cleft speakers there was a relationship between temporal irregularities and intelligibility. No causal relationship was implied from the available data.

General Discussion

Speech timing. The generation of a spoken message is a process which involves numerous stages. These stages or levels of speech production include: the sematic, syntactic and lexical components; the phonological components; the phonetic features; the articulatory transformation; the acoustic transformation, and ultimately result in the perception of a message. Speech timing is specified and modified at many levels of this process. For example, Klatt (1976) suggests that in normal speech "Psychological and semantic variables influence average speaking rate and determine any durational increments due to emphasis or contrastive stress". The phonological component imposes rules which weigh information from the preceding levels and specifies a "duration" for each segment to be produced. Klatt continues,

> "A set of language-specific feature-implementation rules transforms the output representation of the phonological component into a temporal sequence of motor commands to the articulators. The articulatory transformation then imposes physical constraints concerning the mass, compliance, damping, and muscular forces extant in the articulatory system. This results in a temporal pattern of articulatory motions. The temporal pattern of acoustic events is computed from a knowledge of the sound generation and sound propagation properties of the larynx and vocal-nasal tracts" (p 1209).

It is clear from this simplification of the speech process that timing is a complex phenomena which underlies natural speech, and may be studied at a variety of levels. For example, the durational aspects of speech segments (observed in the acoustic record) may convey linguistic information and/or relate to quality differences. For example, in English, the duration of a segment often serves as the primary perceptual cue to phonemic distinctions such as the difference between inherently long versus short vowels or voiced versus voiceless fricatives. Thus, large duration differences may result in the perception of an unintended phoneme while shorter duration errors may result in a distortion of the intended segment.

In normal speech production, segment durations are routinely and systematically altered due to a number of factors including speaking rate, phonetic context and linguistic stress. The effects of these variables on the acoustic output is complex and no comprehensive predictive theory exists. Furthermore, when stresses are imposed on a "normal" articulatory system it is not clear which aspects of timing are preserved and which aspects are allowed to vary. It is assumed, however, that some temporal aspects of speech are more tightly constrained than others.

When speech is clearly abnormal (as with many cleft palate speakers) questions concerning timing are of interest for two primary reasons. Obviously, information concerning temporal irregularities in the speech of a clinical population may provide information useful for treatment planning. Additionally, observations of temporal patterns in the speech of clinical populations may contribute supporting data to a larger theory or understanding of speech timing in general.

For example, the present investigation revealed that when speaking rate was increased some segment types were reduced in duration more than others. Thus the findings of other investigators (Port, 1977; Gay, 1978) were substantiated. The combined data indicate that increased rate results in a nonlinear horizontal compression of the speech signal. The previous studies indicated that the vocalic interval of a CVC accounted for a greater percentage of the total reduction than the other individual segments. This finding was true for most of the subjects in the present investigation. However, two of the low intelligibility cleft speakers reduced the durations of the consonant intervals (which were the most elongated intervals in their productions) rather than reducing the vocalic interval. Therefore, rate alteration from the habitual to the rapid rate appears to be the result of a complicated reorganization strategy. The data derived from the cleft speakers suggest that faced with the task of shortening overall duration, the reorganization appears to take into consideration both segment type and the initial duration of the segment.

A second example of the nonlinear nature of duration reduction was seen in the speech of the high intelligibility cleft subject who produced longer final /b/ constriction durations in the rapid condition as compared with the habitual condition. When reduction of one segment (final /b/ constriction) appeared to be constrained, the other segments in the CVC were free to shorten to a greater extent than expected in order to yield a net reduction in CVC duration.

While some temporal aspects of cleft speech differed markedly from those observed in normal speech, some aspects remained unchanged. For example, vowel periodicity duration was effected by specific vowel identity and consonant environment in the same manner for both groups. One interpretation of this finding would suggest that since absolute durations of vocalic segments were not as inappropriately elongated in cleft speech as the stop durations, it is not surprising that the relative timing patterns for vocalic segments were preserved. However, it is also plausible that durational differences for vowels reflect tightly programmed temporal contrasts in English and were therefore more resistant to alteration from the normal pattern.

The preceding discussion indicates that the study of timing in disordered speech provides information which may contribute to our expanding theories of speech timing in general.

Cleft palate speech. Observations of timing patterns in cleft speech provide useful information for a dynamic description of the speech disorders associated with cleft lip and palate. Additionally, a detailed description of speech which encompasses temporal aspects is likely to suggest new directions for therapy.

The various findings of the present investigation provide evidence that temporal irregularities do exist in the speech of some individuals with cleft palate, and further, that these irregularities may be more evident in speakers with poor intelligibility. Traditionally, cleft palate speech has been viewed in a static manner with the primary focus directed toward the relationship between anatomic structure and the production of "correct" articulatory targets. However, the present data suggest that the dynamic aspects of speech production are important to a more complete understanding of cleft palate speech.

It seems likely that most of the abnormal temporal patterns observed in cleft speech relate to intelligibility or speech quality in some manner, either by reducing speech quality or in some instances by facilitating it. However, the relationship between timing and intelligibility in cleft speech remains unspecified. Further research should be undertaken to address this relationship. The present results provide some insights on this question. Experiment 1 showed that the slower cleft speakers received the poorest speech ratings. In Experiment 2, the low intelligibility cleft speakers generally produced the longest segment durations, demonstrated more variability in segment durations, and produced a higher frequency of inappropriately placed and elongated silent intervals in the acoustic waveform. Although there appears to be a relationship between abnormal temporal properties and reduced intelligibility, the strength of the relationship is unknown and no causal relationship can be implied from the current data.

Nevertheless, the results do stimulate new directions for future research efforts. It would be of particular value to undertake a synthesis study (such as the study described by Osberger, (1978) in which the effects of timing errors on the intelligibility of deaf children's speech were quantified.) In such a study, the timing errors in cleft speech might be categorized and systematically altered to establish the effects on speech quality and intelligibility. At a less elaborate level, correlation studies might be undertaken to better describe the nature and extent of the relationship between the various types and degrees of timing errors and perceptual judgments of cleft speech.

While it seems necessary to study the relationship between speech timing errors and speech quality, it is also important to address the cause of these patterns. There is no reason to believe that the temporal aspects of speech which are specified at the sematic, syntactic, and lexical levels are disturbed in the cleft speaker. Rather, it is likely that impairments of the speech articulators and disruption of their motor innervation result in abnormal interarticulator coordination and timing.

While aberrant timing patterns may originate with mechanical constraints at the articulatory level they may reflect compensatory strategies for articulatory abnormalities past or present. Therefore, the nature of the timing errors may vary within and between speakers. The errors may be random responses to demands on the articulatory system. Or, for some speakers, timing abnormalities may not be errors as such, but may be systematic productions which reflect a deviant phonological system. Still other apparent errors may reflect strategies for producing intelligible speech.

The current results provide several examples of temporal patterns in cleft speech which differed from those observed in noncleft speech. Among these were patterns which may have reflected adaptive strategies. For example, the overall reduction in speaking rate observed for the cleft subjects in Experiment 1 and the prolongation of some segments observed in Experiment 2 may represent an active choice on the part of some speakers. Likewise, the reduction of segment durations in the rapid rate condition of Experiment 2 was different for the low intelligibility cleft speakers and once again, the data suggest that the differences between speakers in reduction patterns may have been the result of active strategies.

Further research should be conducted to relate the timing patterns observed in the acoustic waveform to articulatory patterns and programming. For example, spectral analysis of speech segments would reveal information concerning the relative timing of more microscopic speech events such as the rate and extent of formant transitions. Studies employing cineradiography, EMG, or aerodynamic measures, combined with acoustic and/or perceptual studies and focused on the relative timing of articulatory events would provide invaluable information concerning speech timing in cleft speech. These research efforts would be of particular interest if they related observations at the articulatory or motor programming level to perceptual results.

Generally, the motivation for studying disordered speech is to better understand how it deviates from (and/or remains the same as) normal speech. The ultimate goal is to use this increased knowledge and understanding to facilitate better communication abilities in the communicatively disordered individual.

The results of the present investigation, in conjunction with recent studies of speech timing in general, indicate that the dynamic, temporal aspects of speech are important factors which relate to speech naturalness and intelligibility. Attempts to document and clarify this relationship in disordered speech may result in new directions for therapy. For example, an awareness of the relationship between timing and intelligibility in deaf speech has resulted in the consideration of speech timing in most speech training programs for the deaf. Indeed, as was discovered for many deaf speakers, the traditional therapu-tic focus on static articulatory placement in isolated words often resulted in a preoccupation with the articulation of individual phonemes which actually interfered with the smooth transition from one sound to the next resulting in inappropriate temporal characteristics and distorted speech. It is likely that a similar preoccupation with static articulatory targets results in timing errors in other clinical populations as well. Therefore, the temporal properties of speech should be considered in any speech training program.

The present findings indicate that temporal abnormalities do exist in cleft speech and that some of these irregularities may relate to reduced intelligibility. Therefore, temporal adjustments (such as rate and durational adjustments) in addition to traditional articulation therapies, should be considered in treatment plans for individuals with cleft palate. It is likely that the temporal aspects of speech may be modified resulting in improved communication effectiveness even when it is not possible to modify articulation skills *per se*. For instance, the results of Experiment 1 presented the example of the cleft subjects whose nasality ratings improved with an increase in speaking rate. It is possible that individual adjustments in overall speaking rate for each subject may have resulted in improved speech quality for some of these speakers even when traditional articulation therapies had accomplished all they could.

In conclusion, the present investigation has achieved the intended goal, i.e. to document the existence of temporal irregularities in the speech of individuals with cleft lip and palate. Furthermore, these temporal abnormalities appear to be related to reduced speech quality in cleft speech. Further study on this topic would be of value to a more comprehensive understanding of cleft speech in particular and theories of speech timing in general.

APPENDIX A

Anatomic, surgical, and speech characteristics of cleft subjects

(The following information was gathered from patient records.)

Speaker: MG

Age: 22

Complete bilateral cleft lip and palate

Velopharynx - Pharyngeal flap procedure completed, soft palate moves well and achieves good closure. No discussion of speech.

Speaker: PV

Age: 20

Complete bilateral cleft lip and palate

Velopharynx - Xrays show evidence of pharyngeal flap. Records are incomplete and unable to contact patient. Records note that soft palate moves well.
Speech - good quality, no records pertaining to speech therapy.

Speaker: OL

Age: 17

Complete bilateral cleft lip and palate

Velopharynx - Two previous pharyngeal flap procedures completed, evidence of velopharyngeal closure during speech.
Speech - Obvious nasal voice quality and nasal emission on certain phonemes, particularly affricates and sibilants. Overall intelligibility is low, particularly in connected speech. Received continuous speech therapy from age 3 to present.

Speaker: KR

Age: 19

Complete bilateral cleft lip and palate

Velopharynx - Pharyngeal flap procedure completed - no evidence of velopharyngeal closure during speech.
Speech - hypernasal voice quality, + tendency to overarticulate plosive sounds. Received continuous speech therapy from preschool to present.

Speaker: MH

Age: 16

Complete unilateral cleft lip and palate (left)

Velopharynx - Pharyngeal flap procedure completed, soft palate operates normally with good closure when appropriate.
Speech - accurate articulation with slight nasality .
Speech therapy - intermittent speech therapy throughout elementary school.

Speaker: JC

Age: 20

Complete unilateral cleft lip and palate (left)

Velopharynx - Palate pushback and pharyngeal flap procedures completed, palate moves well, attains consistent closure.
Speech - satisfactory articulation, good oronasal resonance balance with sporadic manifestations of hyponasality. Received speech therapy from age 3 through age 12.

Speaker: JL

Age: 22

Complete unilateral cleft lip and palate (left)

Velopharynx - Pharyngeal flap procedure completed, palate shows good movement, closes consistently and adequately.
Speech - Articulation accurate with exception of /s/ phoneme. No discernible nasal emission but has a "nasal cast" in his voice quality. Received intermittent speech therapy throughout elementary and junior high school.

Speaker: CD

Age: 19

Complete bilateral cleft lip and palate

Velopharynx - No pharyngeal flap procedure undertaken. Soft palate appears short, palate does not appear to make contact with posterior pharyngeal wall.
Speech - Accurate tongue and lip placements for production of words in isolation. Sporadic nasal friction is associated with /s/ and /z/ and hypernasality is obvious particularly in connected speech. No record of any speech therapy.

Speaker: AC

Age: 19

Complete unilateral cleft lip and palate (right)

Velopharynx - pharyngeal flap procedure completed, nasopharynx is deep but velopharyngeal closure appears to be adequate.
Speech - articulation is accurate and voice quality is satisfactory in terms of oronasal resonance. No record of any speech therapy.

Speaker: JD

Age: 17

Complete bilateral cleft lip and palate

Velopharynx - pharyngeal flap procedure completed resulting in wide nasopharyngeal port on right side. Left port closes for all speech sounds while right port does not achieve closure.
Speech - accurate articulation on individual sounds in isolation except for the /s/ and /z/ phonemes on which there is conspicuous oral air escape. In connected speech there are sound omissions and "slurring", particularly when speaking rapidly. In general, voice quality is acceptable in terms of oronasal resonance. Received speech therapy from preschool through age 10.

APPENDIX B

Mean speech ratings over six judges; speech sample duration, and speaking rate for two rate conditions for individual subjects.

Group Subject	Mean Speech Ratings						Speech sample duration*		Speaking rate**	
							Habitual Rate Condition	Rapid Rate Condition	Habitual Rate Condition	Rapid Rate Condition
	Nasality	Artic.	Intell.	Nasality	Artic.	Intell.				
Noncleft										
PC	1.3	2.0	1.7	1.7	3.7	3.2	13.1	11.6	4.6	5.2
SK	1.3	1.3	1.0	1.3	1.5	1.2	12.5	9.8	4.8	6.1
JB	2.2	1.5	1.5	2.5	1.7	1.5	13.4	9.9	4.5	6.1
PM	1.0	1.5	1.2	1.2	1.7	1.2	13.5	11.5	4.4	5.2
BM	1.0	1.2	1.0	1.3	2.2	2.2	13.2	9.1	4.5	6.6
CC	2.5	2.0	1.8	2.3	2.3	2.3	14.0	10.4	4.3	5.8
LB	1.2	1.0	1.0	1.0	1.0	1.0	15.0	10.6	4.0	5.7
MR	1.2	1.5	1.2	1.2	1.7	1.5	14.4	10.2	4.2	5.9
RF	2.2	1.7	1.5	2.7	1.7	1.5	14.4	11.1	4.2	5.4
AS	1.3	1.3	1.0	1.3	1.5	1.3	13.2	10.3	4.5	5.8

APPENDIX B (CONTINUED)

Group Subject	Mean Speech Ratings						Speech sample duration*		Speaking rate**	
							Habitual Rate Condition	Rapid Rate Condition	Habitual Rate Condition	Rapid Rate Condition
	Nasality	Artic.	Intell.	Nasality	Artic.	Intell.				
Cleft										
MG	4.2	3.0	2.5	5.3	3.2	2.5	17.7	12.0	3.4	5.0
PV	4.8	2.7	2.3	4.2	3.3	3.0	14.4	9.4	4.2	6.4
OL	7.0	6.3	6.2	7.0	6.3	6.5	28.9	17.5	2.1	3.4
KR	6.8	5.8	5.2	7.0	6.2	6.3	23.8	16.6	2.5	3.6
MH	3.7	2.8	2.5	4.5	3.2	2.5	15.7	12.0	3.8	5.0
JC	3.7	3.7	3.2	3.5	3.2	2.7	16.4	14.0	3.7	5.0
JL	3.5	2.5	2.2	2.8	3.2	3.3	14.8	9.7	4.1	6.2
CD	6.8	5.5	5.3	7.0	5.8	5.0	16.3	11.9	3.7	5.0
AC	4.8	2.2	2.0	4.5	2.5	2.8	13.9	9.2	4.3	6.5
JD	6.2	4.3	4.2	6.0	5.3	4.5	24.3	12.8	2.5	4.7

*"Speech sample duration" expressed in seconds

**"Speaking rate" expressed in syllables per second

KEY TO ABBREVIATIONS USED IN APPENDICES C AND D.

GROUP 1 = Noncleft

GROUP 2 = High intelligibility cleft

GROUP 3 = Low intelligibility cleft

RATE 1 = Habitual rate condition

RATE 2 = Rapid rate condition

TCP = Total sentence segment

C1 = /p/ silence segment

VOT = /p/ burst segment

VOWEL = Vowel periodicity segment

C2 = /p/ silence + burst segment

MEAN = Mean

STD = Standard deviation

VOWEL A = /a/

VOWEL H = /ae/

VOWEL I = /i/

VOWEL U = /u/

APPENDIX C

Mean segment duration and standard deviation values for individual subjects averaged across vowels.

SUBJECT	RATE	TCPMEAN	TCPSTD	C1MEAN	C1STD	VOTMEAN	VOTSTD	VOWELMN	VOWELSTD	C2MEAN	C2STD
BM	1	856.50	39.950	68.25	6.725	32.25	4.325	96.50	7.725	92.75	8.900
BM	2	632.75	27.325	54.75	9.150	24.00	3.000	82.75	10.725	75.25	10.475
CD	1	1016.00	83.725	87.00	7.425	45.25	6.600	99.00	9.325	103.25	8.225
CD	2	766.00	28.925	69.50	8.375	34.75	5.675	86.75	7.700	94.00	7.375
JD	1	1016.25	108.750	102.50	16.950	50.25	6.525	94.25	13.275	137.00	15.575
JD	2	810.75	50.925	77.50	9.150	46.25	9.600	89.25	8.950	114.75	10.750
JL	1	1105.00	74.675	90.75	8.475	66.25	8.200	78.25	11.175	108.50	5.425
JL	2	673.75	44.300	50.75	6.875	42.50	11.575	42.75	9.650	76.50	10.975
LB	1	804.50	32.375	79.75	4.750	40.25	8.925	99.75	7.250	96.50	8.375
LB	2	694.75	28.375	69.75	8.775	26.75	4.475	98.75	7.075	80.50	5.975
MH	1	1086.75	78.750	79.50	10.775	47.25	9.025	104.25	9.725	122.25	16.000
MH	2	862.50	39.450	65.00	10.000	42.00	6.250	91.00	7.600	105.25	14.025
MR	1	976.50	58.875	80.00	4.500	41.50	7.825	84.00	10.450	93.75	4.525
MR	2	763.00	28.500	66.25	6.250	31.25	3.600	71.00	10.400	83.25	8.700
OL	1	1203.75	76.025	79.50	10.400	54.00	6.000	89.25	9.075	144.25	12.650
OL	2	865.25	85.500	69.50	8.475	51.75	10.425	81.25	6.100	124.50	15.450
PV	1	944.75	55.625	80.25	7.775	52.75	7.900	78.75	7.025	99.00	9.050
PV	2	604.75	41.900	63.00	6.225	31.00	8.300	66.50	7.125	92.75	11.875

APPENDIX D

Mean segment duration and standard deviation values for individual subjects and individual vowels.

GROUP	SUBJECT	VOWEL	RATE	TCPMEAN	TCPSTD	C1MEAN	C1STD	VOTMEAN	VOTSTD	VOWELMN	VOWELSTD	C2MEAN	C2STD
1	BM	A	1	811	48.7	72	5.2	22	4.1	116	8.6	89	10.3
1	BM	H	1	909	52.9	75	8.0	18	1.1	127	8.0	95	8.4
1	BM	I	1	876	36.2	59	5.7	46	3.8	78	6.0	92	6.8
1	BM	U	1	830	22.0	67	8.0	43	8.3	65	8.3	95	10.1
1	BM	A	2	611	16.6	57	6.9	16	2.3	89	11.7	70	5.7
1	BM	H	2	622	36.4	50	6.4	19	1.3	100	4.5	73	12.1
1	BM	I	2	630	22.6	58	6.3	28	4.0	76	12.2	88	9.2
1	BM	U	2	668	33.7	54	17.0	33	4.4	66	14.5	70	14.9
1	LB	A	1	842	21.8	80	2.2	44	6.4	122	1.7	99	8.2
1	LB	H	1	834	53.1	83	6.5	44	10.8	113	7.0	99	9.8
1	LB	I	1	785	22.9	80	3.4	28	7.7	88	7.0	94	6.7
1	LB	U	1	757	31.7	76	6.9	45	10.8	76	13.3	94	8.8
1	LB	A	2	696	25.0	58	18.7	28	7.1	111	4.0	79	4.6
1	LB	H	2	709	42.3	74	6.5	22	4.5	125	10.0	75	6.5
1	LB	I	2	705	17.4	80	3.3	21	4.0	81	6.5	87	5.2
1	LB	U	2	669	28.8	67	6.6	36	2.3	78	7.8	81	7.6
1	MR	A	1	991	65.8	84	5.2	44	8.4	99	13.8	96	4.5
1	MR	H	1	979	61.6	79	4.0	48	10.3	99	12.9	95	7.2
1	MR	I	1	997	45.3	83	3.8	38	3.6	72	8.8	96	3.5
1	MR	U	1	939	62.8	74	5.0	36	9.0	66	6.3	88	2.9
1	MR	A	2	738	28.9	66	5.6	31	3.3	82	12.7	79	14.1
1	MR	H	2	771	23.4	63	4.3	24	2.1	91	9.0	88	3.8
1	MR	I	2	762	34.2	68	8.1	36	4.7	56	7.3	77	10.9
1	MR	U	2	781	27.5	68	7.0	34	4.3	55	12.6	89	6.0
2	JL	A	1	1141	64.9	97	14.8	96	11.5	65	22.6	117	2.8
2	JL	H	1	1087	35.2	89	8.7	61	10.4	102	7.4	104	8.3
2	JL	I	1	1096	99.4	85	3.2	49	5.7	70	3.1	113	5.1
2	JL	U	1	1096	99.2	92	7.2	59	5.2	76	11.6	100	5.5

APPENDIX D (continued)

GROUP	SUBJECT	VOWEL	RATE	TCPMEAN	TCPSTD	C1MEAN	C1STD	VOTMEAN	VOTSTD	VOWELMN	VOWELSTD	C2MEAN	C2STD
2	JL	A	2	648	38.8	55	7.7	42	11.6	42	14.8	72	14.8
2	JL	H	2	747	86.0	48	8.9	36	16.3	67	8.4	77	11.6
2	JL	I	2	634	16.7	49	5.0	44	8.3	29	7.8	71	10.0
2	JL	U	2	666	35.7	51	5.9	48	10.1	33	7.6	86	7.5
2	MH	A	1	1125	108.8	83	18.2	48	7.5	131	11.7	127	8.8
2	MH	H	1	1017	41.5	78	13.7	36	8.4	117	4.0	127	18.4
2	MH	I	1	1099	53.1	72	4.5	64	14.1	73	12.8	124	12.5
2	MH	U	1	1106	111.6	85	6.7	41	6.1	96	10.4	111	24.3
2	MH	A	2	864	33.4	62	14.5	33	7.1	108	4.8	106	8.9
2	MH	H	2	798	45.3	67	11.3	34	4.1	101	7.5	111	16.9
2	MH	I	2	893	22.6	61	10.1	57	4.5	79	8.2	109	12.0
2	MH	U	2	895	56.5	70	4.1	44	9.3	76	9.9	95	18.3
2	PV	A	1	874	33.7	73	6.7	49	4.0	86	10.2	79	8.1
2	PV	H	1	973	45.9	83	5.3	49	9.1	104	3.8	110	9.3
2	PV	I	1	1011	75.0	82	7.3	54	10.2	65	8.0	105	6.8
2	PV	U	1	921	67.9	83	11.8	59	8.3	60	6.1	102	12.0
2	PV	A	2	594	47.4	60	7.0	26	9.8	72	7.9	88	16.0
2	PV	H	2	615	42.0	70	4.2	28	12.5	78	6.5	99	14.4
2	PV	I	2	626	48.2	65	7.9	31	6.7	58	2.9	95	9.8
2	PV	U	2	584	30.0	57	5.8	39	4.2	58	11.2	89	7.3
3	CD	A	1	1091	108.0	75	7.2	45	6.9	116	9.0	103	5.3

APPENDIX D (continued)

GROUP	SUBJECT	VOWEL	RATE	TCPMEAN	TCPSTD	C1MEAN	C1STD	VOTMEAN	VOTSTD	VOWELMN	VOWELSTD	C2MEAN	C2STD
3	CD	H	1	970	65.1	85	4.9	45	4.3	119	4.5	104	6.1
3	CD	I	1	1012	93.1	89	9.0	53	8.9	86	9.4	105	4.5
3	CD	U	1	991	68.7	99	8.6	38	6.3	75	14.4	101	17.0
3	CD	A	2	772	46.8	72	7.9	35	4.0	93	5.3	108	6.6
3	CD	H	2	772	28.0	69	7.3	33	2.6	96	13.2	83	7.2
3	CD	I	2	766	14.9	57	14.4	41	7.4	86	4.7	95	5.2
3	CD	U	2	754	26.0	80	3.9	30	8.7	72	7.6	90	10.5
3	JD	A	1	974	94.9	112	10.7	43	3.3	102	10.9	153	13.0
3	JD	H	1	1071	103.4	103	24.0	50	8.2	114	14.2	140	11.2
3	JD	I	1	1024	118.7	83	14.4	61	9.2	69	13.9	123	16.5
3	JD	U	1	996	118.0	112	18.7	47	5.4	92	14.1	132	21.6
3	JD	A	2	788	24.7	68	12.9	51	16.2	96	8.3	127	15.3
3	JD	H	2	848	59.1	85	5.9	37	9.2	113	6.6	117	8.0
3	JD	I	2	772	40.4	68	9.0	52	10.2	60	7.4	110	6.2
3	JD	U	2	835	79.5	89	8.8	45	2.8	88	13.5	105	13.5
3	OL	A	1	1240	129.6	72	14.8	44	9.0	101	23.3	146	9.7
3	OL	H	1	1112	74.4	75	11.8	56	5.0	119	5.1	147	12.2
3	OL	I	1	1158	91.0	86	11.5	51	7.9	66	7.9	135	13.9
3	OL	U	1	1305	9.1	85	3.5	65	2.1	71	0.0	149	14.8
3	OL	A	2	895	83.4	68	2.1	51	19.7	93	1.4	122	9.1
3	OL	H	2	875	56.2	74	9.5	51	3.5	91	8.7	160	22.0
3	OL	I	2	815	96.1	70	11.9	50	10.0	66	6.0	114	12.9
3	OL	U	2	876	106.3	66	10.4	55	8.5	75	8.3	102	17.8

KEY TO ABBREVIATIONS USED IN APPENDICES E AND F.

R = Rate

V = Vowel

In appendices E and F, the term "Group" is used in a different context than in Appendices C and D:

G1 = Analysis between 2 groups
Noncleft and Cleft

G2 = Analysis between 3 groups
Noncleft, High intelligibility cleft, and Low intelligibility cleft

APPENDIX E

Analysis of variance for mean total sentence duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	54660464.000000	54660464.000000	974.477	0.0000			
BETWEEN SUBJECTS	8	639848.625000						
G (GROUP)	2	303299.937500	151649.937500	2.704	0.1445			
G 1	1	249833.187500	249833.187500	4.454	0.0787			
G 2	1	53466.718750	53466.718750	0.953	0.3712			
SUBJECTS WITHIN GROUPS	6	336552.625000	56092.101563					
WITHIN SUBJECTS	63	1452266.000000						
R (RATE)	1	1213159.000000	1213159.000000	94.173	0.0001	0.0001	0.0001	0.0001
GR	2	67280.750000	33640.375000	2.611	0.1517	0.1517	0.1517	0.1517
G 1 R	1	53746.796875	53746.796875	4.172	0.0865	0.0865	0.0865	0.0865
G 2 R	1	13533.992188	13533.992188	1.051	0.3424	0.3424	0.3424	0.3424
R X SUBJ W GPS	6	77293.375000	12882.226563					
V (VOWEL)	3	83.266083	27.755356	0.010	0.9986	0.9986	0.9933	0.9244
GV	6	9735.539063	1622.589844	0.581	0.7428	0.7428	0.6985	0.5910
G 1 V	3	4237.167969	1412.389160	0.506	0.6856	0.6856	0.6345	0.5073
G 2 V	3	5498.371094	1832.790283	0.656	0.5925	0.5925	0.5530	0.4529
V X SUBJ W GPS	18	50284.660156	2793.592041					
RV	3	3932.171631	1310.723877	0.991	0.4237	0.4237	0.4079	0.3627
GRV	6	6690.636719	1115.105957	0.843	0.5567	0.5567	0.5318	0.4796
G 1 RV	3	6167.902344	2055.967285	1.554	0.2334	0.2334	0.2474	0.2571
G 2 RV	3	522.743408	174.247803	0.132	0.9404	0.9404	0.8856	0.7311
RV X SUBJ W GPS	18	23815.121094	1323.062256					

APPENDIX E (continued)

Analysis of variance for /p/ silence duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	395160.437500	395160.437500	1253.815	0.0000			
BETWEEN SUBJECTS	8	3608.687256						
G (GROUP)	2	1717.749023	858.874512	2.725	0.1428			
G 1	1	663.062012	663.062012	2.104	0.1957			
G 2	1	1054.687012	1054.687012	3.346	0.1162			
SUBJECTS WITHIN GROUPS	6	1890.999756	315.166504					
WITHIN SUBJECTS	63	9890.738281						
R (RATE)	1	5796.050781	5796.050781	33.890	0.0011	0.0011	0.0011	0.0011
GR	2	398.527588	199.263794	1.165	0.3710	0.3710	0.3710	0.3710
G 1 R	1	275.006592	275.006592	1.608	0.2499	0.2499	0.2499	0.2499
G 2 R	1	123.521118	123.521118	0.722	0.4322	0.4322	0.4322	0.4322
R X SUBJ W GPS	6	1026.164795	171.027466					
V (VOWEL)	3	214.278687	71.426224	1.305	0.3011	0.3011	0.3046	0.2946
GV	6	472.471191	78.745193	1.439	0.2525	0.2525	0.2837	0.3064
G 1 V	3	304.242432	101.414139	1.853	0.1725	0.1725	0.2022	0.2207
G 2 V	3	168.229309	56.076431	1.025	0.4021	0.4021	0.3810	0.3479
V X SUBJ W GPS	18	984.999268	54.722168					
RV	3	54.722107	18.240692	0.463	0.7137	0.7078	0.6075	0.5251
GRV	6	234.360901	39.060150	0.991	0.4641	0.4633	0.4465	0.4288
G 1 RV	3	193.964966	64.654984	1.641	0.2136	0.2155	0.2391	0.2457
G 2 RV	3	40.395935	13.465311	0.342	0.7969	0.7906	0.6791	0.5831
RV X SUBJ W GPS	18	709.165527	39.398071					

APPENDIX E (continued)

Analysis of variance for /p/ burst duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	128355.500000	128355.500000	466.324	0.0000			
BETWEEN SUBJECTS	8	4938.683594						
G (GROUP)	2	3287.189453	1643.594727	5.971	0.0371			
G 1	1	3287.107422	3287.107422	11.942	0.0134			
G 2	1	0.083333	0.083333	0.000	0.9868			
SUBJECTS WITHIN GROUPS	6	1651.499756	275.249756					
WITHIN SUBJECTS	63	7491.656250						
R (RATE)	1	2200.043213	2200.043213	25.582	0.0023	0.0023	0.0023	0.0023
GR	2	386.693359	193.346680	2.248	0.1854	0.1854	0.1854	0.1854
G 1 R	1	1.361172	1.361172	0.016	0.9047	0.9047	0.9047	0.9047
G 2 R	1	385.332275	385.332275	4.481	0.0781	0.0781	0.0781	0.0781
R X SUBJ W GPS	6	515.997803	85.999634					
V (VOWEL)	3	456.111328	152.037109	1.187	0.3401	0.3401	0.3355	0.3154
GV	6	279.470947	46.578491	0.364	0.8931	0.8931	0.8257	0.7115
G 1 V	3	147.054489	49.018158	0.383	0.7683	0.7683	0.6861	0.5621
G 2 V	3	132.416702	44.138901	0.345	0.7949	0.7949	0.7110	0.5816
V X SUBJ W GPS	18	2305.160889	128.064484					
RV	3	123.833069	41.277679	0.968	0.4334	0.4334	0.4054	0.3677
GRV	6	457.082275	76.180374	1.787	0.1574	0.1574	0.2041	0.2443
G 1 RV	3	11.916660	3.972219	0.093	0.9631	0.9631	0.8940	0.7721
G 2 RV	3	445.165527	148.388504	3.481	0.0373	0.0373	0.0715	0.1105
RV X SUBJ W GPS	18	767.331055	42.629501					

APPENDIX E (continued)

Analysis of variance for vowel periodicity duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	522923.437500	522923.437500	396.868	0.0000			
BETWEEN SUBJECTS	8	10405.308594						
G (GROUP)	2	2499.693359	1249.846680	0.949	0.4426			
G 1	1	458.673096	458.673096	0.348	0.5798			
G 2	1	2041.020264	2041.020264	1.549	0.2578			
SUBJECTS WITHIN GROUPS	6	7905.746094	1317.624268					
WITHIN SUBJECTS	63	25195.011719						
R (RATE)	1	2887.996338	2887.996338	18.261	0.0052	0.0052	0.0052	0.0052
GR	2	531.081787	265.540771	1.679	0.2617	0.2617	0.2617	0.2617
G 1 R	1	105.062408	105.062408	0.664	0.4502	0.4502	0.4502	0.4502
G 2 R	1	426.019531	426.019531	2.694	0.1508	0.1508	0.1508	0.1508
R X SUBJ W GPS	6	948.914795	158.152466					
V (VOWEL)	3	16376.390625	5458.796875	45.732	0.0000	0.0000	0.0000	0.0005
GV	6	666.970703	111.161774	0.931	0.5001	0.5001	0.4861	0.4484
G 1 V	3	603.408691	201.136230	1.685	0.2043	0.2043	0.2218	0.2402
G 2 V	3	63.562378	21.187454	0.178	0.9109	0.9109	0.8518	0.6905
V X SUBJ W GPS	18	2148.581787	119.365646					
RV	3	320.889160	106.963043	1.805	0.1811	0.1811	0.2099	0.2261
GRV	6	247.360977	41.226822	0.696	0.6589	0.6589	0.6001	0.5383
G 1 RV	3	166.131912	55.377304	0.934	0.4485	0.4485	0.4168	0.3756
G 2 RV	3	81.229065	27.076355	0.457	0.7178	0.7178	0.6275	0.5277
RV X SUBJ W GPS	18	1066.747803	59.263763					

APPENDIX E (continued)

Analysis of variance for /p/ silence + burst duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	755629.500000	755629.500000	583.079	0.0000			
BETWEEN SUBJECTS	8	20656.582031						
G (GROUP)	2	12881.179688	6440.589844	4.970	0.0529			
G 1	1	8587.105469	8587.105469	6.626	0.0418			
G 2	1	4294.074219	4294.074219	3.314	0.1177			
SUBJECTS WITHIN GROUPS	6	7775.582031	1295.930176					
WITHIN SUBJECTS	63	10899.113281						
R (RATE)	1	5033.386719	5033.386719	33.051	0.0012	0.0012	0.0012	0.0012
GR	2	43.361465	21.680725	0.142	0.8711	0.8711	0.8711	0.8711
G 1 R	1	38.028137	38.028137	0.250	0.6377	0.6377	0.6377	0.6377
G 2 R	1	5.333340	5.333340	0.035	0.8588	0.8588	0.8588	0.8588
R X SUBJ W GPS	6	913.750000	152.291656					
V (VOWEL)	3	455.661377	151.887115	1.587	0.2256	0.2256	0.2400	0.2527
GV	6	756.914795	126.152466	1.318	0.2972	0.2972	0.3127	0.3329
G 1 V	3	261.832520	87.277496	0.912	0.4587	0.4587	0.4378	0.3810
G 2 V	3	495.082275	165.027420	1.725	0.1963	0.1963	0.2146	0.2354
V X SUBJ W GPS	18	1722.416748	95.689819					
RV	3	28.499924	9.499974	0.109	0.9542	0.9542	0.9299	0.7546
GRV	6	372.082031	62.013672	0.710	0.6488	0.6488	0.6270	0.5323
G 1 RV	3	130.249939	43.416641	0.497	0.6913	0.6913	0.6582	0.5109
G 2 RV	3	241.832550	80.610840	0.922	0.4539	0.4539	0.4431	0.3785
RV X SUBJ W GPS	18	1572.916016	87.384216					

APPENDIX F

Analysis of variance for standard deviation values for total sentence duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	215145.312500	215145.312500	291.299	0.0000			
BETWEEN SUBJECTS	8	20383.242188						
G (GROUP)	2	15951.855469	7975.925781	10.799	0.0102			
G 1	1	12674.964844	12674.964844	17.161	0.0060			
G 2	1	3276.890625	3276.890625	4.437	0.0792			
SUBJECTS WITHIN GROUPS	6	4431.429688	738.571533					
WITHIN SUBJECTS	63	46797.195313						
R (RATE)	1	12121.199219	12121.199219	10.133	0.0189	0.0189	0.0189	0.0189
GR	2	1081.746094	540.873047	0.452	0.6588	0.6588	0.6588	0.6588
G 1 R	1	951.724609	951.724609	0.796	0.4110	0.4110	0.4110	0.4110
G 2 R	1	130.021576	130.021576	0.109	0.7546	0.7546	0.7546	0.7546
R X SUBJ W GPS	6	7177.164063	1196.193848					
V (VOWEL)	3	260.673096	86.891022	0.192	0.9011	0.9011	0.8352	0.6788
GV	6	2578.067139	429.677734	0.950	0.4885	0.4885	0.4754	0.4420
G 1 V	3	1412.996582	470.998779	1.042	0.3951	0.3951	0.3799	0.3443
G 2 V	3	1165.070557	388.356689	0.859	0.4840	0.4840	0.4562	0.3942
V X SUBJ W GPS	18	8138.054688	452.114014					
RV	3	1995.217529	665.072510	1.686	0.2042	0.2042	0.2221	0.2401
GRV	6	6342.710938	1057.118408	2.679	0.0485	0.0485	0.0782	0.1463
G 1 RV	3	1427.721680	475.907227	1.206	0.3335	0.3335	0.3304	0.3119
G 2 RV	3	4914.992188	1638.330566	4.152	0.0210	0.0210	0.0394	0.0871
RV X SUBJ W GPS	18	7102.164063	394.564453					

APPENDIX F (continued)

Analysis of variance for standard deviation values for /p/ silence duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	5070.226563	5070.226563	160.456	0.0000			
BETWEEN SUBJECTS	8	331.436279						
G (GROUP)	2	141.846924	70.923462	2.245	0.1858			
G 1	1	104.039581	104.039581	3.293	0.1187			
G 2	1	37.807434	37.807434	1.196	0.3137			
SUBJECTS WITHIN GROUPS	6	189.592651	31.598770					
WITHIN SUBJECTS	63	1050.334717						
R (RATE)	1	4.499952	4.499952	0.314	0.5982	0.5982	0.5982	0.5982
GR	2	101.930405	50.965195	3.561	0.0949	0.0949	0.0949	0.0949
G 1 R	1	94.089661	94.089661	6.574	0.0424	0.0424	0.0424	0.0424
G 2 R	1	7.840754	7.840754	0.548	0.4909	0.4909	0.4909	0.4909
R X SUBJ W GPS	6	85.878632	14.313105					
V (VOWEL)	3	26.342651	8.780884	0.619	0.6143	0.6143	0.5503	0.4651
GV	6	136.827820	22.804626	1.609	0.2005	0.2005	0.2377	0.2738
G 1 V	3	50.037125	16.679031	1.177	0.3438	0.3438	0.3379	0.3174
G 2 V	3	86.790695	28.930222	2.041	0.1431	0.1431	0.1747	0.2016
V X SUBJ W GPS	18	255.173798	14.176322					
RV	3	36.361069	12.120356	0.645	0.5989	0.5887	0.5143	0.4564
GRV	6	65.177902	10.862984	0.578	0.7447	0.7322	0.6531	0.5923
G 1 RV	3	49.753769	16.584579	0.883	0.4725	0.4680	0.4247	0.3882
G 2 RV	3	15.424160	5.141386	0.274	0.8447	0.8297	0.7179	0.6224
RV X SUBJ W GPS	18	338.140137	18.785553					

APPENDIX F (continued)

Analysis of variance for standard deviation values for vowel periodicity duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	5713.785156	5713.785156	242.108	0.0000			
BETWEEN SUBJECTS	8	143.136230						
G (GROUP)	2	1.535874	0.767937	0.033	0.9684			
G 1	1	0.030624	0.030624	0.001	0.9726			
G 2	1	1.505250	1.505250	0.064	0.8104			
SUBJECTS WITHIN GROUPS	6	141.601074	23.600174					
WITHIN SUBJECTS	63	1127.769775						
R (RATE)	1	20.908813	20.908813	4.915	0.0680	0.0680	0.0680	0.0680
GR	2	45.730148	22.865067	5.375	0.0456	0.0456	0.0456	0.0456
G 1 R	1	36.099991	36.099991	8.486	0.0267	0.0267	0.0267	0.0267
G 2 R	1	9.630163	9.630163	2.264	0.1818	0.1818	0.1818	0.1818
R X SUBJ W GPS	6	25.523254	4.253876					
V (VOWEL)	3	87.485825	29.161942	1.546	0.2354	0.2418	0.2567	0.2583
GV	6	61.866165	10.311028	0.546	0.7680	0.7468	0.6671	0.6082
G 1 V	3	25.872299	8.624100	0.457	0.7177	0.6928	0.5985	0.5276
G 2 V	3	35.993881	11.997960	0.636	0.6044	0.5852	0.5135	0.4595
V X SUBJ W GPS	18	339.624268	18.868011					
RV	3	89.897537	29.965836	1.458	0.2574	0.2574	0.2634	0.2707
GRV	6	86.869461	14.478243	0.705	0.6525	0.6525	0.6306	0.5345
G 1 RV	3	80.050568	26.683517	1.299	0.3032	0.3032	0.3048	0.2958
G 2 RV	3	6.818933	2.272977	0.111	0.9531	0.9531	0.9287	0.7526
RV X SUBJ W GPS	18	369.869385	20.548294					

APPENDIX F (continued)

Analysis of variance for standard deviation values for /p/ burst duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	3653.689453	3653.689453	265.965	0.0000			
BETWEEN SUBJECTS	8	208.366180						
G (GROUP)	2	125.943192	62.971588	4.584	0.0615			
G 1	1	112.183044	112.183044	8.166	0.0287			
G 2	1	13.760147	13.760147	1.002	0.3530			
SUBJECTS WITHIN GROUPS	6	82.424774	13.737462					
WITHIN SUBJECTS	63	762.539307						
R (RATE)	1	1.306806	1.306806	0.097	0.7679	0.7679	0.7679	0.7679
GR	2	94.846741	47.423370	3.515	0.0969	0.0969	0.0969	0.0969
G 1 R	1	84.486542	84.486542	6.262	0.0460	0.0460	0.0460	0.0460
G 2 R	1	10.360209	10.360209	0.768	0.4188	0.4188	0.4188	0.4188
R X SUBJ W GPS	6	80.949844	13.491640					
V (VOWEL)	3	20.552597	6.850865	0.637	0.6037	0.6037	0.5644	0.4591
GV	6	109.078354	18.179718	1.691	0.1794	0.1794	0.2057	0.2597
G 1 V	3	43.927872	14.642624	1.362	0.2842	0.2842	0.2891	0.2854
G 2 V	3	65.150497	21.716827	2.019	0.1462	0.1462	0.1670	0.2036
V X SUBJ W GPS	18	193.564636	10.753591					
RV	3	38.001495	12.667165	1.435	0.2636	0.2636	0.2743	0.2741
GRV	6	65.332855	10.888809	1.233	0.3330	0.3330	0.3456	0.3533
G 1 RV	3	39.515640	13.171880	1.492	0.2486	0.2486	0.2620	0.2658
G 2 RV	3	25.817230	8.605743	0.975	0.4306	0.4306	0.4094	0.3662
RV X SUBJ W GPS	18	158.906479	8.828137					

APPENDIX F (continued)

Analysis of variance for standard deviation values for /p/ silence + burst duration.

	DF	SS	MSS	F	P	P(E*-ADJ)	P(E-ADJ)	P(CONSV)
MEAN	1	7550.136719	7550.136719	108.256	0.0000			
BETWEEN SUBJECTS	8	630.850586						
G (GROUP)	2	212.393433	106.196716	1.523	0.2897			
G 1	1	210.008301	210.008301	3.011	0.1324			
G 2	1	2.385240	2.385240	0.034	0.8604			
SUBJECTS WITHIN GROUPS	6	418.459961	69.743317					
WITHIN SUBJECTS	63	992.901855						
R (RATE)	1	10.503573	10.503573	0.394	0.5567	0.5567	0.5567	0.5567
GR	2	29.795212	14.897606	0.558	0.6022	0.6022	0.6022	0.6022
G 1 R	1	1.120045	1.120045	0.042	0.8456	0.8456	0.8456	0.8456
G 2 R	1	28.675171	28.675171	1.075	0.3374	0.3374	0.3374	0.3374
R X SUBJ W GPS	6	160.097015	26.682831					
V (VOWEL)	3	135.323471	45.107819	2.642	0.0800	0.0800	0.1220	0.1541
GV	6	80.553909	13.425652	0.786	0.5948	0.5948	0.5469	0.5010
G 1 V	3	35.431732	11.810577	0.692	0.5720	0.5720	0.5059	0.4415
G 2 V	3	45.122177	15.040726	0.881	0.4733	0.4733	0.4334	0.3886
V X SUBJ W GPS	18	307.285156	17.071396					
RV	3	41.768188	13.922729	1.790	0.1837	0.1881	0.2168	0.2277
GRV	6	87.601273	14.600212	1.878	0.1392	0.1466	0.1978	0.2310
G 1 RV	3	64.439011	21.479660	2.762	0.0715	0.0770	0.1189	0.1465
G 2 RV	3	23.162277	7.720758	0.993	0.4228	0.4212	0.3907	0.3622
RV X SUBJ W GPS	18	139.968826	7.776046					

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