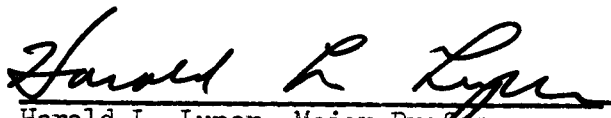
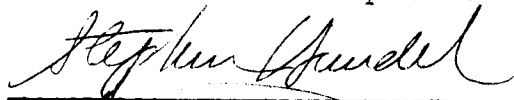


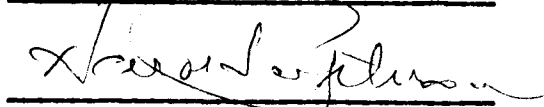
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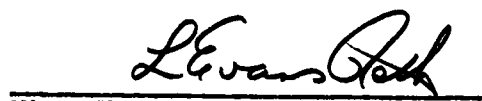








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AN ACOUSTICAL STUDY OF FLUENT SPEECH
IN STUTTERERS AND NONSTUTTERERS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

C. Rebekah Hand

December 1979

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ABSTRACT

The research investigated coarticulatory timing and attainment of frequency targets in perceptually fluent utterances of adult, male stutterers and nonstutterers. The specific acoustic characteristics assessed were: voice onset time; transition, steady-state, and total vowel durations; velocity of movement through the transitions; and the amount of the shift in frequency across the consonant in selected V_1CV_2 sequences. These characteristics were assessed in two rate conditions: (1) the speaker's own judgment of a normal rate of speech, and (2) a fast rate of speech. A fast rate was operationally defined as a minimum of two seconds shorter than the time to complete five repetitions of the experimental utterance at a normal rate.

Recordings were made of each subject reading a constant carrier phrase into which a changing medial bisyllable was embedded ("Say the word ____ please"). The bisyllabic stimuli consisted of a vowel-consonant-vowel, in which the voiced plosives, /b, g/, and the vowels, /i, u/, were used. Four symmetric and four asymmetric stimuli were thus constructed.

Wideband, linear-expand spectrograms were made of the recorded stimulus items. Only fluent (medial) repetitions were analyzed for acoustic characteristics.

Temporal delays, as measured at the second formant, occurred within the speech intervals of voice onset time, vocalic transitions, and steady-state portions. The data concerning stutterers' velocity of movement, although equivocal, suggest adequate articulatory speed at

normal rates of speech. The specific conclusions, regarding group differences, drawn from the results of this study are:

1. Stutterers differ significantly from nonstutterers in voice onset time. The observed difference was approximately 4 msec at a normal rate of speech and 6 msec at a fast rate.

2. Stutterers, on the average, spent less time in vocalic transitions than did nonstutterers. At normal rates stutterers' transitions averaged 6 to 8 msec less than nonstutterers. At fast rates the two groups performed similarly, as stutterers exhibited up to 3 msec shorter transitions.

3. Stutterers averaged longer steady-state durations than nonstutterers. At normal rates stutterers' steady-state portions averaged 7 to 13 msec longer, while at fast rates differences were approximately 11 to 12 msec longer than those of nonstutterers.

4. The durations of the total vocalic elements were comparable between stutterers and nonstutterers. Greater similarities were observed at normal speaking rates than at fast rates.

5. Results regarding overall velocity of the transitional movement are equivocal. There was a tendency for stutterers to exhibit smaller velocities and this difference was even greater at fast rates of speech.

6. Stutterers did not differ significantly from nonstutterers in the amount of frequency shift across the consonant in the V_1CV_2 sequences.

In as much as physiological movement can be inferred from changes in the acoustic signal, the observed results suggest that temporal disruptions exist in the perceptually fluent speech of stutterers. These disruptions in timing were observed in articulatory-phonatory and

steady-state patterns. Stutterers were apparently able to produce transitional shifts appropriate to the phonetic environment, but they appeared to delay the initiation of these coarticulatory movements. The results are discussed within the framework of two hypotheses. Aberrant speech timing may suggest an involvement in the planning or integration of articulatory/coarticulatory movements rather than difficulties with movement execution. An alternate hypothesis that aberrant speech timing is only one aspect of a Central Nervous System timing disruption is explored. Future research needs to investigate this relationship are put forth.

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CHAPTER I

INTRODUCTION, REVIEW OF THE LITERATURE AND STATEMENT OF THE PROBLEM

I. INTRODUCTION

Coarticulation is a process whereby the properties of a speech segment are altered due to the influences exerted on it by neighboring segments (Hammarberg, 1977). A single acoustic segment therefore carries information about preceding and succeeding phonological segments. The latter process has been termed forward coarticulation (a right to left, or anticipatory influence) and has been posited to be the result of a preprogrammed mechanism which scans the sequence and overlaps articulatory gestures of the following phones when they are not in conflict (Henke, 1962; Daniloff and Hammarberg, 1973; Daniloff and Moll, 1968).

Acoustical studies of coarticulation using the human speech spectrum typically have analyzed systematic changes in the parameters of frequency, intensity, and duration (Black, 1939; House and Fairbanks, 1953; Lindblom, 1963; Öhman, 1966; Peterson and Lehiste, 1960). Acoustic analyses have also been performed on a variety of speech disorders to increase understanding of the vocal tract function and possible underlying systems of motor control. Formant locations, frequency transitions, intensity, and durational changes have been investigated in voice disorders (Cooper, 1974; Wolfe and Bacon, 1976), articulation disorders (Faircloth and Faircloth, 1970), apraxia of speech (Hamre and Harn, 1977), and the speech of the deaf (Angelocci, Kopp, and Holbrook, 1964; Monsen, 1976).

Wingate (1969) defined stuttering as a "phonetic transition defect" in that stutterers have difficulty, not on a particular sound, but in passing beyond or onto the next sound. Wingate however did not enumerate the actual defective parameters in the transition, nor provide data to substantiate his definition. Several investigators (Adams, 1978a; Adams and Reis, 1971; Adams, Lewis, and Besozzi, 1973; Manning and Coufal, 1976) concur with Wingate's notion of a transition defect and likewise view stuttering as a deficit in motor sequencing ability.

Acoustical investigations of stuttered speech seem to substantiate the existence of transitional differences, although such studies suffer from lack of controlled methods of measurement (Adams, 1978a; Agnello, 1966; Montgomery and Cooke, 1976; Stromsta, 1965). If one accepts the notion that stuttered speech often lacks normal transitional movements, as posited by these investigators, then the next logical question arises: Is the preprogrammed mechanism governing forward coarticulation (1) chronically aberrant in stutterers or (2) just prone to intermittent asynchrony? In the first situation, one would expect the frequency, duration, and/or intensity parameters of stutterers' disfluent and fluent utterances to be different from those of nonstutterers. In the second situation one would expect these acoustic parameters to be similar in stutterers' fluent productions to those of nonstutterers. Frequency, duration, or intensity differences would become apparent only during a stutterer's disfluencies or when the stutterer is forced to speak in a manner which strains his own system's competence for

coordination of coarticulatory movements, perhaps as during rapid rates of speech.¹

Adams' (1978b) viewpoint appears consistent with the second situation in that no acoustic differences would be expected. He stated that fluent utterances produced by normals and stutterers are consistently associated with the prompt, smooth initiation and maintenance of voicing, and the integration of respiration, phonation, and articulation.

In contrast, the available evidence suggests that differences, in at least some parameters, do exist between nonstutterers' and stutterers' perceptually fluent utterances. Wendahl and Cole (1961) deleted the disfluent speech of stutterers from recorded samples to see if listeners perceptually would judge the remainder as normal. These modified samples were detected as different and were judged to be characterized by poorer rate, greater force, and less rhythm than normal speech. Young (1964) duplicated the study by Wendahl and Cole, but obtained different results. Namely, listeners could not distinguish stutterers from nonstutterers by listening to their fluent speech. Similar results were obtained by Few and Lingwall (1972), indicating a lack of perceivable difference. However Allen, Peters, and Williams (1975) contend that the binomial test statistic used by Few and Lingwall was inappropriate. A reanalysis of the data using Chi-square showed that listeners were indeed able to identify the speaker's fluency

¹This notion of "competence" for coarticulatory movements was put forth by Starkweather (1978) as a possible explanation for enhanced fluency in speaking situations using reduced rate. Perhaps stutterers tend to be disfluent when speaking at rates which surpass their system's reaction time ability.

classification. The question of whether listeners can perceive the difference between stutterers' and nonstutterers' speech therefore remains open. The physical characteristics of stutterers' fluent speech, as studied acoustically and physiologically, have supplied some evidence that stutterers employ slower speech movements.

Studies of voice onset time and voice termination time have shown consistently that stutterers' perceptually fluent utterances are characterized by slower articulatory release and voicing onset/termination (Agnello, 1975; Hillman and Gilbert, 1977). Starkweather and Myers (1978) expanded the study of durational differences by measuring subsegmental durations within an intervocalic interval (IVI) produced by nonstutterers and stutterers. After only preliminary data analysis of one IVI, Starkweather and Myers reported that stutterers are indeed slower in their rate of movement, and speculated that it is only these non-steady-state portions which are lengthened (i.e., the transitions). Further investigation of subsegmental durational differences is warranted. In particular, additional intervocalic intervals need to be studied before concluding that the temporal disruptions can be attributed to the transitions.

Zimmermann (1979), using cineradiography, investigated temporal and spatial patterning of lip and jaw movements during fluent syllabic utterances of stutterers and nonstutterers. Stutterers reportedly took longer time within and between articulatory gestures than did nonstutterers.

Zimmermann's (1979) results, the work of Starkweather and Myers (1978), and the results of several voice onset investigations (Agnello, 1975; Hillman and Gilbert, 1977; Metz, Conture, and Caruso, 1978), do

indicate that some differences exist in the fluent speech of stutterers. The acoustic parameter of frequency, an indirect representation of vocal tract shape and movement, has yet to be investigated in fluent productions of stutterers. Coarticulatory effects are typically observed in the frequency, intensity, and duration of neighboring speech segments, and to conclude that coarticulatory differences exist after only durational measures have been collected would be premature.

The present study was designed to obtain acoustic information on fluent utterances of the effects of various phonetic environments and rates of speech. More specifically, vowel-consonant-vowel bisyllables were studied in order to specify the nature of coarticulatory effects in terms of second formant frequency transitions and of subsegmental durations in the speech of adult stutterers and nonstutterers.

II. REVIEW OF THE LITERATURE

The conceptualization that stuttering is associated with incoordination of the respiratory, phonatory, and/or articulatory processes of speech is certainly not new. In particular, Arnott in 1827 (cited by Kenyon, 1940) attributed stuttering to a delay in vocalization. Recent research has confirmed vocalization onset delay in stutterers and has noted that the delays characterize fluent as well as disfluent utterances of stutterers (Agnello, 1975; Hillman and Gilbert, 1977). Attempts have also been made to identify more specifically the level in the speech production process when factors such as onset, rate, and duration of steady state and transitional movements may differ between stutterers and nonstutterers. A basic

knowledge of the state of the art of research in normal adult speech is necessary to the understanding of durational and transitional differences of stutterers as a group.

Coarticulatory Studies of Adult Speech

Acoustical studies of coarticulation typically investigate changes in the parameters of frequency, intensity, and duration as a function of systematically controlled conditions of phonetic environments and/or rate of speech. Öhman (1966) studied coarticulation in vowel-voiced stop consonant-vowel (VCV) utterances by normal speakers of Swedish, American English, and Russian. Acoustic analysis, using wideband sound spectrograms, showed that second formant (F2) transitions of a vowel varied depending on the particular vowel which followed or preceded it. In the case of anticipatory coarticulation, the articulatory motion from the initial vowel into the stop consonant, as inferred by the formant transitions, was observed to be modified by the vowel that followed the consonant. Öhman also demonstrated acoustically the converse situation. When the final vowel was kept constant and initial vowel was varied, the formant transition of the final vowel changed. Thus the initial vowel's influence crossed the intervocalic consonant to affect the final vowel's transition. Backward or carry-over coarticulation occurred over two phones.

Öhman (1966) also demonstrated acoustically that forward coarticulatory movements toward the second vowel in VCV utterances coincided in time with movement toward the consonantal closure. He concluded that speech production proceeds as vowel to vowel gestures with consonants superimposed on this vowel substrate. Conceivably, if

stutterers' coarticulatory movements are delayed in time, then transitions toward the second vowel would be absent or considerably reduced at the end of the formant of the first vowel (i.e., the tongue had not yet begun movement toward the second vowel at the time of consonantal closure).

Daniloff and Moll (1968) utilized cineflourography to determine over how many phones in a string the forward coarticulatory lip-rounding gesture for the vowel /u/ could be observed in normal speaking adults. The effects of rate of utterance and location of word and syllable boundaries also were studied. Frame-by-frame analyses of the rounded vowel, embedded in meaningful stimuli, showed that articulator movement onsets overlapped other phone gestures. Coarticulation extended over four consonants in the string "construe," an observation that was interpreted as evidence for a "look ahead" mechanism in speech production. When a nonspecified goal for a feature occurs, the system apparently looks ahead to the next specified goal and prepares for that gesture. Coarticulation was not affected by syllable or word boundaries but was said to have been enhanced at fast speaking rates.

Kuehn (1976) utilized cineflourography to investigate coarticulation as a function of phonetic environment and rate of speech. At fast rates of speech there was undershoot of articulator displacement (the velum) and reduced durations of the articulatory gestures.

More recently, Gay (1978) used spectrographic analysis to determine the effects of rate on the attainment of vowel targets, and the relative time and speed of movements toward these presumed targets. Normal adult speakers uttered CVC and CVCVC stimuli in the carrier phrase, "It's a ____ again." Two rates of speech were studied, one

normal (or slow) and one fast, with both determined by each speaker's own judgment of natural slow and fast rates. Wideband spectrograms were made from the subjects' recordings. Duration measurements were made for the stop gap closure of the initial consonant, the CV transition, vowel nucleus, and closure for the final consonant. Formant frequency measurements of formant one (F1), formant two (F2), and formant three (F3) were made at the time of release of the initial consonant, the vowel midpoint, and the time of closure for the final consonant.

The reduction in syllable durations that was obtained during fast speaking rates was obtained primarily by reducing the duration of the vowel. Differences in the durations of the vowel nuclei for normal and fast speech ranged from 20 to 35 msec, depending on the particular vowel. The consonant segments were also consistently shorter. The contributions of the initial and final consonants accounted for one-third of the total reduction in syllable durations. The transition durations within each rate were relatively stable across the different vowels; however, transition time was reduced during the fast rate by about 5 to 10 msec. Transition times ranged from 40 to 50 msec for the normal rate and 35 to 45 msec for the fast rate condition.

Additionally, the acoustic targets of vowels, as measured at formant frequency midpoints, did not vary with rate in this investigation. To achieve such consistency at both rates, the articulatory gesture was modified by (1) beginning articulator movement toward the vowel target earlier, i.e., closer to the time of initial consonant closure, and (2) producing the movement at a faster rate of speed. The first modification was seen spectrographically when the onset frequency of the formant transition appeared closer to that of the

target frequency for faster speech. An estimation of the second modification was the overall velocity of the formant transition itself (rate of change calculated by dividing the difference between the F2 onset and F2 midpoint frequencies by the transition duration). All subjects appeared to utilize higher onset frequencies of F2 during the fast rate condition; F2 rates of change were essentially unaffected across the two rates.

The results of these studies using normal speaking adults, indicate that coarticulation is an observable phenomenon through the use of cineflourography or sound spectrography. Furthermore these studies also suggest that the degree of coarticulation is a function of, among other things, phonetic environment and rate of speech.

Acoustic Characteristics of Stuttered Speech

Acoustic manifestations of stuttered speech have not been widely published. Of the studies reported, most have failed to employ rigorous experimental controls, predetermined speech stimuli for inter-subject comparison, or controlled methods of measurement rather than mere visual inspection. Despite these design inadequacies, there appears a consensus that stuttered speech is characterized by disrupted coarticulation.

Agnello (1975) cited previous research by Agnello and Goehl in which spectrograms of stuttered speech were analyzed. Results were: (1) less variance in formant structures; (2) compressed frequency toward the lower part of the spectrum; (3) compressed time during phonation; (4) difficulty in coordinating the glottal source with specific articulatory juncture; and (5) more discrete segments which

suggested coarticulation failure. In particular, Agnello stated that there was a high degree of variance in the second formant pattern during the period of disfluency. Furthermore, the more severe the stuttering, the more the likelihood of a definite formant pattern in which F1 and F2 are parallel and lowered.

Montgomery and Cooke (1976) reported that 62 percent of the CV transitions, spliced from recordings of stuttered conversational speech of 16 stutterers, differed in the "rate and/or extent of formant movement" when compared with fluent productions of the same word. However no specific formant measurements were made other than a subjective judgment of same-different based on visual inspection of wideband spectrograms. Measurements were made however on the durations of consonants in stuttered speech as compared to the fluent productions. Longer consonant durations characterized the disfluent word. Once the initial consonant in the stuttered word was finished, the remainder of the stuttered word was almost identical in duration to the corresponding portion of the fluent word.

Williams (1974) made observations on the "direction, height, and presence" of the first three formants of stuttered and fluent words spliced from tape recorded repeated readings of the "My Grandfather" passage. The formants were subjectively studied before, during, and after the specified phoneme in the samples judged to be disfluent. The formant patterns of these stuttered samples were then compared and subjectively judged to be like or unlike the fluent patterns. Williams concluded that there did not appear to be a significant difference between the transitions of the stuttered and fluent samples. When differences in transitions were noted, it was difficult, according to

Williams, to tell if the differences were due to normal variations of articulation between readings. Specifically it was noted that in stuttered reading, the formants were changing before the stuttered word, even though they terminated abruptly. This observation of formant movement into the moment of stuttering, including prolongations, contradicts most opinions in the literature.

Adams (1978a) investigated transitions between adjacent articulatory events on either side of a word boundary. A single part-word repetition spliced from the taped recording of a prose reading of one subject revealed lack of transition between articulatory events within the syllable preceding the perceptible disfluency, absence of acoustic output between syllables, and "hard" onset of succeeding phoneme which was then repeated (part-word repetition). The results reported in this study are descriptive in nature as no specific measurements were made. Adams, in a footnote, mentioned that spectrograms of nonstutterers did not show similar acoustic events, however no normative data were provided.

Stromsta (1965) also noted transitional abnormalities in disfluent speech samples of children. The disfluencies had been labeled as stuttering by the parents. The identified samples of disfluency were spectrographically analyzed and the visual displays categorized on a forced-choice basis by judges as (1) displaying formant transitions and normal terminations of phonation, or (2) displaying a lack of formant transitions and/or abnormal terminations of phonation. Ten years later questionnaires were mailed to the parents to collect follow-up information on the speech of the children. The data reported were based on 38 returned questionnaires. Of 27 spectrographic analyses judged previously

as abnormal, 24 cases were reported to be stuttering 10 years later. Stromsta concluded that abnormal formant transitions and terminations of phonation suggest a chronicity of stuttering in children.

Substitution of the schwa vowel for the appropriate vowel has been reported in the literature. Van Riper (1971) provided anecdotal reports of the prevalence of the schwa vowel in the repetitive abortive releases of many stutterers and attributed this behavior to a "searching and hunting for the appropriate transition." Furthermore, he discussed the substitution of the schwa as indicating further development of the disorder and the possibility of perpetuating stuttering on a more permanent basis.

Allen, Peters, and Williams (1975) commented that there is some confusion in thinking that substitution of the schwa vowel is the reason for the lack of proper articulatory movement as reflected in formant transitions. They stated that there should be virtually as much movement of the articulators and formants when a consonant is released into a schwa vowel as into any other vowel. They posited that the reason for a lack of transitions is more likely a simultaneous glottal stop, which inhibits voicing during the transition period. Similarly Gautheron, Liorzou, Even, and Vallancien (1973) stated that substitution of a glottal catch, in stuttered speech, occurs often (in 60 percent of the cases) in the transition from a consonant to a vowel.

Likewise, a perceptual study performed by Montgomery and Cooke (1976) seriously questions the prevalence of the schwa vowel in stuttered speech. Part-word repetitions (CV) were spliced from tapes of conversational speech. The CV segments were played to five judges who were to transcribe the vowel they perceived. Confusion matrices

of intended versus perceived vowel were set up. Perceptually, stutterers did not produce the schwa very frequently in repetitions. Less than 25 percent were perceived as schwas with the vast majority of schwa confusions occurring when either /ʒ/ or /aɪ/ was intended.

Another acoustic characteristic of stuttered speech was discussed by Van Riper (1971). Vocal fry and intermittent bits of weak phonation are said to occur frequently in severe stutterers and have been posited as a searching behavior to loosen laryngeal closure and emit the word (Van Riper, 1971). Spectrographic recordings of vocal fry prolongations, according to Van Riper, do not have transitional components until just prior to the release of the word.

Similarly, Allen, Peters, and Williams (1975) noted that glottalization was a frequently observed acoustic characteristic in the disfluent and perceptually fluent speech of stutterers. Two criteria for the spectrographic identification of glottalization were used: (1) the release of glottal stops or the unaspirated release of non-glottal stops; and (2) an irregular pattern of glottal pulses during sustained phonation.

Agnello (1966), as cited by Van Riper (1971), reported that acoustic pause characteristics of the stuttering disfluencies of stutterers differed from their normal speech disfluencies. The intersyllabic pauses were longer and more variable during stuttering. In contrast, Van Riper (1971) stated that the pauses between syllables are much shorter in stuttered repetitions. He suggested that these pause characteristics distinguish the abnormal from the normal syllabic repetitions. Finally, Love and Jeffress (1971) reported that there were more 150 to 250 msec pauses than normal in stutterers' fluent speech. The nature of pause

characteristics in the fluent and disfluent speech of stutterers has not been clearly identified and current evidence seems contradictory.

In summary, studies and conceptualizations investigating the acoustic characteristics of stuttered speech indicate that formant transitions appear to be abnormal, although specific measurements have not been made. In addition, disfluent speech may be characterized by abnormal termination of phonation, substitution of the schwa vowel in repetitions, and vocal fry phonation during prolongations, although contradictory evidence exists. It has also been posited that these acoustic characteristics may indicate chronicity of a stuttering disorder when observed in a child. Finally, studies suggest that a primary focal point of stuttering may be in effecting appropriate movement and timing relationships within the speech production process.

Temporal Patterns of Stutterers' Fluent Speech

Disruptions in the timing of articulatory-phonatory patterns of the fluent speech of stutterers have recently been investigated. Voice onset time (VOT) studies have indicated that stutterers are slower than nonstutterers in initiating voicing in conjunction with supraglottal articulatory events. Preliminary work has been done to discover where the temporal delays occur within a specified interval of speech. Temporal and spatial patterning of specific articulatory gestures also have been undertaken to describe coarticulatory parameters in the fluent utterances of stutterers as compared to nonstutterers.

Agnello (1975) used simultaneous intraoral pressure tracings and spectrograms for timing measurements. Voice onset time (VOT) was defined as the time from which the point of the pressure trace began

its greatest drop to the point of the first glottal pulse of the open vocalic period. Voice termination time (VTT) was defined as the time from glottal arrest (last pulse) to the point of maximum excursion of the pressure trace from baseline. The monosyllables /pa, ba, ap, ab/ were read three times by each of 23 stutterers and 23 nonstutterers. Only fluent syllables were analyzed. Stutterers, as a group, employed longer voice onset and voice termination times. VTT appeared to contribute most to the observed significant differences.

Hillman and Gilbert (1977) measured the duration of VOT for voiceless stop consonants in the fluent readings of 10 adult stutterers and 10 nonstutterers. Intervocalic voiceless stop consonant segments in unstressed contexts were spliced from recorded readings of the "Rainbow" passage and displayed on wideband spectrograms. Results of VOT measurements obtained indicated that stutterers displayed longer VOT values than did nonstutterers (averaged 9 msec longer). Furthermore VOT values increased in duration as place of articulation of the stop consonants moved back in the oral cavity for both stutterers and nonstutterers.

Gautheron, Liorzou, Even, and Vallancien (1973) analyzed conversational speech of four stutterers by means of a microphone and an electrical glottograph in conjunction with a double track oscillograph. The researchers proposed a lack of phono-articulatory synergy with sustained laryngeal tension in stutterers as the silence between the consonant and the vowel was always longer than that obtained with normal speakers. In the example /ʃa/, frication was followed by a 100 msec silence before the vowel was uttered by a stutterer. In nonstutterers the noise of frication was immediately followed by the vowel.

Voice onset time and durations of frication and aspiration in stutterers' fluent speech were further investigated by Metz, Conture, and Caruso (1978). Five adult stutterers and five nonstutterers read 72 monosyllabic English words embedded in the carrier phrase, "Say ____ again." The word list consisted of 18 word-initial stop consonants and stop consonant clusters, followed by the vowels /i/, /e/, /ɛ/, or /u/. Broadband spectrograms were made of the test words. The VOT interval was defined using Klatt's (1975) criteria, as the release (burst of noise) of the plosive consonant to the onset of voicing, identified by regularly appearing vertical striations in the second and higher formants. By measuring from F2, instances of prevoicing were excluded from consideration. A secondary segmentation of the VOT interval was made on target words containing initial /t/ and /k/ phonemes. Frication burst, or the concentrated acoustic energy, was segmented from the aspiration interval of diffuse acoustic energy. Stutterers' mean VOT was significantly longer than nonstutterers' for six word-initial sounds or sound clusters, /p, b, br, pr, tw, bl/, but there was no significant difference in VOT for the remaining 12 word-initial sounds or sound clusters, /dr, d, ɡ, t, k, tr, kr, ɡr, pl, kl, ɡl, kw/. Frication bursts and aspiration intervals for the words where segmentation of aspiration was possible, showed no significant difference between stutterers and nonstutterers.

Starkweather and Myers (1978) segmented a specific interval of speech into subsegmental durations. Fourteen stutterers and their controls read the "Rainbow" passage. Fluent utterances of the vowel-fricative-vowel, /əs/ from the phrase "the sunlight," were analyzed at one quarter speed. This intervocalic interval was divided into seven

subsegment durations identified on wideband spectrograms and simultaneous intensity by time displays. The subsegments corresponded to the: (1) decline in frequency and intensity of the first vowel (V_1); (2) interval between the last V_1 pulse and frication of the consonant; (3) on-glide of frication; (4) steady-state of the consonant; (5) off-glide of the consonant; (6) interval between consonant frication and voicing of the second vowel (V_2); and (7) rise in intensity and frequency of V_2 . The four odd-numbered subsegments refer to transitional changes in frequency or intensity corresponding to movements of the tongue and larynx, whereas the even-numbered subsegments correspond to steady states. Stutterers were slower than controls in transitional subsegments, but not in steady-state subsegments. The results were interpreted by Starkweather and Myers as suggesting that stutterers are not able to move their laryngeal and supralaryngeal structures as quickly as nonstutterers.

Di Simoni (1974) examined the fluent speech of stutterers for the effects (1) of final consonants on the duration of preceding vowels and (2) of final vowels on the duration of preceding consonants. The study therefore investigated timing and duration relationships other than voice onset timing relationships. Six adult stutterers served as subjects and were instructed to repeat utterances heard through earphones. Symmetrical monosyllabic CVC utterances were generated using the consonants /p, s, b, z/ and the vowels /a, i/, and embedded in the phrase, "Say the word ____ again" for the first part of the experiment. Utterances used in the second part of the experiment were limited to /isi/, /isa/, /asa/, and /asi/ and were repeated 25 times each; the first five and last five repetitions were analyzed. Durational

measurements were made to the nearest 2 msec after the recorded signals had been transduced to graphic form using an optical oscillograph. Consonants and vowels were segmented on the basis of amplitude differences.

The data showed that mean vowel durations, as a function of final consonant contexts (part one), were lengthened in stutterers. However the normative data to which the subjects were compared were taken from an earlier study by House and Fairbanks (1953) which used different methods and procedures. Di Simoni's data showed stutterers' vowel durations to be 137 msec longer than nonstutterers in plosive contexts, 189 msec longer in fricative contexts, 124 msec longer when context was voiceless consonant, and 201 msec longer in voiced consonant contexts. Although the vowel durations of stutterers were lengthened, the essential vowel duration relationships due to the nature of final consonants were retained. Hence vowels in plosive contexts were shorter than in fricative contexts, and vowels in voiceless consonant environments were shorter than in voiced consonant environments.

Durations of /s/ in /i/ and /a/ final vowel environments (part two) were longer in stutterers than those of a control group which was subsequently tested. Both stutterers and nonstutterers exhibited significant differential durations for /s/ depending on the final vowel for the first set of repetitions. On the last set of repetitions however, the stutterers' durations were not differentiated by the final vowel. Variances between the two groups of subjects also differed with stutterers showing more variability in consonant duration control.

High speed cineradiography was used by Zimmermann (1979) to describe the spatial and temporal organization of perceptually fluent

speech in six stutterers and seven nonstutterers. Movements of the lower lip and jaw were analyzed in the CVC's /mam/, /pap/, and /bab/, spoken at a "comfortable" rate. Stutterers consistently showed (1) longer transition times of the downward movement for each utterance, i.e., the time between movement onset and offset; (2) longer lags between movement onset and voice onset as determined by synchronous acoustic recordings; (3) longer times between movement onset and peak velocity in the CV gesture; and (4) longer steady-state positions of the lip and jaw during the vowel portion of the gesture. In addition, stutterers as a group achieved lower peak velocities and smaller displacements than did nonstutterers. The data on articulatory timing were also different between groups. Stutterers showed greater asynchrony between lip and jaw movement.

In conclusion, investigations of voice onset time have shown stutterers to be slower in initiating fluent articulatory-phonatory adjustments for the majority of phonemes studied. Disrupted temporal adjustments in fluent speech have also been observed within an intervocalic interval and, in particular, within the transitional subsegments of the interval. In addition there is some evidence to suggest that temporal differences are not confined to transitions but that mean consonant and vowel steady-state durations are also lengthened in stutterers' fluent utterances as compared to nonstutterers. Finally, stutterers appear slower in achieving peak velocities of movement and the velocities obtained are often lower than those of nonstutterers. Together, these results suggest that in perceptually fluent utterances the temporal organization of events necessary for speech production differs between groups of stutterers and nonstutterers, however additional research is needed to confirm these observations.

III. STATEMENT OF THE PROBLEM

The purpose of this study was to assess acoustic characteristics in the fluent speech (vowel-consonant-vowel or V_1CV_2 stimuli) of adult stutterers and nonstutterers, at normal and fast rates of speech. The experimental questions were:

1. Do stutterers differ in voice onset time from nonstutterers for the consonants /b/ and /g/ at fast and normal rates?

2. Do the two groups, stutterers and nonstutterers, differ in the durations of the second formant transitions of V_1C and CV_2 at fast and normal rates?

3. Do the two groups differ in the durations of the steady-state portions of V_1 and V_2 , as measured at the second formant, for both fast and normal rates?

4. Do the two groups differ in the durations of the vocalic elements of V_1 and V_2 , as measured at the second formant, for both fast and normal rates?

5. Do the two groups differ in terms of overall velocity of second formant transitions at fast and normal rates?

6. Do the two groups differ in the amount of the shift in frequency across the consonant for selected V_1CV_2 sequences at fast and normal rates?

CHAPTER II

METHODS AND PROCEDURES

I. METHOD

Subjects

Ten stutterers and ten nonstutterers served as subjects for this study. The subjects met the following selection criteria:

1. In order to obtain an optimal ratio between the bandwidth of the spectrograph and the fundamental frequency of the subjects, only male subjects were chosen (Hansen and Møller, 1976).

2. A chronological age within the range of 18 to 32 years so that measurement error of formant frequencies associated with age was minimized.

3. Subjects were matched for age within two years.

4. Subjects were matched for race (Caucasian).

5. All subjects were native English (American) speakers.

6. Self-reported duration of stuttering, for the experimental group, to have been at least since elementary school to the present.

7. Control group subjects exhibited normal articulation, voice, and fluency as judged by the investigator and reported no history of a speech or language disorder sufficient in degree to have warranted therapeutic intervention.

8. Experimental group subjects exhibited normal articulation and voice as judged by the investigator.

9. Subjects exhibited bilateral hearing acuity of 20 dB SPL or better for the frequencies 500, 1000, and 2000 Hz.

Appendix A further describes the subjects used in this investigation.

Stimuli

The VCV structure is a phonological sequence capable of systematic variation for experimental purposes. The voiced stop consonants /b/ and /g/ were combined with the vowels /i/ and /u/ to form four symmetric and four asymmetric vowel-stop consonant-vowel sequences (see Table 1). The vowels chosen for study represent the articulatory extremes of the traditional physiological vowel quadrangle in terms of front versus back vowels.

The consonants provide velar and bilabial contrasts, and information collected on duration using voiced stops would add to the knowledge of voice onset time in stutterers. Recall that Starkweather and Myers (1978) investigated one intervocalic interval using the fricative /s/ and Hillman and Gilbert (1977) utilized voiceless plosives, /p, t, k/. Corroborative data are needed to confirm voice onset times for /b/ and /g/ as reported by Metz, Conture, and Caruso (1978). Furthermore stop consonants minimize acoustic segmentation errors as their manner of production provides visible phone boundaries. The acoustic correlate of stops, during the closure phase when pressure is built up, is seen as "silence" or a gap of spectral energy. The release of the stop consonant however appears as a burst of spectral energy (Halle, Hughes, and Radley, 1957).

When the stop is adjacent to a vowel, the movement in the oral cavity to and/or from the closure results in rapid changes in the formant frequencies. These rapid changes in vowel formants adjacent to a silence are known as transitions (Halle, Hughes, and Radley, 1957; Liberman, Delattre, Gerstman, and Cooper, 1956). Transitions constituted a basis for some measurements in this investigation. Specifically, the

TABLE 1. The Vowel-Consonant-Vowel (V_1CV_2) Sequences Constituting the Eight Test Stimuli.

Consonant	Vowel Context	
	Symmetrical ($V_1 = V_2$)	Asymmetrical ($V_1 \neq V_2$)
/b/	/ibi/	/ibu/
	/ubu/	/ubi/
/g/	/igi/	/igu/
	/ugu/	/ugi/

distinctions of the stop gap and stop burst served as an important measuring tool for establishing the terminal formant frequency of the initial vowel in the VCV sequence and the beginning of the final vowel transition. Furthermore, Öhman (1966) viewed the VCV sequence as a basic diphthongal gesture with an independent stop consonant gesture superimposed on its transitional portion. Öhman utilized a set of stop consonants, /b, d, g/, which include the two employed in the present investigation. Two stops were utilized to limit the number of measurements without sacrificing the essential information. In this regard the consonant /b/ was selected since its closure is nonlingual and the tongue is "freer" to assume a position appropriate for the surrounding vowel context, i.e., freer to coarticulate (Kuehn and Tomblin, 1974). Likewise the consonant /g/ was utilized since formant frequencies of vowels in its context appeared more dissimilar from /b/ than did /d/ (Öhman, 1966).

To decrease the likelihood of eliciting stuttering in the experimental conditions, in particular the fast rate condition, the VCV stimuli were not embedded in meaningful words. The nonpropositional bisyllables were placed, however, in the meaningful phrase "Say the word _____ please," to provide a linguistically "real" situation in which the influence of the changing medial bisyllable on the constant sentence frame could be investigated.

Rate Conditions

Adams, Lewis, and Besozzi (1973) stated that the more complex or difficult a particular transition, the greater the likelihood of a disfluency. Specifically, they suggested that a stutterer is more apt

to stutter when attempting rapid transitional movements. The experimental stimuli, constructed to minimize disfluencies, were spoken by the subjects at (1) a normal rate and (2) a fast rate, to ascertain whether stutterers as a group can produce fluent but rapid transitional movements (velocity of formant transitions) and whether they employ similar articulatory strategies, as measured spectrographically, for increasing rate as do nonstutterers. Typically a steady-state interval can be reduced by greater coarticulatory overlapping, while transitional intervals can be reduced by faster movement. Preliminary data suggest that stutterers are slower in both types of intervals but how they perform when required to employ faster rates has not been investigated.

The VCV bisyllables embedded in the carrier phrase were repeated five times each to decrease the likelihood of eliciting disfluencies (adaptation on repeated material) and to allow the subject a sufficient amount of overall talking time to produce the utterances at the desired rates. "Normal" rates were determined by each subject's own judgment of natural/normal rate of speaking. The fast rate of speaking was operationally defined to be at least two seconds less than the overall time to complete the five repetitions at the subject's normal rate as determined to stopwatch accuracy. Pilot data revealed that a two second reduction was a realistic criterion for this particular task. Fast speaking rates of 50 percent of the time used at normal speaking were reported by Ingham, Martin, and Kuhl (1974) but did not appear feasible for the present task. In the pilot data, a two second reduction corresponded to a 29 to 34 percent reduction.

Recording System

Instrumentation for the calibration of the recording system is shown in Figure 1. The Brüel & Kjaer microphone amplifier (Model 2603) was calibrated to 124 dB SPL (re: $.002 \text{ dynes/cm}^2$) using the Brüel & Kjaer pistonphone (Model 4220) attached to the Brüel & Kjaer condenser microphone (Model 4145). Adjacent to the condenser microphone was an Electro-Voice microphone (Model RE 20); both microphones were placed six inches from a Grason-Stadler loudspeaker (Model 162-4). The VU meters of the Shure microphone mixer (Model M 67) and channel one of the Ampex tape recorder (Model AG 440B) were adjusted to -5 dB VU when presented with broadband white noise from a Grason-Stadler noise generator (Model 455C) at a level of 75 dB SPL per the microphone amplifier. Approximately thirty seconds of noise were recorded for later use in adjusting the playback to -5 dB VU.

Subject responses were then recorded in the sound treated booth (IAC, Model 1403-ACT) (see Figure 2). Stimuli were recorded from the output of the Electro-Voice microphone on a studio stand, placed six inches from the subject's mouth.

II. PROCEDURES

Subject Preparation

Each subject sat erect and was instructed to maintain a constant mouth-to-microphone distance of six inches. To establish appropriate intensity levels for recording, each subject was instructed to count aloud. If the subject was speaking too softly (-10 dB VU) or too loudly (+2 dB VU) he was asked to raise or lower his voice accordingly.

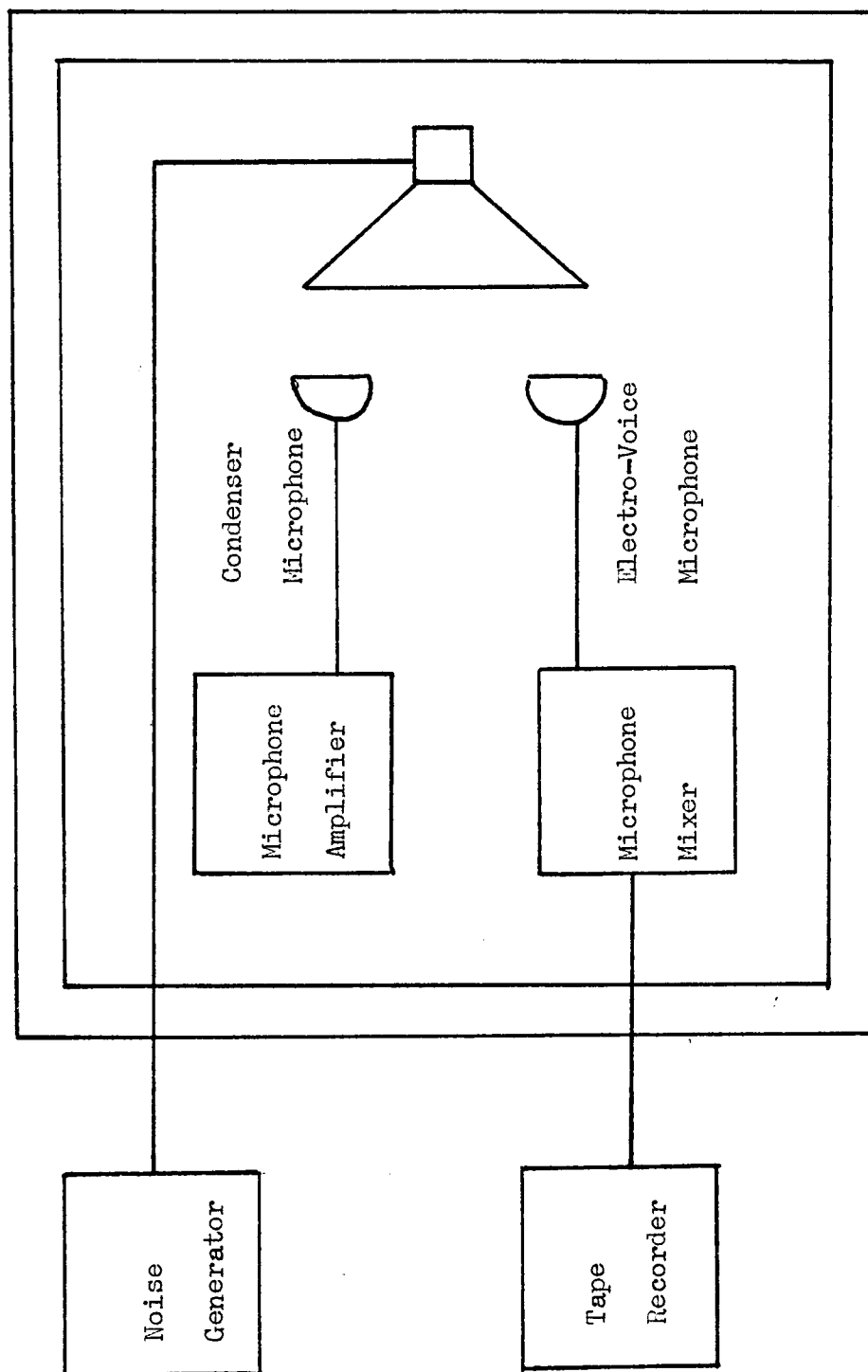


Figure 1. Instrumentation for the Calibration of the Recording System.

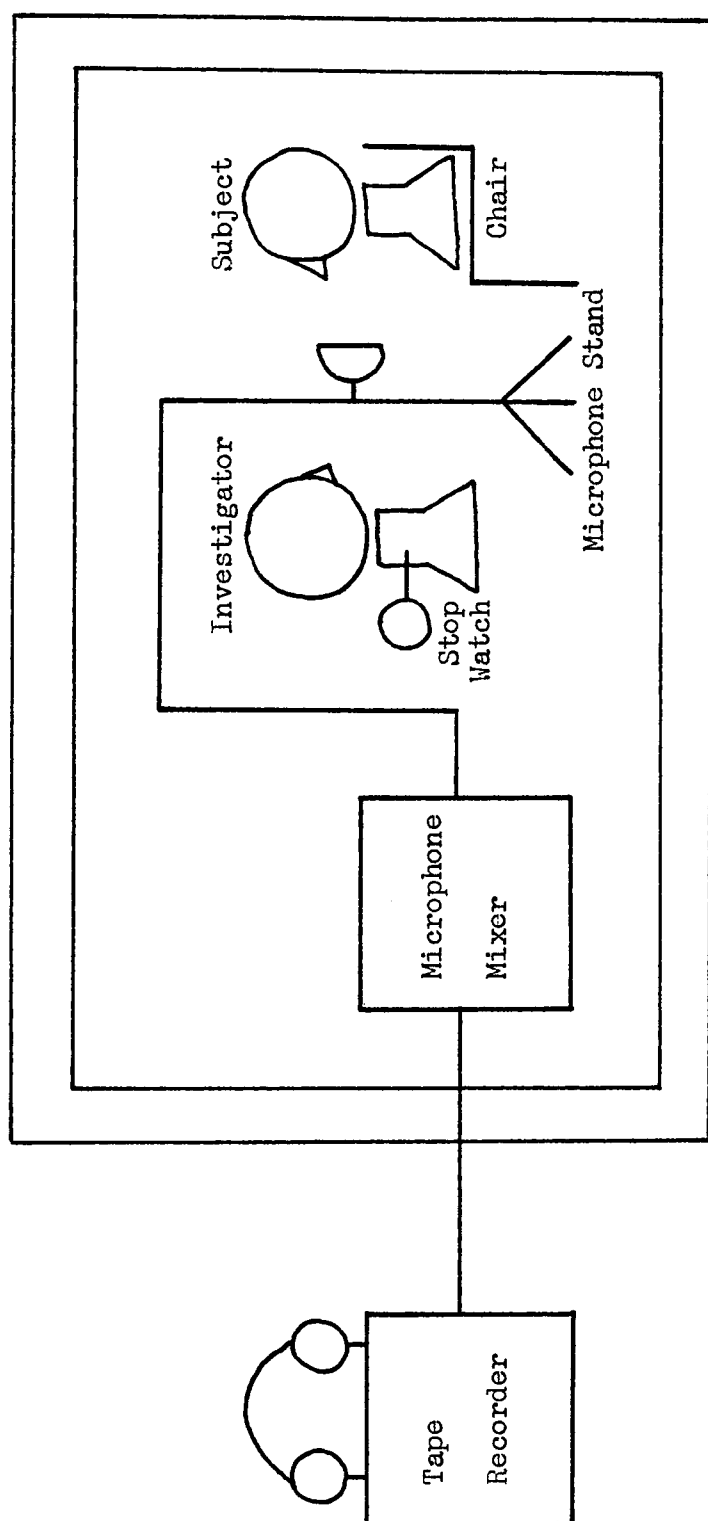


Figure 2. Instrumentation for the Retording of Test Stimuli.

Instructions were read to each subject prior to initiating the experimental task (see Appendix B). The nature of the investigation and specific measures to be made were not explained to the subjects other than the general statement that the purpose was to measure their ability to speak nonmeaningful syllables at normal and fast rates of speech. Each subject was trained to produce the VCV syllables and was allowed to practice reading the carrier phrase and syllable stimuli at both rates of speech until he felt he could perform the task. The investigator used a silent-slide stopwatch (Meylan, Model 207) to time the overall utterance length of each of the set of five repetitions of the VCV stimuli spoken at the subject's normal rate. Practice was allowed to train the subject to perform the repetition task at a fast rate, as operationally defined.

Testing Procedures

The experimental task required the subject to read the carrier phrase and syllable stimuli, printed one per index card and hand-held, five times in succession. All eight stimuli were read first using a normal rate of speech, then the eight stimuli were read again using a fast rate. Each subject received the bisyllables in random order.

The investigator remained in the booth during testing to judge utterances as perceived fluent or perceived disfluent² and as to acceptability of pronunciation. To qualify as a fluent utterance, all words in the carrier phrase and the VCV bisyllable had to have been perceived as fluent. A score sheet (see Appendix B) was used to code the

²Disfluencies were defined as part-word repetitions, whole word repetitions, prolongations, or struggle behavior (Ryan, 1979).

occurrence of disfluencies or nonrepresentative pronunciations during the repetitions, as perceived by the investigator or as hand signaled by the subject after each repetition. If the third, fourth, and fifth repetitions of an utterance were disfluent, the stimulus was repeated for another block of five repetitions, or until a fluent utterance was obtained for analysis purposes. The investigator timed overall repetition rates during the fast rate condition using a stopwatch. Stimuli were immediately repeated that did not conform to the operational definition of a fast production. All responses were recorded on an Ampex tape recorder (Model AG 440B) at $7\frac{1}{2}$ inches per second using Scotch 207 magnetic recording tape.

Acoustic Analysis

A total of 320 spectrograms were analyzed (8 VCV sequences at 2 rates by 20 subjects). Wideband (300 Hz broadband pass filter) spectrograms were made of the VCV stimuli using the Voice Identification (Series 700) unit. A high frequency shaping circuit and linear expand mode set at 0 - 4000 Hz were used for analysis in order to include the plosive burst for /g/ which covers a wide energy range concentrated at 1500 - 4000 Hz (Halle, Hughes, and Radley, 1957).

The third VCV production of each five repetitions was selected for analysis unless it had been scored as disfluent or unacceptable by either the subject or the investigator. If the third production was scored as disfluent then the first succeeding fluent production was utilized for analysis.

Duration and formant frequency measurements were adapted from the procedures used by Gay (1978), and by Lehiste and Peterson (1961).

Voice onset measures were based on procedures used by Klatt (1975) and by Metz, Conture, and Caruso (1978). Figure 3 illustrates the sites of measurement (datum points) as coded alphabetically for the duration measures, segmentation lines were drawn at the second formant and distances were measured. Conversions were made to millisecond values. Duration measurements were made for the following:

A. Voice onset time, denoting the duration between the release of an articulatory constriction or burst transient and the onset of phonation of the vowel, identified by regularly appearing vertical striations in the second formant.

B. The VC transition of vowel one.

C. The steady-state portion of vowel one.

D. The duration of the total vocalic element of vowel one.

E. The CV transition of vowel two.

F. The steady-state portion of vowel two.

G. The duration of the total vocalic element of vowel two.

The time interval within the vowel where the formants were parallel to the time axis was considered the extent of the steady-state portion. In instances where no fixed or parallel target occurred, the interval containing a noticeable change in the slope (minimal frequency change over time) of the moving formant was selected as the steady-state portion (Lehiste and Peterson, 1961). The transition was defined as the maximum frequency change over time, into or from a steady-state portion of spectral energy. If rapid frequency changes were not present, the transition assumed a duration value of 0 msec.

Frequency measurements were based on the second formant as Gay (1978) stated that F2 provided the most reliable and useful transition

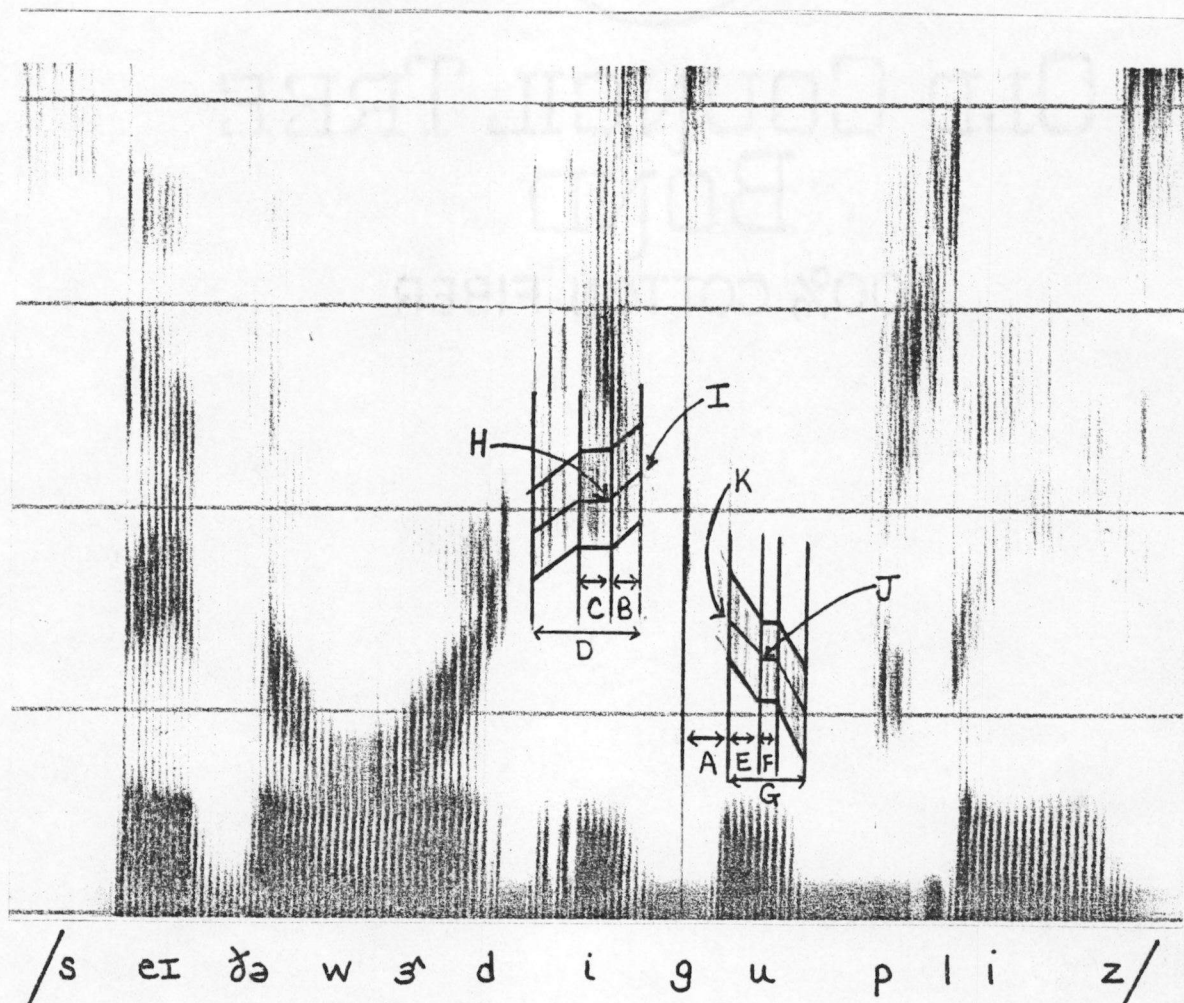


Figure 3. Spectrogram Indicating Points where Duration and Formant Frequency Measurements were Made, in the Utterance "Say the word eegoo please."

movement information as compared to F1 or F3. Frequency measurements were made at:

H. The midpoint of vowel one, where the F2 transition reached a steady-state.

I. The time of consonant closure for vowel one, as identified at the end of V_1 where the acoustic energy became absent.

J. The midpoint of vowel two.

K. The time of vowel onset for V_2 .

The method of locating the measuring points involved drawing a pencil line through the center of both the transition and steady-state portions of the second formant. Measurements were made where the line intersected the point of consonant closure or release, and at the vowel midpoint (at the point adjacent to the transition).

Eleven datum points (A through K) were identified on each of 320 spectrograms and combined to yield the following derived criterion measures under investigation:

1. Voice onset time (point A).
2. Durations of F2 transitions (points B and E).
3. Durations of F2 steady-states (points C and F).
4. Durations of the vocalic elements (points D and G).
5. Overall velocity of F2 transitions (the difference in frequency between points H and I divided by the duration at point B, for vowel one, and the difference in frequency of J and K divided by E, for vowel two).
6. The shift in frequency across the consonant (the frequency difference between points I and K).

CHAPTER III

RESULTS

The data were analyzed to investigate the effects of three experimental variables of Group (stutterers, nonstutterers), Rate (normal, fast), and Bisyllable (/ibi/, /ubu/, /ibu/, /ubi/, /igi/, /ugu/, /igu/, /ugi/) on selected duration and frequency measures in acoustic signals of fluent speech. Repeated measures were made on the experimental variables of Rate and Bisyllable. Individual subjects were considered nested within the two levels of the Group factor (Winer, 1971). A summary of the statistical design is presented in Appendix C.

Analysis of variance procedures were employed to investigate if there were significant differences among the three experimental variables with respect to each of the criterion measures:

1. Voice onset time
2. Duration of the V_1C transition
3. Duration of V_1 steady-state
4. Total duration of V_1
5. Duration of CV_2 transition
6. Duration of V_2 steady-state
7. Total duration of V_2
8. Velocity of V_1 transition
9. Velocity of V_2 transition
10. Frequency shift across the consonant.

The results of each analysis of variance on these criterion measures will be presented separately. Appendix D contains the raw data for each of the criterion measures.

I. RELIABILITY

Repeated measurements were performed to establish intrajudge reliability for duration and frequency measures. Five utterances were randomly selected from each of the experimental conditions (stutterers normal rate, stutterers fast rate, nonstutterers normal rate, nonstutterers fast rate) and duplicated spectrographically at the time the original spectrograms were made. The duplicate set of 20 spectrograms were remeasured. Reliability was computed using the following formula:

$$\text{Standard Error} = \sqrt{\frac{(X_1 - X_2)^2}{2N}}$$

Intrajudge reliability was established for each of the 11 datum points identified spectrographically (see Table 2). The standard error for the duration measures was consistently less than 4 msec. Klatt (1975) reported standard deviations of voice onset time measurements to be approximately 5 msec for voiced plosives: /b, d, g/. Gay (1978) reported duration measurements accurate within the range of ± 10 msec. Similarly, Starkweather and Myers (1978) achieved interjudge reliability for duration within 3 msec.

The standard error for frequency measures made at the second formant was approximately 19 Hz or less (see Table 2). Gay (1978) reported formant frequency measurements accurate to ± 25 Hz, a range consistent with that achieved by Öhman (1966). Eguchi and Hirsh (1969) reported an intrajudge reliability of approximately 10 Hz for measurements derived from the steady-state portion of vowels. Lindblom (1961) reported the accuracy of formant frequency measurements of vowels produced by male voices to have a standard deviation of 40 Hz, a value larger than the previous studies.

TABLE 2. Reliability of Standard Error of the Mean: Measures of Duration (in msec) and Frequency (in Hz).

Duration		Frequency	
Datum Point	Standard Error	Datum Point	Standard Error
Voice Onset Time	3.40 msec	V ₁ Midpoint	19.09 Hz
V ₁ C Transition	1.98 msec	V ₁ at Closure	17.54 Hz
V ₁ Steady-State	3.12 msec	V ₂ Midpoint	14.87 Hz
V ₁ Total	3.30 msec	V ₂ at Onset	16.70 Hz
CV ₂ Transition	1.65 msec		
V ₂ Steady-State	3.75 msec		
V ₂ Total	1.86 msec		

II. VOICE ONSET TIME

Results of the three-dimensional analysis of variance for voice onset time (VOT) are presented in Table 3. The main effects of the three factors: Group, Rate, and Bisyllable, were statistically significant. The two-way and three-way interactions proved nonsignificant.

Averaging over the speaking rates and the vowel-consonant-vowel bisyllables yielded a significant difference among the groups ($F = 6.98$, $p < .01$). As seen in Figure 4, voice onset times of stutterers averaged 4.70 msec longer than those of nonstutterers. The range of VOT values for stutterers averaged 18.03 to 28.64 msec (standard deviation = 13.00 msec), while the range for nonstutterers averaged 14.57 to 27.40 (standard deviation = 12.86 msec). Figure 4 illustrates considerable overlap of VOT values obtained by individual subjects. However only two stutterers had mean voice onset times less than the nonstutterers' average, and one nonstutterer had average voice onset times surpassing the mean duration of stutterers.

Voice onset time was significantly decreased at fast speaking rates ($F = 7.48$, $p < .03$). Voice onset times at normal rates, for all subjects, averaged 24.49 msec; fast rates averaged 21.33 msec. On the average, VOT was decreased nearly 13 percent at fast rates. The group by rate interaction was not significant. Inspection of Figure 5 indicates that stutterers, as a group, employed longer voice onset times at both rates of speech. The voice onset times of stutterers at fast rates ($\bar{X} = 24.19$ msec) approximated, but did not equal the voice onset time of nonstutterers at normal rates ($\bar{X} = 22.66$). Furthermore stutterers did not decrease VOT as

TABLE 3. Analysis of Variance Summaries for the Mean Voice Onset Time.

	SS	df	MS	F
<u>Between</u>				
Group	1760.16	1	1760.16	6.98**
Subject (Group)	4093.90	18	227.44	
<u>Within</u>				
Syllable	14387.07	7	2055.30	24.17***
Rate	798.85	1	798.85	7.48*
Group x Rate	86.01	1	86.01	.67
Group x Syllable	257.25	7	36.75	.43
Rate x Syllable	747.36	7	106.77	1.26
Group x Rate x Syllable	895.39	7	127.91	1.50
Error	22957.71	270	85.03	

*Significant at the .05 level

**Significant at the .01 level

***Significant at the .0001 level

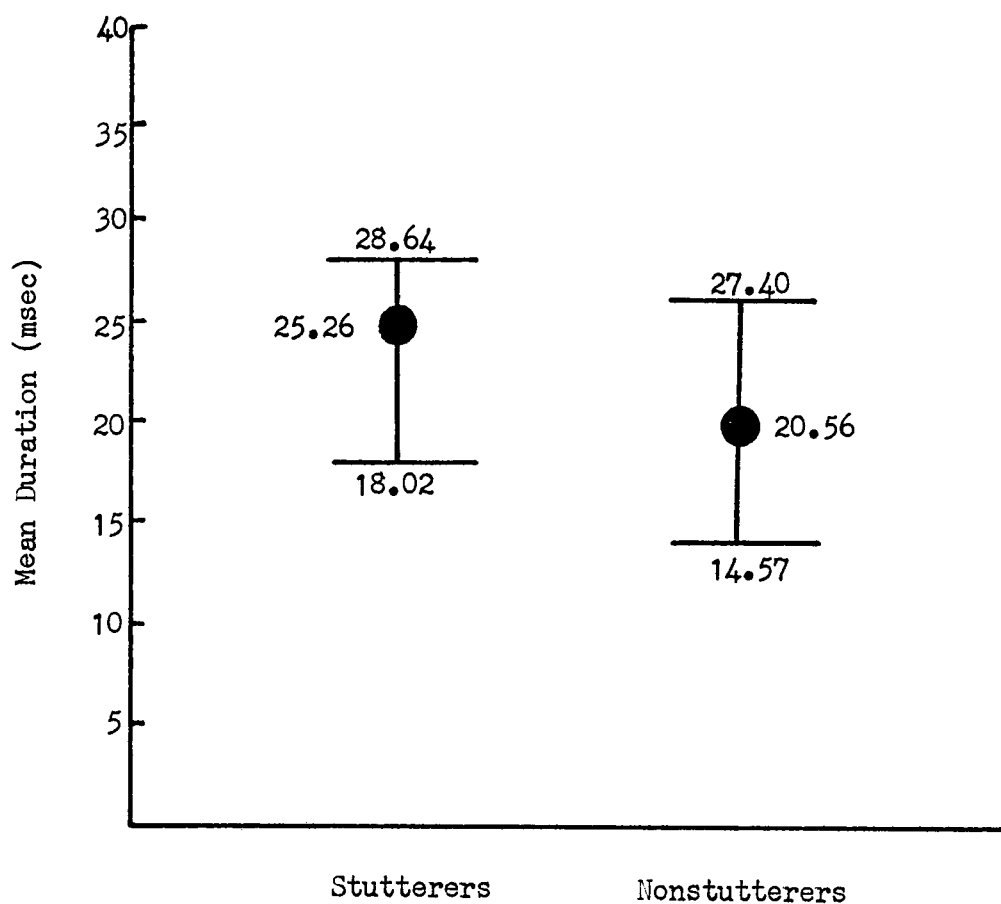


Figure 4. Range and Mean Duration of Voice Onset Times (in msec) for Stutterers and Nonstutterers Averaged Over Bisyllables and Rates.

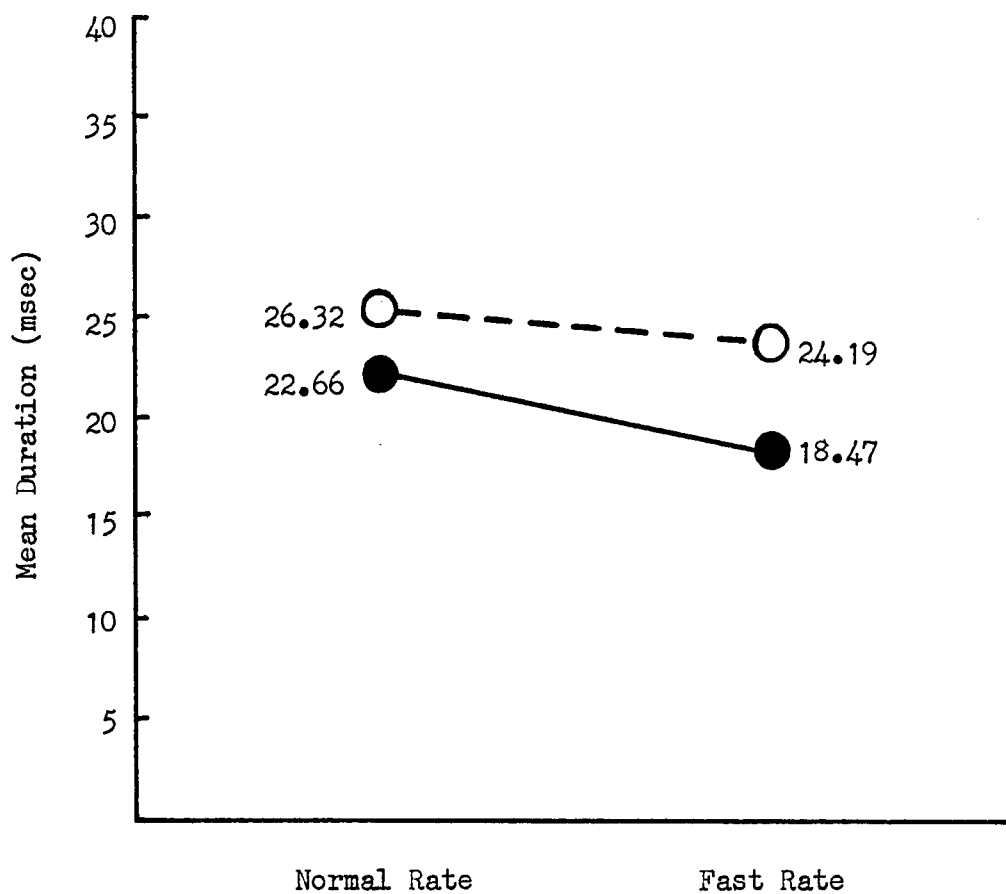


Figure 5. Voice Onset Times (in msec) of Stutterers (o--o) and Nonstutterers (●—●) at Normal and Fast Rates of Speech.

much as nonstutterers in the fast rate condition (8 percent and 18 percent reduction, respectively).

Voice onset time as a function of vowel-consonant-vowel syllable combinations was significant ($F = 24.17$, $p < .0001$). Post hoc testing, using the Tukey A procedures (Winer, 1971), was done to determine which bisyllables were significantly different. Table 4 summarizes the pairwise comparisons of the Tukey A procedures, 15 of which were found to be significant. Bisyllables involving the labial phoneme /b/ had shorter voice onset times than back-of-the-cavity (velar) productions of /g/, even within the same vowel combinations.

Voice onset time for each bisyllable plotted as a function of group (see Figure 6) reveals the consistent pattern of lengthened VOT in stutterers. Stutterers exhibited the same consonant trends (VOT less on /b/ than /g/) and vowel-consonant-vowel trends as did the nonstutterers. Specifically, voice onset times for /b/ averaged 16.61 msec for all subjects combined. The mean VOT for stutterers was 18.76 msec and for nonstutterers 14.47 msec. Voice onset times for /g/ averaged 29.19 msec for all subjects combined. The mean VOT for stutterers was 31.75 msec, while the nonstutterers averaged 26.66 msec.

III. DURATION OF V_1C TRANSITION

Table 5 summarizes the analysis of variance for the duration of the transition of vowel one into the consonant in the V_1CV_2 bisyllabic stimuli. The Group by Rate interaction proved significant, as did the main effects of Rate and Bisyllable.

TABLE 4. Analysis of the Difference between the Mean Voice Onset Times (in msec) for each of the Eight Bisyllables, Utilizing the Tukey A Pairwise Procedures.

Syllable							
	ibi	ibu	igu	ugu	ugi	igi	
Mean	14.71	17.18	20.34	26.50	28.14	29.63	32.49
ubi	14.22	.49	6.12	12.28**	13.92**	15.41**	18.27**
ibi	14.71	2.47	5.63	11.79**	13.43**	14.92**	17.78**
ibu	17.18		3.16	9.32*	10.96*	12.45**	15.31**
ubu	20.34			6.16	7.80*	9.29*	12.15*
igu	26.50				1.64	3.13	5.99
ugu	28.14					1.49	4.35
ugi	29.63						2.86

MSE = 85.03, n = 40, N = 320, df = 270, r = 8

*Significant at the .05 level (critical value = 6.25)

**Significant at the .01 level (critical value = 7.28)

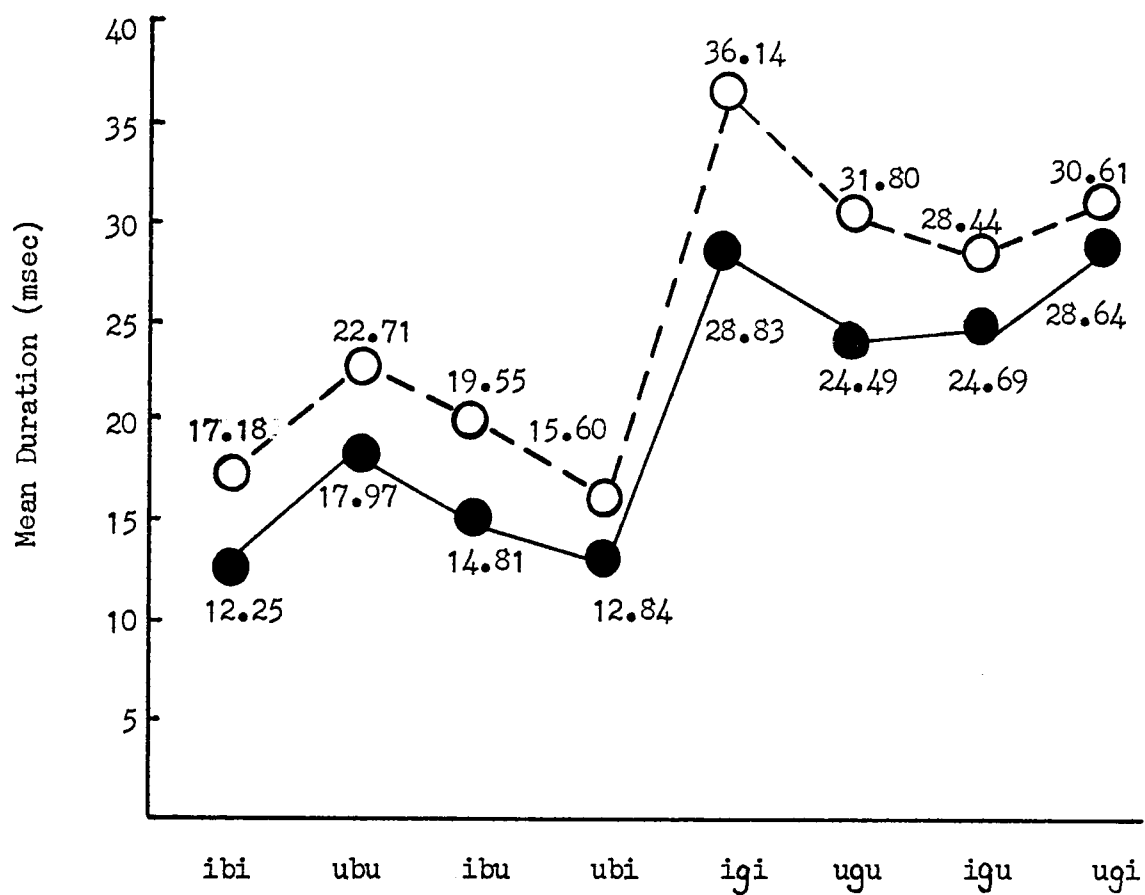


Figure 6. Voice Onset Times (in msec) of Stutterers (o--o) and Nonstutterers (●—●) for Eight Bisyllables.

TABLE 5 . Analysis of Variance Summaries for the Mean Duration of the V₁C Transition.

	SS	df	MS	F
<u>Between</u>				
Group	1527.53	1	1527.53	2.30
Subject (Group)	9174.76	18	509.71	
<u>Within</u>				
Syllable	5812.66	7	830.38	2.37*
Rate	2512.44	1	2512.44	9.49*
Group x Rate	1082.47	1	1082.47	5.94*
Group x Syllable	2143.34	7	306.19	.88
Rate x Syllable	1852.75	7	264.68	.76
Group x Rate x Syllable	1274.68	7	182.10	.52
Error	94452.37	270	349.82	

*Significant at the .05 level.

On the average, the duration of the V_1C transition was 4.37 msec shorter in stutterers ($\bar{X} = 29.06$ msec) than nonstutterers ($\bar{X} = 33.43$ msec). However this difference, representing an average of the two rate conditions, was not statistically significant ($F = 2.30$, $p > .05$).

The Group by Rate interaction was significant ($F = 5.94$, $p < .04$). During the normal rate condition, nonstutterers spent more than 8 msec longer in the V_1C transition than did stutterers. This difference was significant (see Table 6) using Tukey A post hoc procedures (Winer, 1971). At fast rates however, the two groups spent a comparable amount of time in the V_1C transition (approximately 28 msec each). Figure 7 shows that the two groups exhibited different magnitudes of transition reduction relative to their respective normal rates. Nonstutterers reduced transition durations an average of 9.37 msec, a 24 percent reduction, while stutterers reduced transition durations by 1.93 msec, only a 6 percent reduction.

The mean duration of the V_1C transition, averaged across all subjects, varied significantly with respect to the rate of speech ($F = 9.49$, $p < .02$). There was an average reduction of 5.6 msec (approximately 16 percent) in the V_1C transition at the fast rate condition ($\bar{X}$ fast = 28.44 msec, $\bar{X}$ normal = 34.04 msec). Average transition durations ranged from 30.42 to 39.11 msec at normal rates (for /igi/ and /ubi/, respectively), and 19.36 to 35.35 msec at fast rates (for /igi/ and /ubu/, respectively).

The V_1C transition duration was significant with respect to bisyllables ($F = 2.37$, $p < .02$). Considerable regularity in V_1C transition durations is apparent when the coarticulatory effects of the final vowel are considered. Asymmetric bisyllables (V_1CV_2 , where $V_1 \neq V_2$) exhibited

TABLE 6. Analysis of the Difference between the Mean Duration of the V₁ C Transition for the Two Levels of the Group Factor and the Two Rate Conditions Using the Tukey A Pairwise Procedures.

	Nonstutterer Fast	Stutterer Normal	Nonstutterer Normal
Mean	28.79	30.02	38.07
Stutterer Fast	28.09	.70	9.98**
Nonstutterer Fast	28.79	1.23	9.28**
Stutterer Normal	30.02		8.05*

MSE = 349.82, n = 80, N = 320, r = 4

*Significant at the .05 level (critical value = 7.59)

**Significant at the .01 level (critical value = 9.20)

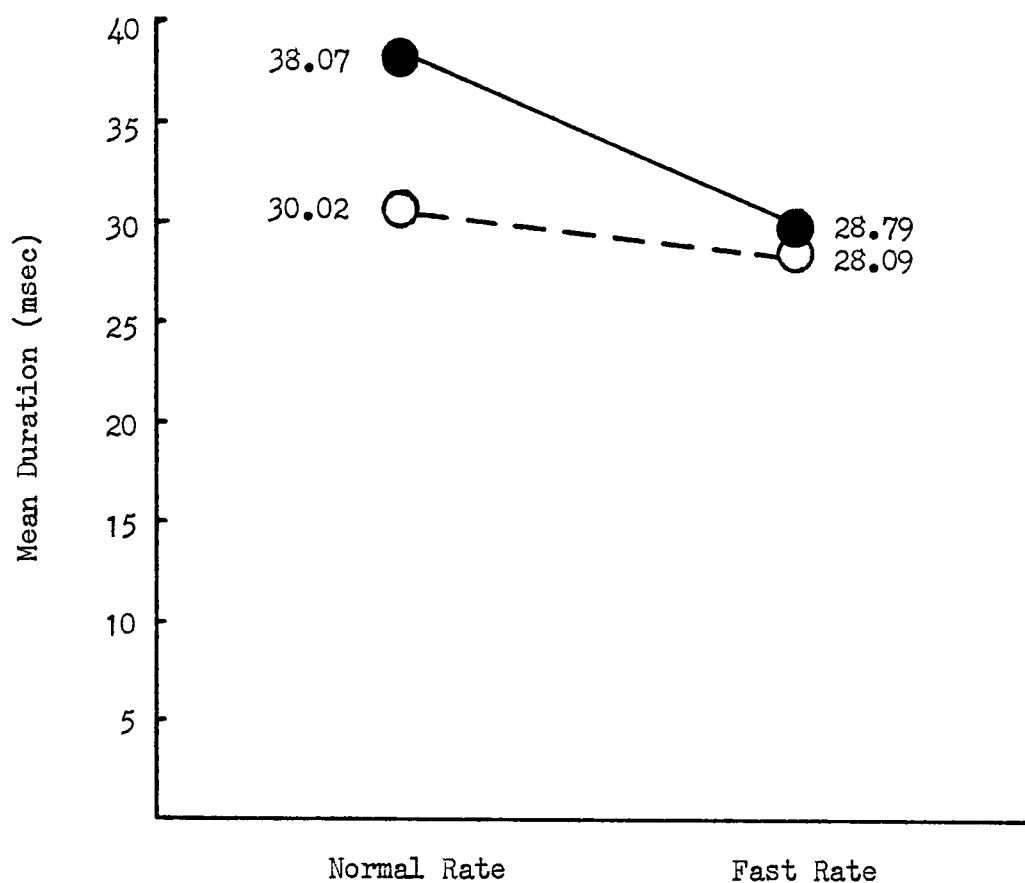


Figure 7. Transition Duration of Vowel One for Stutterers (o--o) and Nonstutterers (●—●) at Normal and at Fast Rates of Speech.

longer V_1 C transitions than did symmetric bisyllables ($V_1 = V_2$). The transition durations may be ordered as follows (* denotes exception):

/ibu/ > /ibi/, /ubi/ > /ibi/, /ubi/ > /ubu/, /ibu/ < /ubu/*,
 /igu/ > /igi/, /ugi/ > /igi/, /ugi/ > /ugu/, /igu/ > /ugu/.

This same trend of asymmetric syllable lengthening of the transition is shown in Figure 8 for stutterers and nonstutterers. The trend however, was not supported in three instances by stutterers (/ugi/ < /ugu/, /igu/ < /ugu/, /ibu/ < /ubu/). Figure 8 also shows that stutterers employed shorter transitions in seven of the eight bisyllables.

IV. DURATION OF V_1 STEADY-STATE

The analysis of variance (see Table 7) with respect to the duration of the steady-state portion of vowel one yielded significant F-ratios for the experimental variables of Group and Rate. Durations of the steady-states for the two vowels, /i/ and /u/, in the symmetric and asymmetric bisyllabic stimuli were not significantly different. Likewise, no two-way or three-way interactions were statistically significant.

Stutterers differed significantly from nonstutterers in the amount of articulatory time spent in the steady-state portion of V_1 ($F = 8.64$, $p < .01$). As seen in Figure 9, stutterers' steady-state portions averaged approximately 10 msec longer than nonstutterers; however considerable overlap is seen in the mean values obtained by subjects in both groups (stutterers' standard deviation = 29.73, nonstutterers' = 16.55 msec). Furthermore, when rate is partitioned out from the group data (see Figure 10) it can be seen that stutterers operate consistently

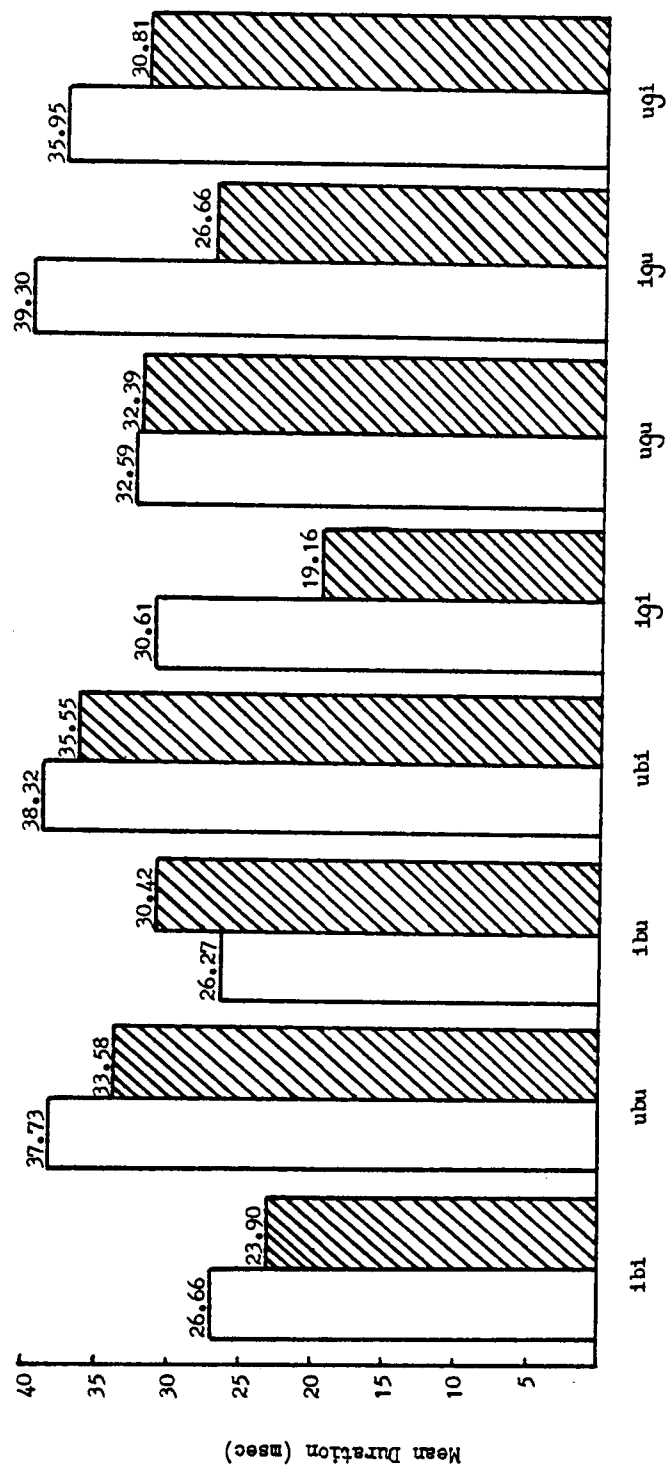


Figure 8 . Transition Durations of Vowel One of Nonstutterers (□) and Stutterers (▨) for the Eight Bisyllables.

TABLE 7. Analysis of Variance Summaries for the Mean Duration of the V_1 Steady-State.

	SS	df	MS	F
<u>Between</u>				
Group	7075.38	1	7075.38	8.64*
Subject (Group)	12365.16	18	686.95	
<u>Within</u>				
Syllable	1359.21	7	194.17	.59
Rate	9362.55	1	9362.55	82.97**
Group x Rate	353.64	1	353.64	1.08
Group x Syllable	1191.83	7	170.26	.52
Rate x Syllable	789.87	7	112.84	.34
Group x Rate x Syllable	747.36	7	106.77	.33
Error	88670.05	270	328.41	

*Significant at the .01 level

**Significant at the .0001 level

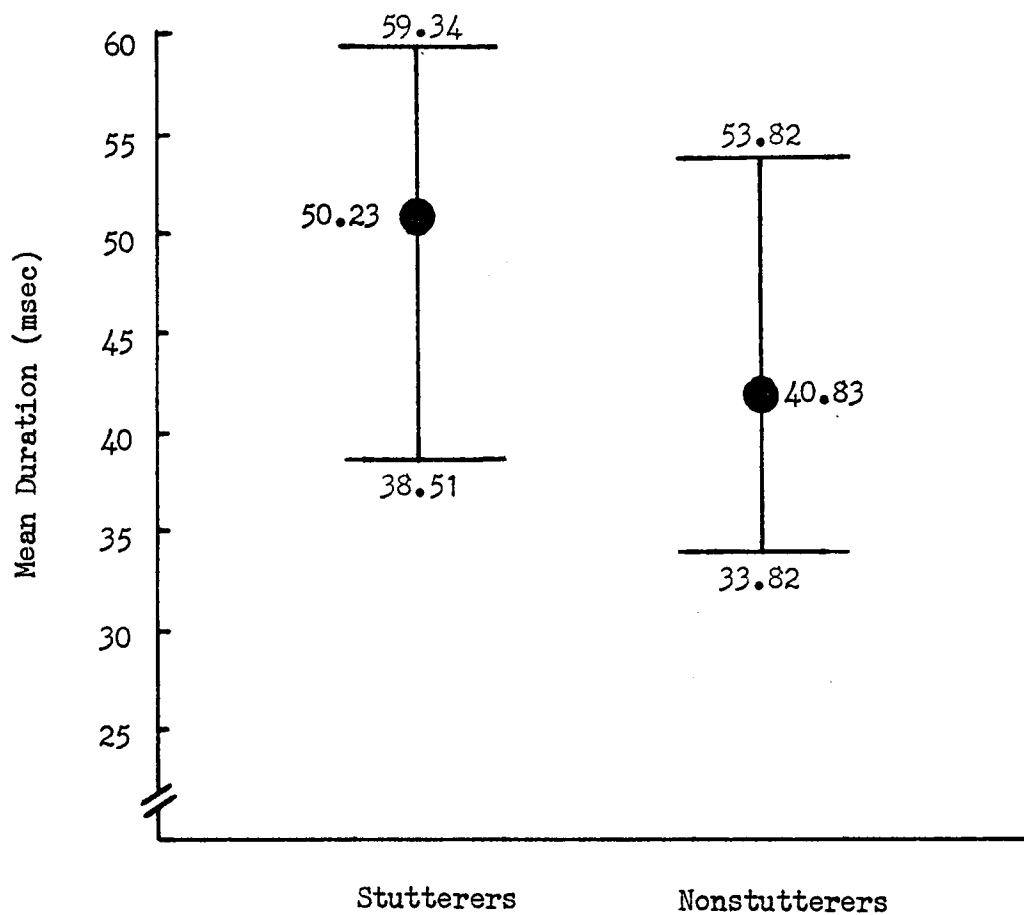


Figure 9. Range and Mean Duration of the Steady-State Portion of Vowel One between Stutterers and Nonstutterers, Averaged Over Rates and Bisyllables.

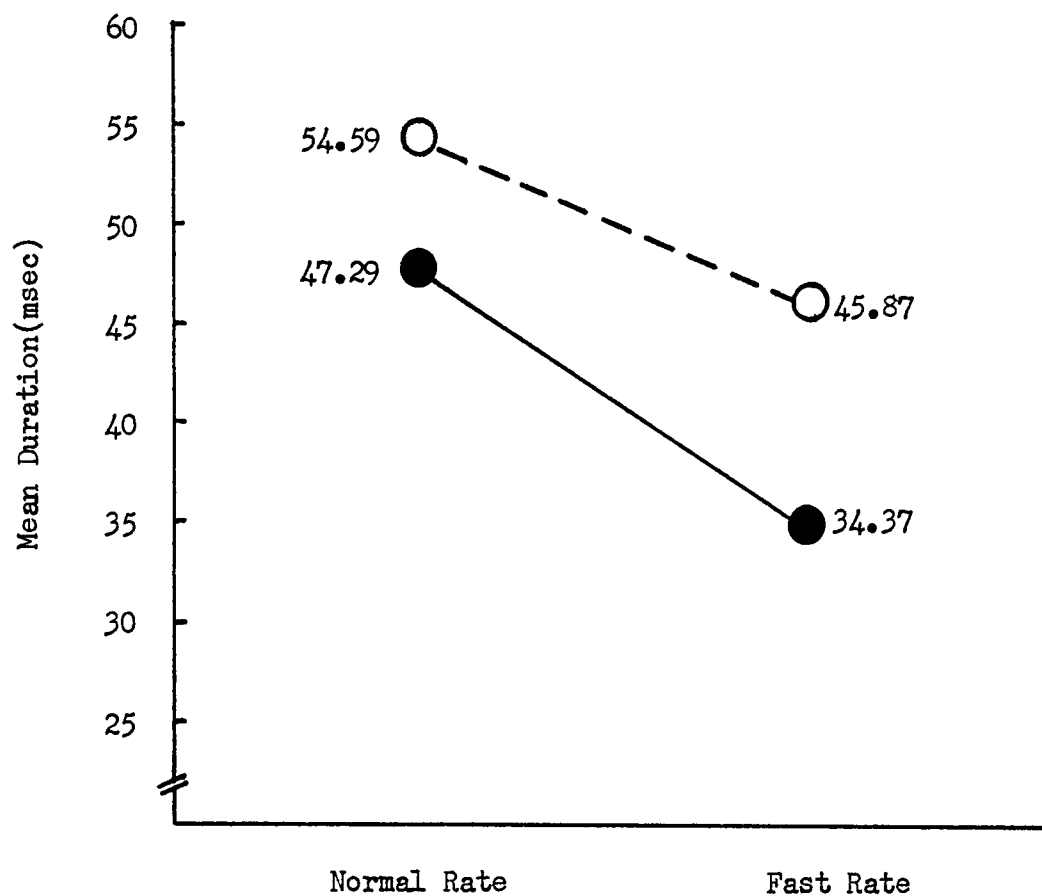


Figure 10. Duration of the Steady-State Portion of Vowel One at Normal and at Fast Rates of Speech for Stutterers (o-o) and Nonstutterers (●-●).

with longer steady-state portions. The amount of time spent in the steady-state portion of V_1 by stutterers at fast rates approximated the steady-state time by nonstutterers at normal speaking rates ($\bar{X} = 45.87$ and 47.29 msec, respectively). Steady-state portions were reduced by 16 percent (8.72 msec) at fast rates by stutterers and 27 percent (12.92 msec) by nonstutterers. Overall, in comparisons of the normal ($\bar{X} = 50.94$ msec) and fast rates ($\bar{X} = 40.12$ msec), there was a 10.82 msec reduction in the steady-state portion of V_1 . This significant reduction ($F = 82.97$, $p < .0001$) in steady-state durations at fast rates corresponds to an overall reduction of 21 percent.

V. TOTAL DURATION OF V_1

Results of the analysis of variance for total duration of the first vowel in the V_1CV_2 bisyllabic stimuli are presented in Table 8. The Group by Rate interaction was significant as were the main effects of Rate and Bisyllable.

Total durations of vowel one of stutterers averaged 8.82 msec longer than nonstutterers ($\bar{X} = 123.07$ and 114.25 msec, respectively). However, this difference, averaged over both rate conditions was not statistically significant ($F = 1.37$, $p > .05$).

As seen in Figure 11, total vowel durations at normal rates were comparable between stutterers and nonstutterers. This difference was not significant (see Table 9) when tested by the Tukey A procedures (Winer, 1971). Total durations of V_1 at fast rates differed significantly between stutterers and nonstutterers (see Table 9), yielding a significant Group by Rate interaction ($F = 15.36$, $p < .006$). Nonstutterers displayed

TABLE 8. Analysis of Variance Summaries for the Mean Total Duration of V_1 .

	SS	df	MS	F
<u>Between</u>				
Group	6214.13	1	6214.13	1.37
Subject (Group)	81661.63	18	81661.63	
<u>Within</u>				
Syllable	9680.52	7	1382.93	2.77*
Rate	42079.99	1	42079.99	75.43**
Group x Rate	5471.85	1	5471.85	15.36*
Group x Syllable	2608.69	7	372.67	.75
Rate x Syllable	3904.87	7	557.84	1.12
Group x Rate x Syllable	2494.40	7	356.34	.71
Error	134818.37	270	499.33	

*Significant at the .01 level

**Significant at the .0001 level

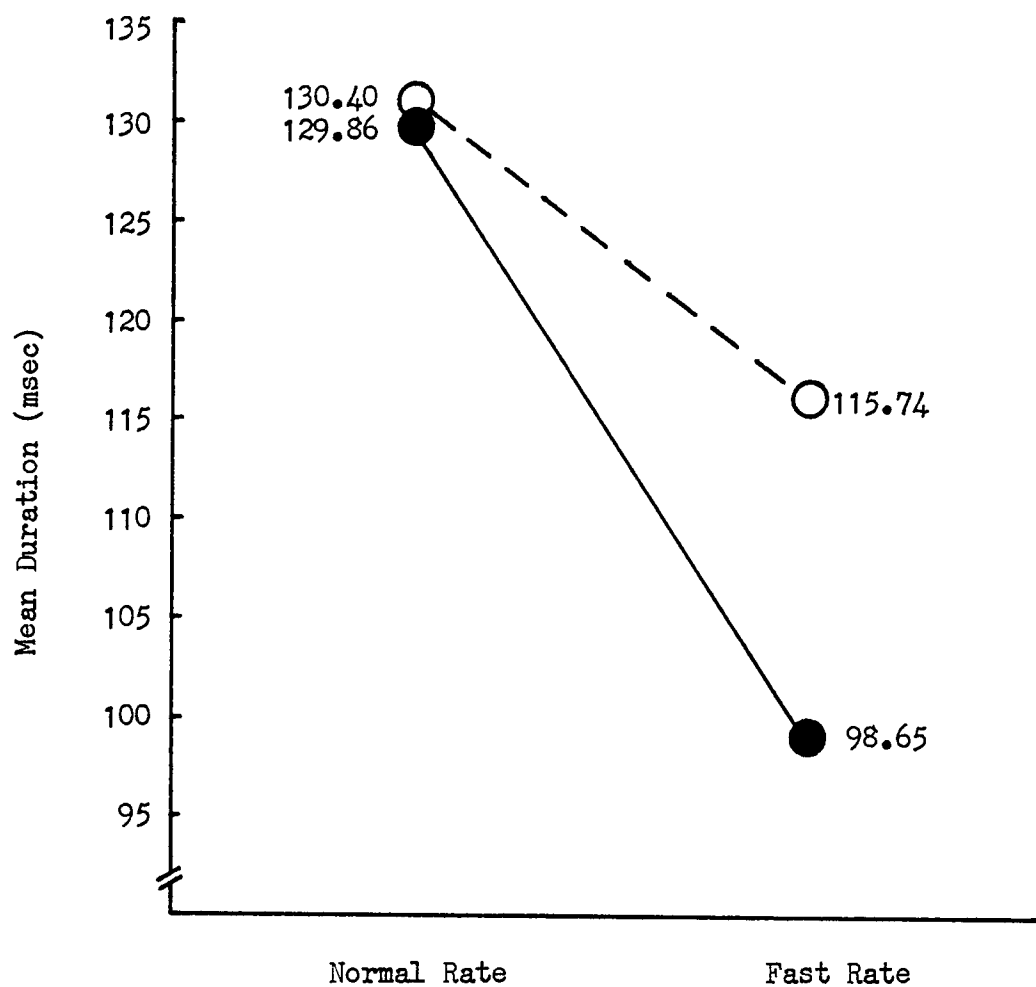


Figure 11. Mean Total Duration of Vowel One of Stutterers (o--o) and Nonstutterers (●—●) at Normal and Fast Rates of Speech.

TABLE 9. Analysis of the Difference between the Mean Duration of Vowel One for the Two Levels of the Group Factor and the Two Rate Conditions Using the Tukey A Pairwise Procedures.

	Stutterer Fast	Nonstutterer Normal	Stutterer Normal
Mean	115.74	129.86	130.40
Nonstutterer Fast	98.65	17.09*	31.75*
Stutterer Fast	115.74	14.12*	14.66*
Nonstutterer Normal			.54

MSE = 499.33, $n = 80$, $N = 320$, $df = 270$, $r = 4$

*Significant at the .01 level (critical value 10.99)

a 24 percent total vowel reduction at fast rates of speech. Stutterers however exhibited only an 11 percent reduction in total vowel duration at fast rates.

Total durations of V_1 were significantly different at normal and fast rates of speech ($F = 75.43$, $p < .0001$). Overall vowel durations ranged from 120.87 to 143.98 msec at the normal rate and from 97.37 to 113.76 msec in the fast rate condition. This represents an average reduction of approximately 18 percent.

The total duration of V_1 as a function of bisyllable was significant ($F = 2.77$, $p < .009$). As may be seen in Figure 12, longer durations were associated with bisyllables which involved /i/ in the vowel one position.

VI. DURATION OF CV_2 TRANSITION

Results of the analysis of variance for the duration of the transition from the consonant into the second vowel (of V_1CV_2 sequences) are summarized in Table 10. The duration of the V_2 transition was not significantly different between stutterers and nonstutterers, however nonstutterers averaged 4.4 msec longer transitions than did stutterers ($\bar{X} = 33.35$ and 28.96 msec, respectively).

The durations of V_2 transitions were significantly different between normal and fast rates of speech ($F = 16.94$, $p < .005$). Mean transition durations at normal rates were 34.79 msec while at fast rates they averaged 27.53 msec. At increased speaking rates, the duration of the transition into V_2 was reduced by 35 percent (over 7 msec).

Figure 13 illustrates the durational differences between stutterers and nonstutterers at both speaking rates. At normal rates of speech,

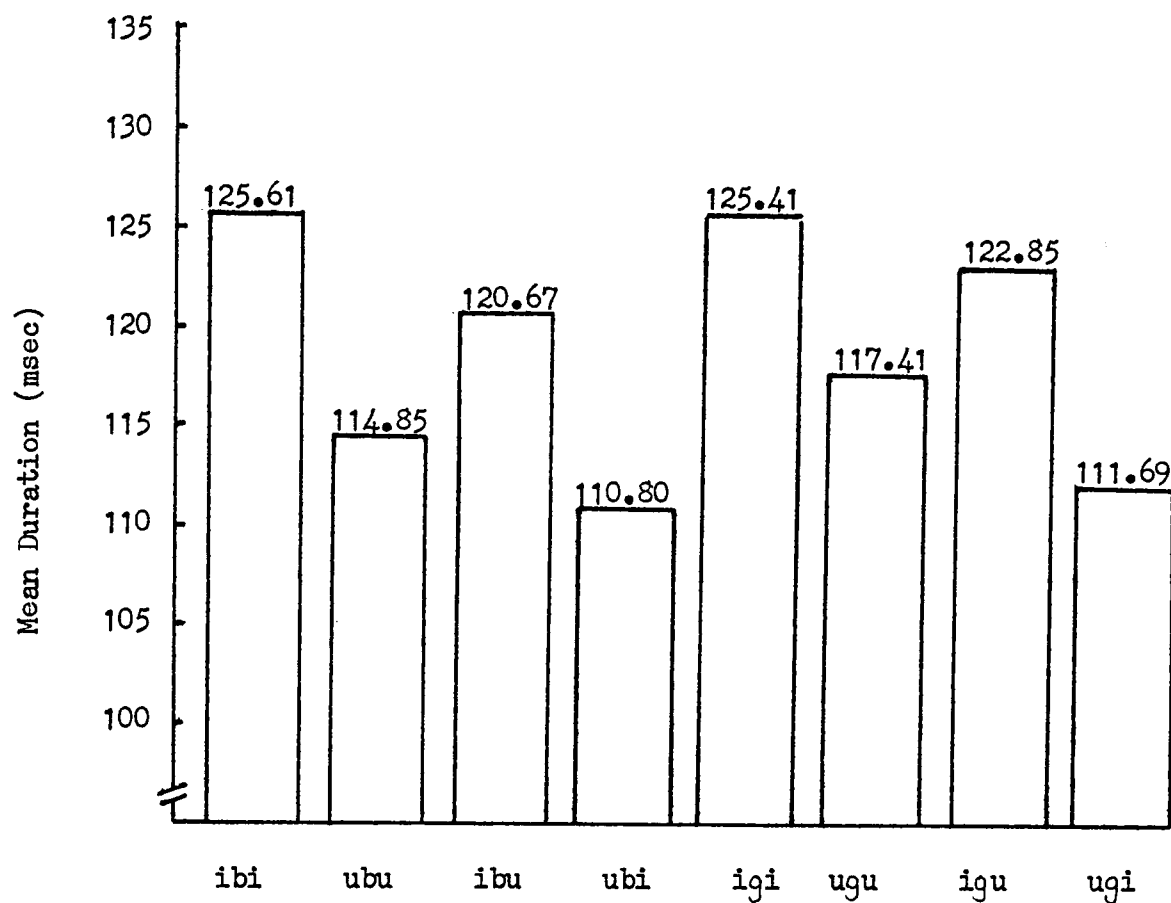


Figure 12. Mean Total Duration of Vowel One for Each of the Eight Bisyllables, Averaged Over Group and Rate.

TABLE 10. Analysis of Variance Summaries for the Mean Duration of the CV₂ Transition.

	SS	df	MS	F
<u>Between</u>				
Group	1543.96	1	1543.96	1.86
Subject (Group)	9762.61	18	542.37	
<u>Within</u>				
Syllable	13188.28	7	1884.04	5.75**
Rate	4215.88	1	4215.88	16.94*
Group x Rate	152.63	1	152.63	1.22
Group x Syllable	3260.97	7	465.85	1.42
Rate x Syllable	1741.82	7	248.83	.76
Group x Rate x Syllable	874.99	7	125.00	.38
Error	88405.57	270	327.43	

*Significant at the .01 level

**Significant at the .0001 level

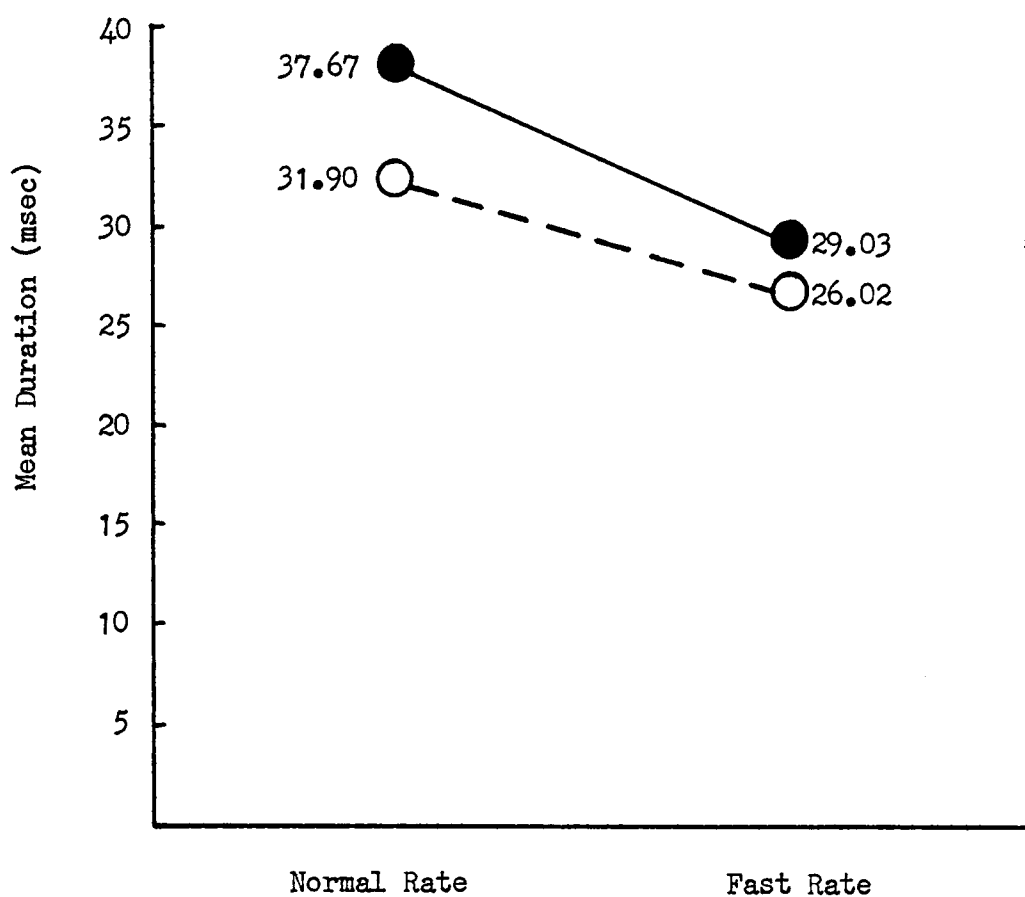


Figure 13. Mean Duration of CV₂ Transition for Stutterers (o--o) and Nonstutterers (●—●) at Normal and Fast Rates of Speech.

stutterers averaged 5.77 msec shorter transitions than the nonstutterers. At fast rates this difference was 3.01 msec. Furthermore, the amount of time spent in the V_2 transition of stutterers at normal rates approximated the duration of nonstutterers at fast rates of speech ($\bar{X} = 31.90$ and 29.03 msec, respectively).

Bisyllables were significantly different with respect to duration of the CV_2 transition ($F = 5.75$, $p < .0001$). Post hoc testing using the Tukey A procedures (Winer, 1971) revealed seven comparisons to be significantly different (see Table 11). Mean durations for each of the eight bisyllables are shown in Figure 14. The CV_2 transition durations were longer in /bi/ combinations ($\bar{X} = 39.27$ msec) than in /bu/ combinations ($\bar{X} = 25.38$ msec); durations associated with /g/ present a mixed pattern.

VII. DURATION OF V_2 STEADY-STATE

The analysis of variance with respect to the duration of the steady-state portion of vowel two was significant for the experimental variables of Rate and Bisyllable. Table 12 summarizes the statistical treatment of the data.

The steady-state portions of V_2 averaged 11.55 msec longer in stutterers ($\bar{X} = 53.67$ msec) than nonstutterers ($\bar{X} = 42.12$). This difference, however failed to reach statistical significance ($F = 3.77$, $p > .05$).

The V_2 steady-states were significantly different at the two rates of speech ($F = 164.52$, $p < .0001$). Mean durations of the steady-state portions were 56.63 msec at the normal rate and 39.15 msec at the fast rate. On the average, V_2 steady-states, for all subjects, were reduced

TABLE 11. Analysis of the Difference between the Mean Duration of the CV₂ Transition for each of the Eight Bisyllables Utilizing the Tukey A Pairwise Procedures.

Syllable							
	ibu	ugu	ubu	ugi	ibi	igu	ubi
Mean	24.89	25.08	25.87	32.69	36.90	37.43	41.64
ugi	24.76	.13	.32	7.93	12.14	12.67*	16.88**
ibu	24.89		.19	7.80	12.01	12.54*	16.75**
ugu	25.08		.79	7.61	11.82	12.35*	16.36**
ubu	25.87			6.82	11.03	11.56	21.23**
ugi	32.69				4.21	4.74	8.95
ibi	36.90					.53	4.74
igu	37.43						4.21

MSE = 327.43, n = 40, N = 320, df = 270, r = 8

*Significant at the .05 level (critical value = 12.27)

**Significant at the .01 level (critical value = 14.28)

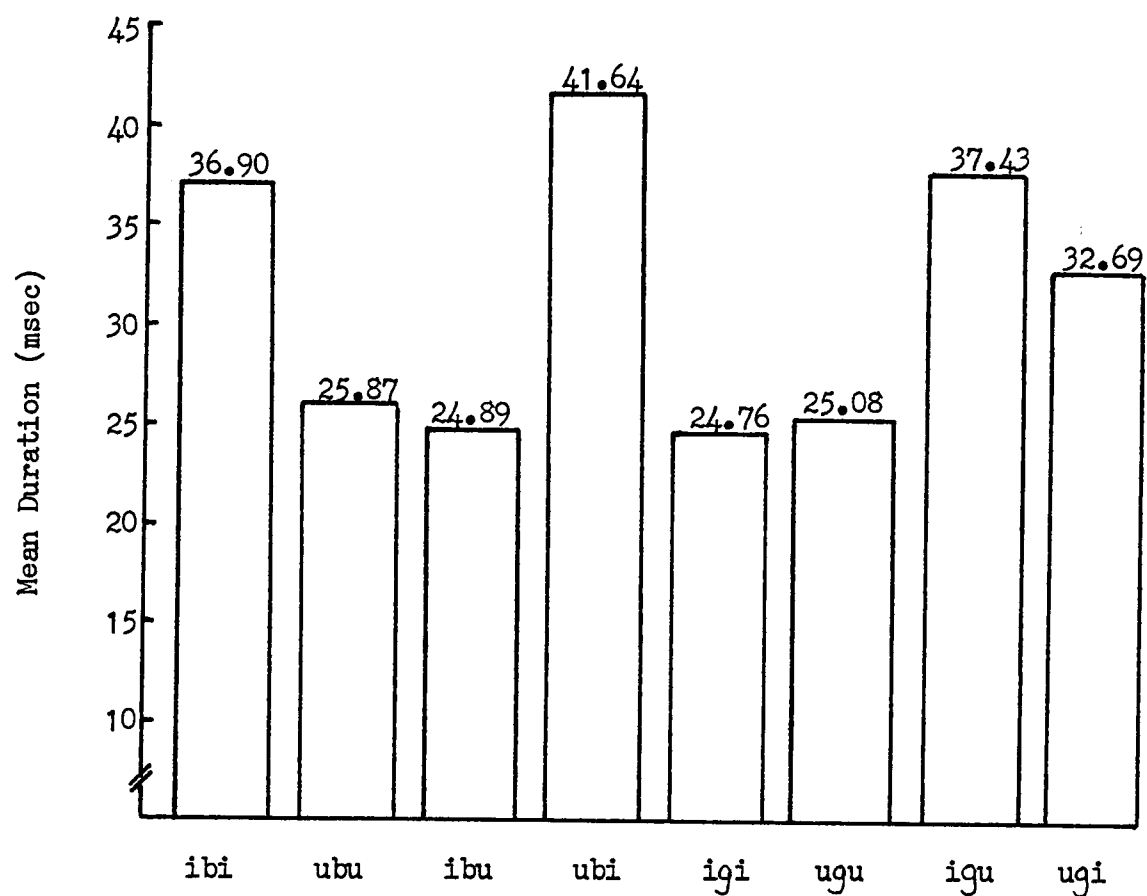


Figure 14. Mean Duration of CV₂ Transition for Each of the Eight Bisyllables.

TABLE 12. Analysis of Variance Summaries for the Mean Duration of the V₂ Steady-State.

	SS	df	MS	F
<u>Between</u>				
Group	10679.13	1	10679.13	3.77
Subject (Group)	46340.21	18	2574.46	
<u>Within</u>				
Syllable	28412.15	7	4058.88	9.05*
Rate	24440.54	1	24440.54	164.52*
Group x Rate	94.40	1	94.40	.40
Group x Syllable	2639.16	7	377.02	.84
Rate x Syllable	1039.91	7	148.56	.33
Group x Rate x Syllable	1645.28	7	235.04	.52
Error	121040.29	270	448.30	

*Significant at the .0001 level

17.48 msec, which corresponds to approximately a 31 percent reduction, for the fast rate condition.

The Group by Rate interaction was nonsignificant ($F = .40$, $p > .55$), however Figure 15 illustrates the consistently longer steady-state durations employed by stutterers at both rates of speech. Steady-state portions were reduced by 29 percent (18.56 msec) at fast rates by stutterers and 33 percent (16.39 msec) by nonstutterers.

The amount of time spent in the steady-state portions of V_2 differed significantly among bisyllables ($F = 9.05$, $p < .0001$). Post hoc testing using the Tukey A procedures (Winer, 1971) yielded eight significant mean comparisons (see Table 13). The mean differences are displayed in Figure 16, and it can be seen that symmetric bisyllables ($V_1 = V_2$) involving /i/ were longer in duration than other bisyllables within each consonant group. Furthermore the asymmetric bisyllables in which $V_2 = /i/$ displayed longer steady-state portions than those where $V_2 = /u/$.

VIII. TOTAL DURATION OF V_2

Table 14 summarizes the analysis of variance for the total duration of the second vowel in the V_1CV_2 bisyllabic stimuli. The only experimental variable to reach statistical significance was Rate. Group differences in the total duration of V_2 were nonsignificant (stutterers' $\bar{X} = 118.11$ msec, nonstutterers' $\bar{X} = 104.92$ msec) as were the main effects of Bisyllables (range 107.34 to 119.59 msec). All interactions were nonsignificant.

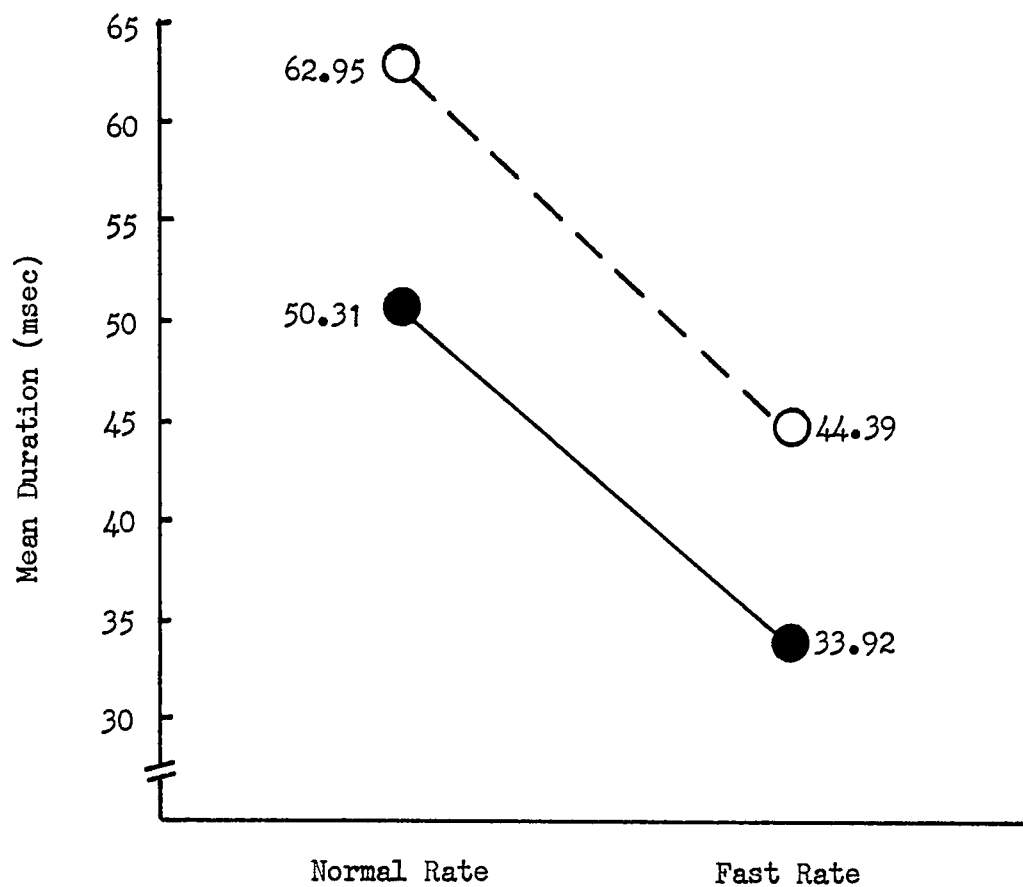


Figure 15. Mean Duration of V_2 Steady-State Portions for Stutterers (o--o) and Nonstutterers (●—●) at Normal and Fast Rates of Speech.

TABLE 13. Analysis of the Difference between the Mean Duration of the V_2 Steady-State for each of the Eight Bisyllables Utilizing the Tukey A Pairwise Procedures.

	Syllable						
	ibu	ugu	ubu	ubi	ibi	ugi	igi
Mean	40.59	42.56	44.73	45.43	53.23	56.09	66.16
igu	34.37	6.22	10.26	11.06	18.86**	21.72**	31.79**
ibu	40.59	1.97	4.14	4.84	12.64	15.50*	25.57**
ugu	42.56		2.17	2.87	10.67	13.53	23.60**
ubu	44.73			.70	8.5	11.36	21.43**
ubi	45.43				7.8	10.66	20.73**
ibi	53.23					2.86	12.93
ugi	56.09						10.07

MSE = 448.30, n = 40, N = 320, df = 270, r = 8

*Significant at the .05 level (critical value = 14.36)

**Significant at the .01 level (critical value = 16.71)

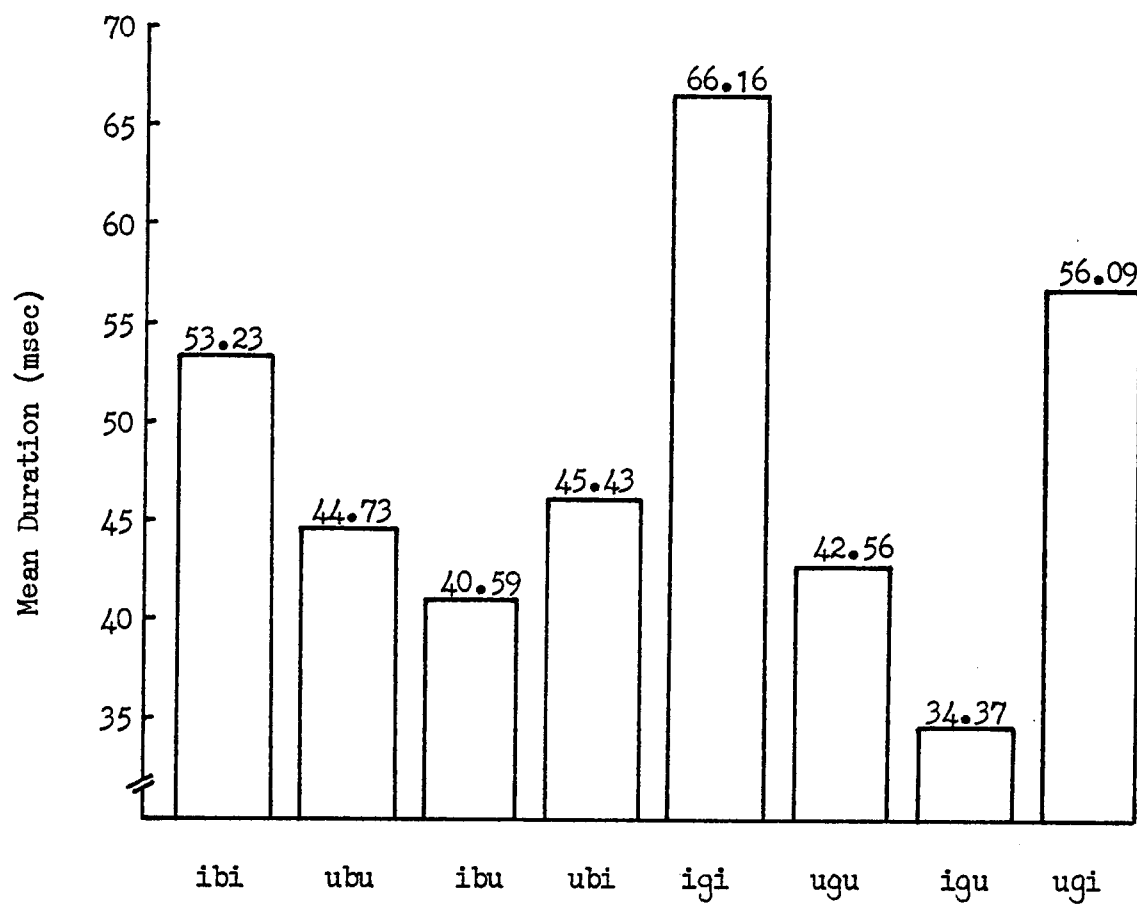


Figure 16. Mean Duration of V_2 Steady-State Portions for Each of the Eight Bisyllables.

TABLE 14. Analysis of Variance Summaries for the Mean Total Duration of V_2 .

	SS	df	MS	F
<u>Between</u>				
Group	13903.58	1	13903.58	1.86
Subject (Group)	135170.70	18	7509.48	
<u>Within</u>				
Syllable	6424.13	7	917.73	1.59
Rate	95292.46	1	95292.46	234.21*
Group x Rate	23.60	1	23.60	.03
Group x Syllable	2016.43	7	288.06	.50
Rate x Syllable	2848.04	7	406.86	.71
Group x Rate x Syllable	4787.43	7	683.92	1.19
Error	155385.30	270	575.50	

*Significant at the .0001 level.

Total durations of V_2 , as seen in Figure 17, were significantly different at normal ($\bar{X} = 128.77$ msec) as compared to fast ($\bar{X} = 94.26$ msec) rates of speech ($F = 234.21$, $p < .0001$). Vowel durations decreased 27 percent at fast rates when averaged over all subjects (25 percent by stutterers, 29 percent by nonstutterers). Overall vowel durations ranged from 120.87 to 138.05 msec at the normal rate and from 89.47 to 101.12 msec at the fast rate.

IX. VELOCITY OF V_1 TRANSITION

The difference in formant frequencies of V_1 measured at the vowel midpoint and at the end of the transition (data points H-I, page 33) was not significantly different (see Appendix E-1) between stutterers and nonstutterers ($\bar{X} = 144$ and 154 Hz, respectively), nor between normal and fast rates ($\bar{X} = 152$ and 146 Hz, respectively). This shift of frequency, corresponding to the numerator of the velocity equation, was tested per unit of time (the transition duration of V_1). The rate of change, or the velocity of vowel one transition, was significant for the factors of Group, Rate, and Bisyllable. Table 15 summarizes the analysis of variance for the velocity of the V_1 transition.

The velocity of V_1 transition among stutterers, averaged over both rate conditions, was .82 Hz/msec below that of nonstutterers. This difference is shown in Figure 18 and was statistically significant ($F = 5.00$, $p < .05$). The standard deviation associated with stutterers was 3.11 Hz/msec and 2.68 Hz/msec for nonstutterers.

Averaged over all subjects, greater articulatory velocities occurred at fast rates of speech. Velocity as a function of speaking rate was statistically significant ($F = 7.34$, $p < .03$). However Figure 19 shows

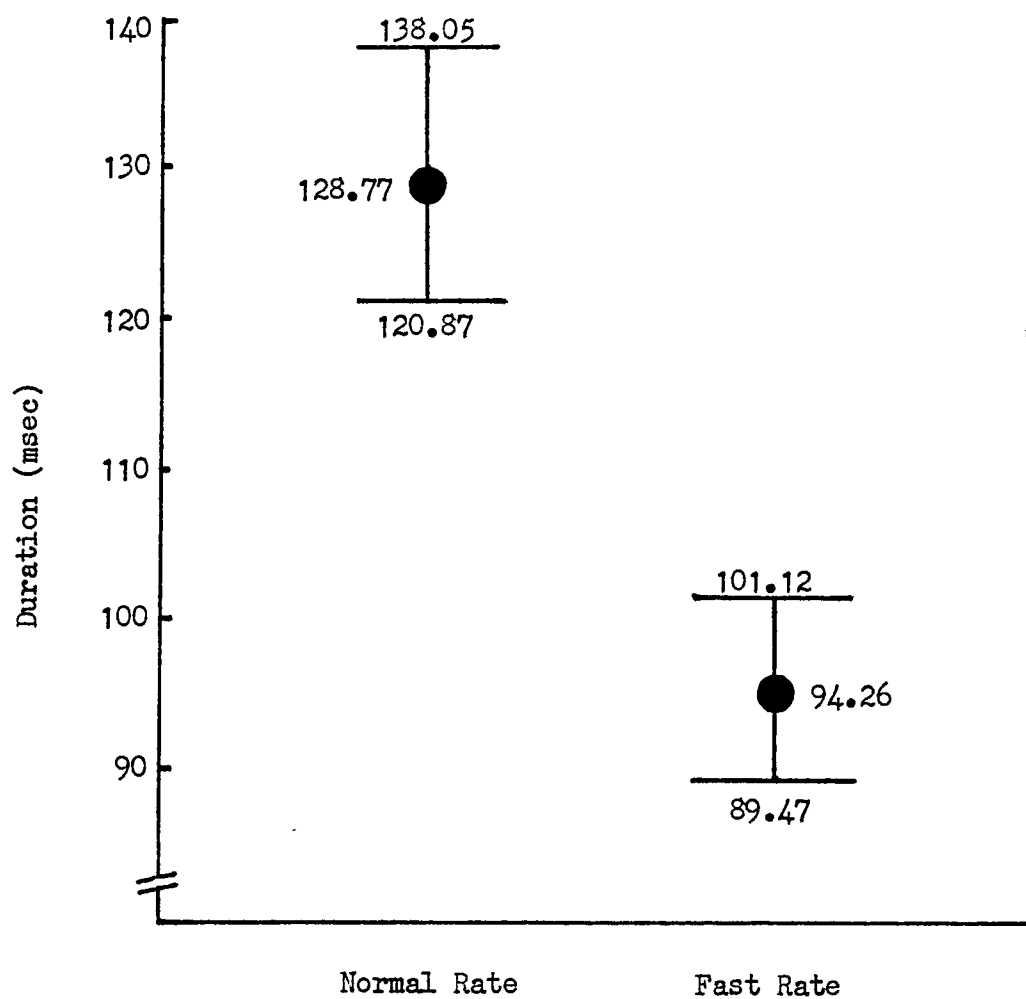


Figure 17. Range and Mean Duration of V_2 at Normal and Fast Rates of Speech.

TABLE 15. Analysis of Variance Summaries for the Mean Velocity of V_1 Transition.

	SS	df	MS	F
<u>Between</u>				
Group	53.20	1	53.20	5.00*
Subject (Group)	82.58	18	4.59	
<u>Within</u>				
Syllable	450.11	7	64.30	8.59**
Rate	15.94	1	15.94	7.34*
Group x Rate	15.58	1	15.58	2.08
Group x Syllable	52.81	7	7.54	1.01
Rate x Syllable	15.20	7	2.17	.29
Group x Rate x Syllable	25.82	7	3.69	.49
Error	2019.98	270	7.48	

*Significant at the .05 level

**Significant at the .0001 level

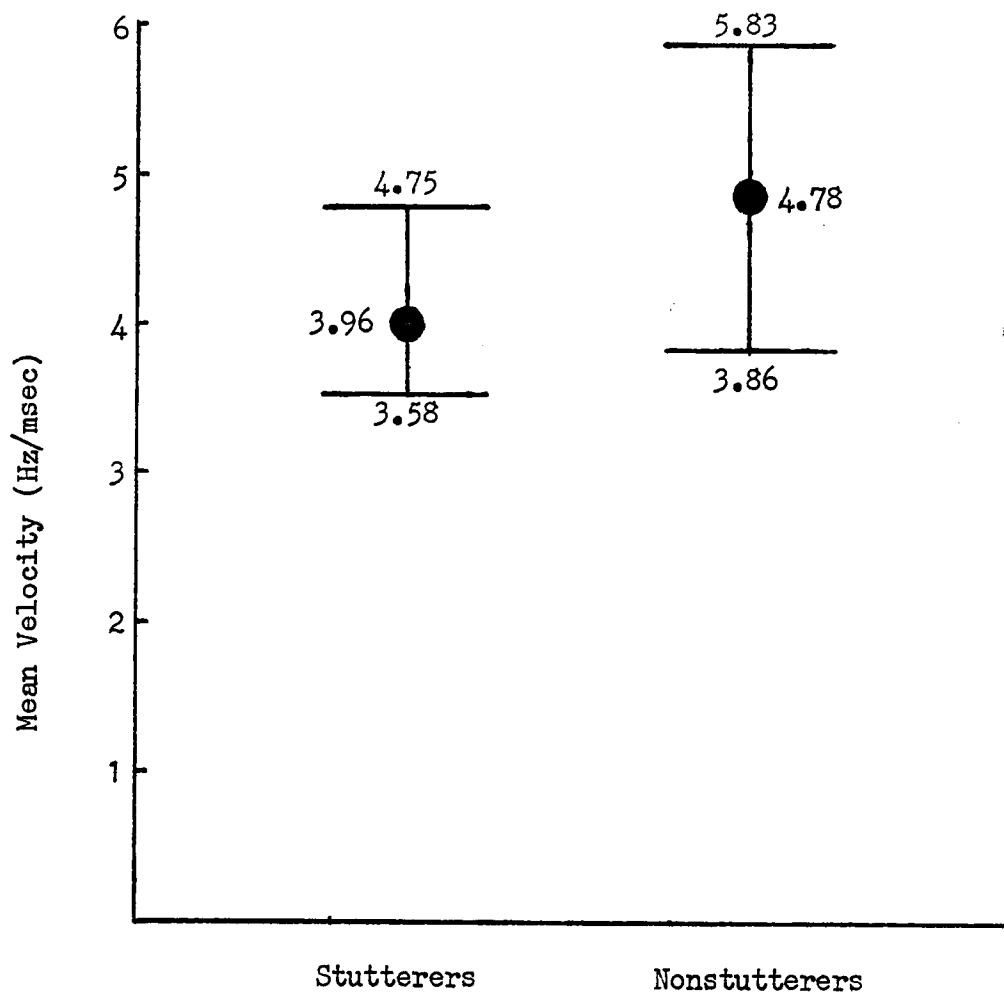


Figure 18. Range and Mean Velocity of V₁ Transition for Stutterers and Nonstutterers.

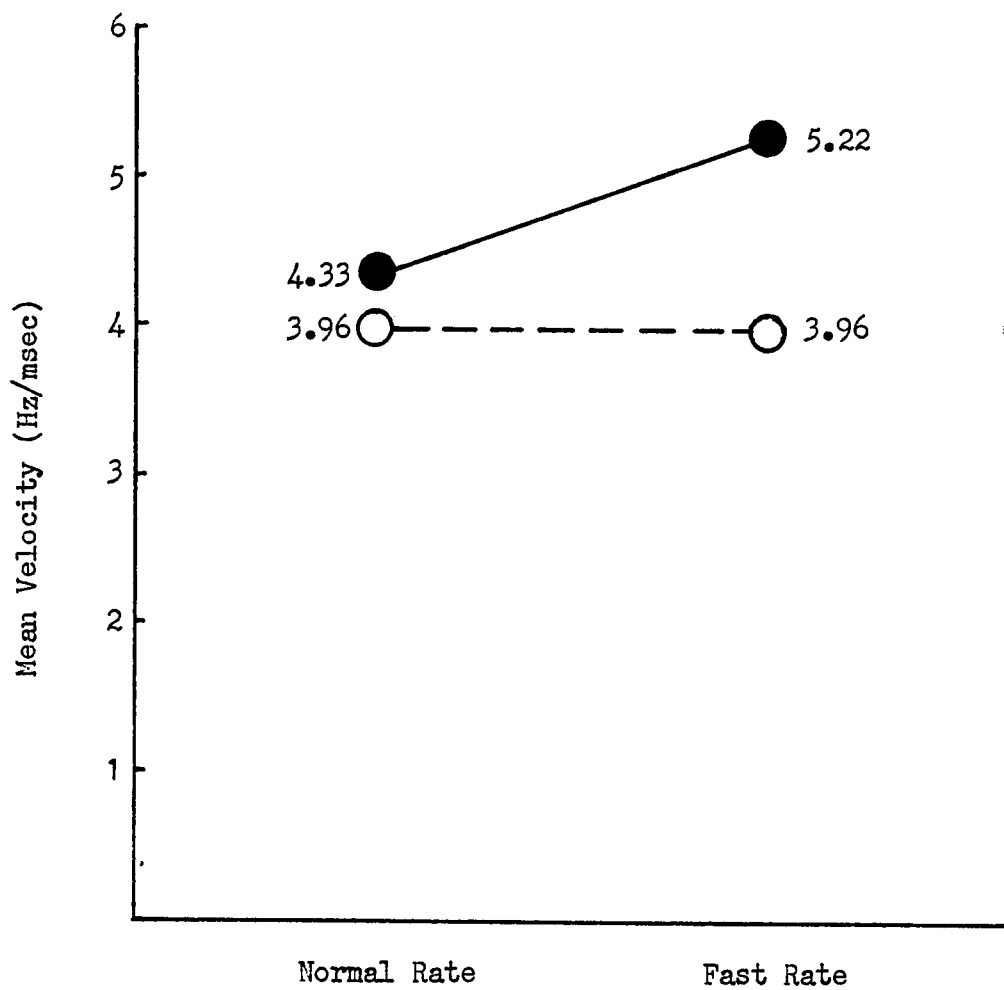


Figure 19. Mean Velocity of V_1 for Stutterers (o--o) and Nonstutterers (●—●) at Normal and Fast Rates.

that stutterers did not alter their articulatory velocities from one speaking rate to the next, while nonstutterers had a 21 percent increase (.9 Hz/msec) in articulatory velocity at fast rates of speech. This Group by Rate interaction failed to reach significance ($F = 4.22$, $p > .08$). Velocities of V_1 transition associated with the factor of Bisyllables were significantly different ($F = 8.59$, $p < .0001$). Post hoc testing using the Tukey A procedures for pairwise comparisons (Winer, 1971) yielded twelve significant mean differences (see Table 16). V_1CV_2 sequences involving /b/ were associated with greater V_1 transition velocities than those involving /g/. The trend was evident in the data from both stutterers and nonstutterers, however, velocities were generally lower for the stutterers. Mean velocities of stutterers and nonstutterers are compared in Figure 20.

X. VELOCITY OF V_2 TRANSITION

The frequency range through which the second vowel formant moved (data points J-K, page 33) was not significantly different (see Appendix E-2) between stutterers ($\bar{X} = 146.8$ Hz/msec) and nonstutterers ($\bar{X} = 146.2$ Hz/msec) nor between the two rate conditions (fast $\bar{X} = 132.5$, normal $\bar{X} = 160.5$ Hz/msec). Subsequent testing of this frequency range (numerator) within the transition time interval (denominator) yielded V_2 transition velocity information which proved significant for the main effects of Rate and Bisyllable. Results of this analysis of variance are presented in Table 17.

Significantly greater articulatory velocities occurred in the fast rate condition ($F = 12.00$, $p < .01$). Mean velocity of V_2 transitions, averaged over all subjects was 3.99 Hz/msec at the normal rate and 4.32

TABLE 16. Analysis of the Difference between the Mean Velocity of V_1 (in Hz/msec) for each of the Eight Bisyllables Utilizing the Tukey A Pairwise Procedures.

	Syllable					
	ugu	igu	ugi	ubi	ubu	ibu
Mean	3.24	3.42	3.52	4.62	5.65	5.89
igi	2.84	.40	.58	1.78	2.81*	3.05*
ugu	3.24	.18	.28	1.38	2.41*	2.65*
igu	3.42		.10	1.20	2.23*	2.47*
ugi	3.52			1.10	2.13*	2.37*
ubi	4.62				1.03	1.27
ubu	5.65					.24
ibi	5.78					.11

MSE = 7.48, $n = 40$, $N = 320$, $df = 270$, $r = 8$

*Significant at the .01 level (critical value = 2.16)

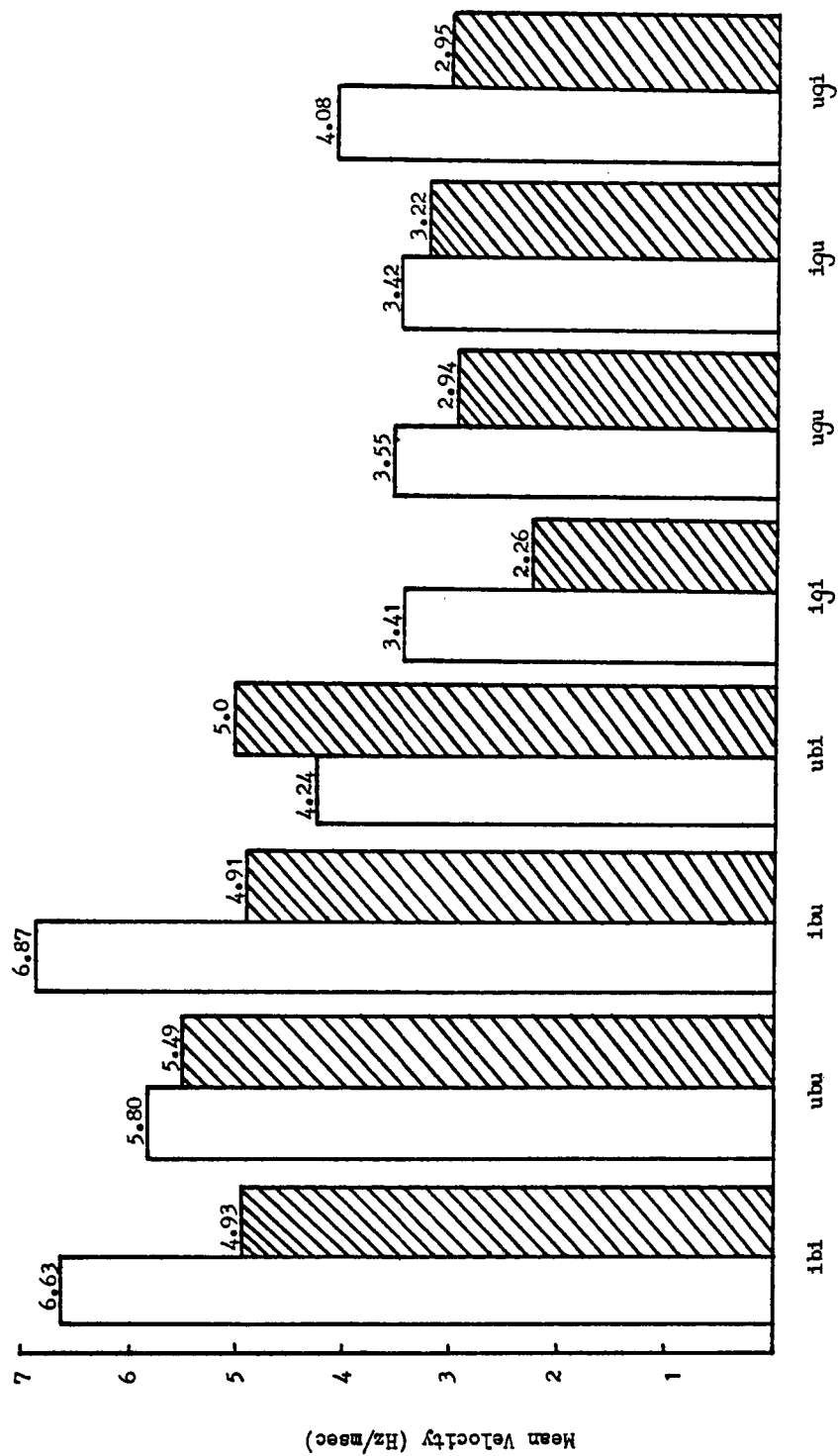


Figure 20. Mean Velocity of Vowel One per Bisyllable for Nonstutterers (□) and Stutterers (▨).

TABLE 17. Analysis of Variance Summaries for the Mean Velocity of V_2 Transition.

	SS	df	MS	F
<u>Between</u>				
Group	36.40	1	36.40	2.56
Subject (Group)	187.62	18	10.42	1.90
<u>Within</u>				
Syllable	506.88	7	72.41	13.17**
Rate	8.45	7	1.21	12.00*
Group x Rate	.93	1	.93	.25
Group x Syllable	41.56	7	5.94	1.08
Rate x Syllable	4.93	7	.70	.13
Group x Rate x Syllable	26.01	7	3.72	.68
Error	1484.14	270	5.50	

*Significant at the .01 level

**Significant at the .0001 level

Hz/msec at the fast rate. Stutterers increased articulatory velocities at fast rates by 6 percent (.22 Hz/msec), as seen in Figure 21. Non-stutterers exhibited more than a 9 percent (.43 Hz/msec) increase.

Velocities of V_2 transitions were significantly different among bisyllables ($F = 13.17$, $p < .0001$). Post hoc testing using the Tukey A procedures for pairwise comparisons (Winer, 1971) yielded 12 significant mean differences (see Table 18).

XI. SHIFT OF FREQUENCY

Table 19 summarizes the analysis of variance for the shift of frequency across the consonant in the V_1CV_2 bisyllabic stimuli. Group differences were nonsignificant (stutterers' $\bar{X} = 366.51$ Hz, nonstutterers' $\bar{X} = 358.87$ Hz) as were frequency differences due to Rate (normal $\bar{X} = 380.92$ Hz, fast $\bar{X} = 344.47$ Hz).

The shift of frequency was significantly different among bisyllables ($F = 58.94$, $p < .0001$). Post hoc testing using the Tukey A pairwise comparison procedures (Winer, 1971) yielded 22 significant mean comparisons (see Table 20). Figure 22 illustrates the mean shift of frequency per bisyllable. Frequency shifts were minimal for symmetric stimuli ($V_1 = V_2$). The shift of frequency for asymmetric stimuli ($V_1 \neq V_2$) was affected by the consonant's place of articulation. Dissimilar places of articulation between the consonant and V_2 caused larger frequency shifts, as in /ibu/ (front-front-back) versus /igu/ (front-back-back).

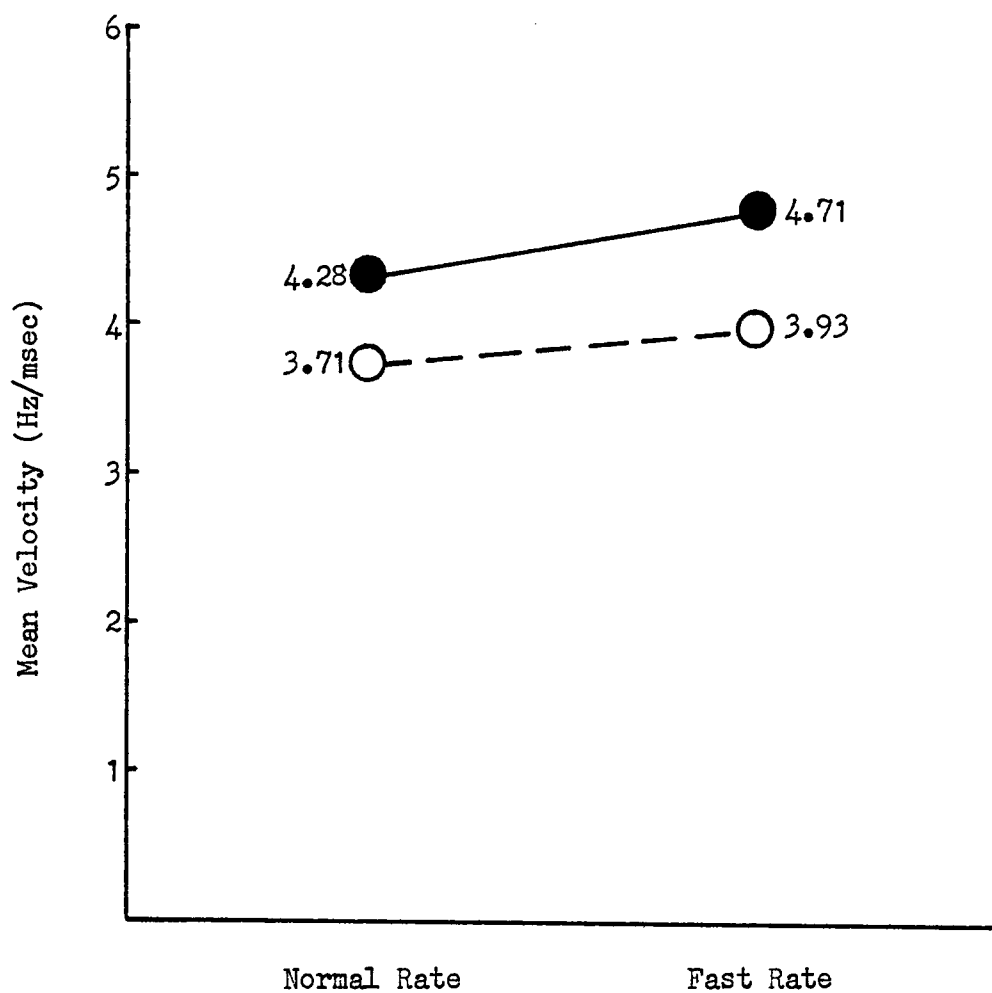


Figure 21. Mean Velocity of V_2 for Stutterers (○-○) and Nonstutterers (●—●) at Normal and Fast Rates.

TABLE 18. Analysis of the Difference between the Mean Velocity of V_2 (in Hz/msec) for each of the Eight Bisyllables Utilizing the Tukey A Pairwise Procedures.

Syllable							
	ugi	ugu	ibu	ubu	ibi	ubi	igu
Mean	3.03	3.29	3.74	3.74	4.53	5.81	6.45
igi	2.69	.34	1.05	1.05	1.84*	3.12*	3.76*
ugi	3.03	.26	.71	.71	1.50	2.78*	3.42*
ugu	3.29		.45	.45	1.24	2.52*	3.16*
ibu	3.74			.00	.79	2.07*	2.71*
ubu	3.74				.79	2.07*	2.71*
ibi	4.53					1.28	1.92*
ubi	5.81						.64

MSE = 5.50, n = 40, N = 320, df = 270, r = 8

*Significant at the .01 level (critical value = 1.85)

TABLE 19. Analysis of Variance Summaries for the Mean Shift of Frequency across the Consonant.

	SS	df	MS	F
<u>Between</u>				
Group	4670.79	1	4670.79	.16
Subject (Group)	4502045.17	18	250113.61	
<u>Within</u>				
Syllable	17008602.37	7	2429800.20	58.94*
Rate	106299.14	1	106299.14	3.79
Group x Rate	8207.33	1	8207.33	.66
Group x Syllable	315222.05	7	4503.15	1.09
Rate x Syllable	196075.19	7	28010.74	.68
Group x Rate x Syllable	87403.90	7	12486.27	.30
Error	11131460.02	270	41227.63	

*Significant at the .0001 level

TABLE 20. Analysis of the Difference between the Mean Shift of Frequency (in Hz) for each of the Eight Bisyllables Utilizing the Tukey A Pairwise Procedures.

	Syllable					
	ibi	ubu	ugu	igu	ubi	ugi
Mean	112.26	128.73	207.82**	498.46**	586.96**	643.87**
igi	100.98	11.28	106.84	397.48**	485.62**	521.50**
ibi	112.26	16.47	95.56	386.20**	474.70**	510.20**
ubu	128.73		79.09	369.73**	458.23**	493.75**
ugu	207.82			290.64**	379.14**	414.66**
igu	498.46				88.50	124.02
ubi	586.96					35.52
ibu	622.48					21.39

MSE = 41227.63, n = 40, N = 320, df = 270, r = 8

*Significant at the .05 level (critical value = 137.73)

**Significant at the .01 level (critical value = 160.22)

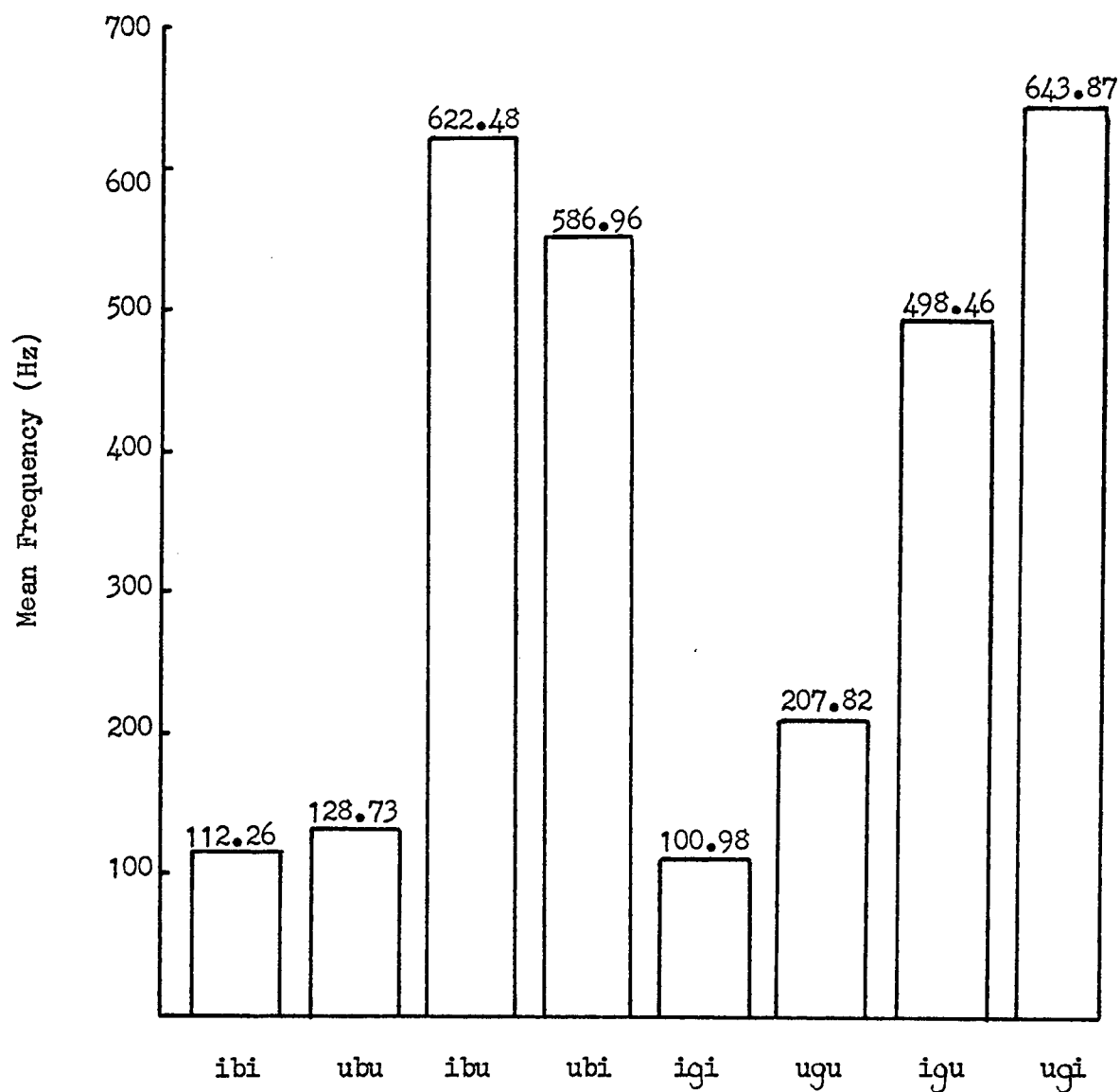


Figure 22. Mean Shift of Frequency Across the Intervocalic Consonant for Each of the Eight Bisyllables.

XII. SUMMARY OF RESULTS

Tables 21, 22, and 23 summarize the results of this study for the main effects of Group, Rate, and Bisyllable (respectively). The tables present average values and levels of significance for each of the ten criterion measures to emphasize group, rate and bisyllable differences.

In summary, with respect to VOT, stutterers exhibited significantly longer voice onset times than nonstutterers. On the average this difference was approximately 5 msec. VOT was decreased an average of nearly 13 percent at fast speaking rates, although stutterers continued to exhibit lengthened VOT. The voice onset times of stutterers at fast rates approximated but did not equal the VOT of nonstutterers at normal rates. Bisyllables involving the labial consonant /b/ had shorter voice onset times than the velar /g/, for both stutterers and nonstutterers. Although stutterers displayed this same pattern, their VOT values remained consistently higher than nonstutterers.

At normal speaking rates, stutterers spent 8 msec less in the V_1C transition. The two groups exhibited different magnitudes of transition reduction, with nonstutterers utilizing a 24 percent reduction while stutterers used only a 6 percent reduction. Transition durations were significantly different at the two rates of speech, averaged across all subjects. Asymmetric bisyllables exhibited longer V_1C transitions than did symmetric in nonstutterers. Stutterers generally upheld this same trend although exceptions existed. Furthermore stutterers employed shorter transitions in seven of the eight bisyllables.

TABLE 21. Summary of the Mean Values and Probability Levels
Obtained by Stutterers and Nonstutterers for the Ten
Criterion Measures.

Measures	Stutterers	Nonstutterers	Probability
Voice Onset Time (msec)	25.26	20.56	$p < .01$
V ₁ C Transition (msec)	29.06	33.43	NS*
V ₁ Steady-State (msec)	50.23	40.83	$p < .01$
V ₁ Total Duration (msec)	123.07	114.25	NS
CV ₂ Transition (msec)	28.96	33.35	NS
V ₂ Steady-State (msec)	53.67	42.12	NS
V ₂ Total Duration (msec)	118.11	104.92	NS
V ₁ Transition Velocity (Hz/msec)	3.96	4.78	$p < .05$
V ₂ Transition Velocity (Hz/msec)	3.82	4.50	NS
Frequency Shift (Hz)	366.51	358.87	NS

*NS denotes non-significance

TABLE 22. Summary of the Mean Values and Probability Levels
at Fast and Normal Rates for the Ten Criterion
Measures Averaged Across all Subjects.

Measures	Fast Rate	Normal Rate	Probability
Voice Onset Time (msec)	21.33	24.49	$p < .03$
V ₁ C Transition (msec)	28.44	34.04	$p < .02$
V ₁ Steady-State (msec)	40.12	50.94	$p < .0001$
V ₁ Total Duration (msec)	107.19	130.13	$p < .0001$
CV ₂ Transition (msec)	27.53	34.79	$p < .005$
V ₂ Steady-State (msec)	39.15	56.63	$p < .0001$
V ₂ Total Duration (msec)	94.26	128.77	$p < .0001$
V ₁ Transition Velocity (Hz/msec)	4.59	4.15	$p < .03$
V ₂ Transition Velocity (Hz/msec)	4.32	3.99	$p < .01$
Frequency Shift	344.47	380.92	NS*

*NS denotes non-significance

TABLE 23. Summary of the Mean Values and Probability Levels of the Bisyllabic Stimuli for the Ten Criterion Measures Averaged Across all Subjects.

Measures	ibi	ubu	ibu	ubi	igi	ugu	igu	ugi	p
Voice Onset Time (msec)	14.71	20.34	17.18	14.22	32.49	28.14	26.56	29.63	p < .0001
V ₁ C Transition (msec)	25.28	35.64	28.34	36.93	24.89	32.49	32.98	33.38	p < .02
V ₁ Steady-State (msec)	49.35	45.69	46.28	45.07	46.09	46.52	42.99	42.23	NS*
V ₁ Total Duration (msec)	125.61	114.85	120.67	110.80	125.41	117.41	122.85	111.69	p < .009
CV ₂ Transition (msec)	36.90	25.87	24.89	41.64	24.76	25.08	37.43	32.69	p < .0001
V ₂ Steady-State (msec)	53.23	44.73	40.59	45.43	66.16	42.56	34.37	56.09	p < .0001
V ₂ Total Duration (msec)	111.49	107.34	108.72	109.51	119.59	107.84	109.22	118.40	NS
V ₁ Velocity (Hz/msec)	5.78	5.65	5.89	4.62	2.84	3.24	3.42	3.52	p < .0001
V ₂ Velocity (Hz/msec)	4.53	3.74	3.74	5.81	2.69	3.29	6.45	3.03	p < .0001
Frequency Shift (Hz)	112.26	128.73	622.48	586.96	100.98	207.82	498.46	643.87	p < .0001

*NS denotes non-significance

Stutterers differed significantly from nonstutterers in the amount of articulatory time spent in the steady-state portions of V_1 . This difference averaged 10 msec. At both rates of speech, stutterers exhibited longer steady-state portions, although some reductions were made at fast rates.

Total durations of V_1 of stutterers averaged almost 9 msec longer than nonstutterers, however this difference was not statistically significant. Vowel durations were reduced significantly at fast rates of speech by both stutterers and nonstutterers. Stutterers, however, exhibited a smaller reduction at fast rates than did nonstutterers. Averaged across all subjects, durations of /i/ tended to be longer than of /u/.

The duration of the CV_2 transition averaged more than 4 msec shorter in stutterers than nonstutterers, although this difference was not statistically significant. At increased speaking rates, the duration of the transition was reduced 35 percent, averaged across all subjects. At both rates of speech, stutterers exhibited shorter transition durations. Phonetic environment also affected the durations of the CV_2 transitions.

Steady-state portions of V_2 averaged more than 11 msec longer in stutterers than nonstutterers. Furthermore stutterers employed longer steady-state durations at both rates of speech. Averaged across all subjects, rate of speech and bisyllabic phonetic environment significantly affected V_2 steady-state durations.

Stutterers and nonstutterers did not differ significantly in the durations of V_2 . Likewise the vowels in the bisyllabic stimuli did not differ. Vowel durations decreased an averaged of 27 percent at fast rates; stutterers and nonstutterers exhibited comparable decreases.

Stutterers exhibited significantly lower velocities for V_1 than nonstutterers. Furthermore stutterers did not alter their articulatory velocities from one speaking rate to the next. Averaged over all subjects, greater articulatory velocities occurred at fast rates of speech and in bisyllabic stimuli.

Velocities of V_2 were not significantly different between stuttees and nonstutterers although articulatory velocities of stutterers increased by smaller magnitudes at fast rates. Rate and bisyllabic environments significantly affected velocities of V_2 , averaged across all subjects.

The shift of frequency across the consonant was similar between stutterers and nonstutterers and between fast and normal rates. Frequency shifts differed in the bisyllabic stimuli, with symmetric V_1CV_2 sequences displaying minimal frequency shifts across the consonant.

In summary, Figure 23 illustrates some of the durational differences that were observed in the subsegments of stutterers and nonstutterers at both rates of speech. Although individual variability existed among the subjects, group and rate differences are apparent in the data.

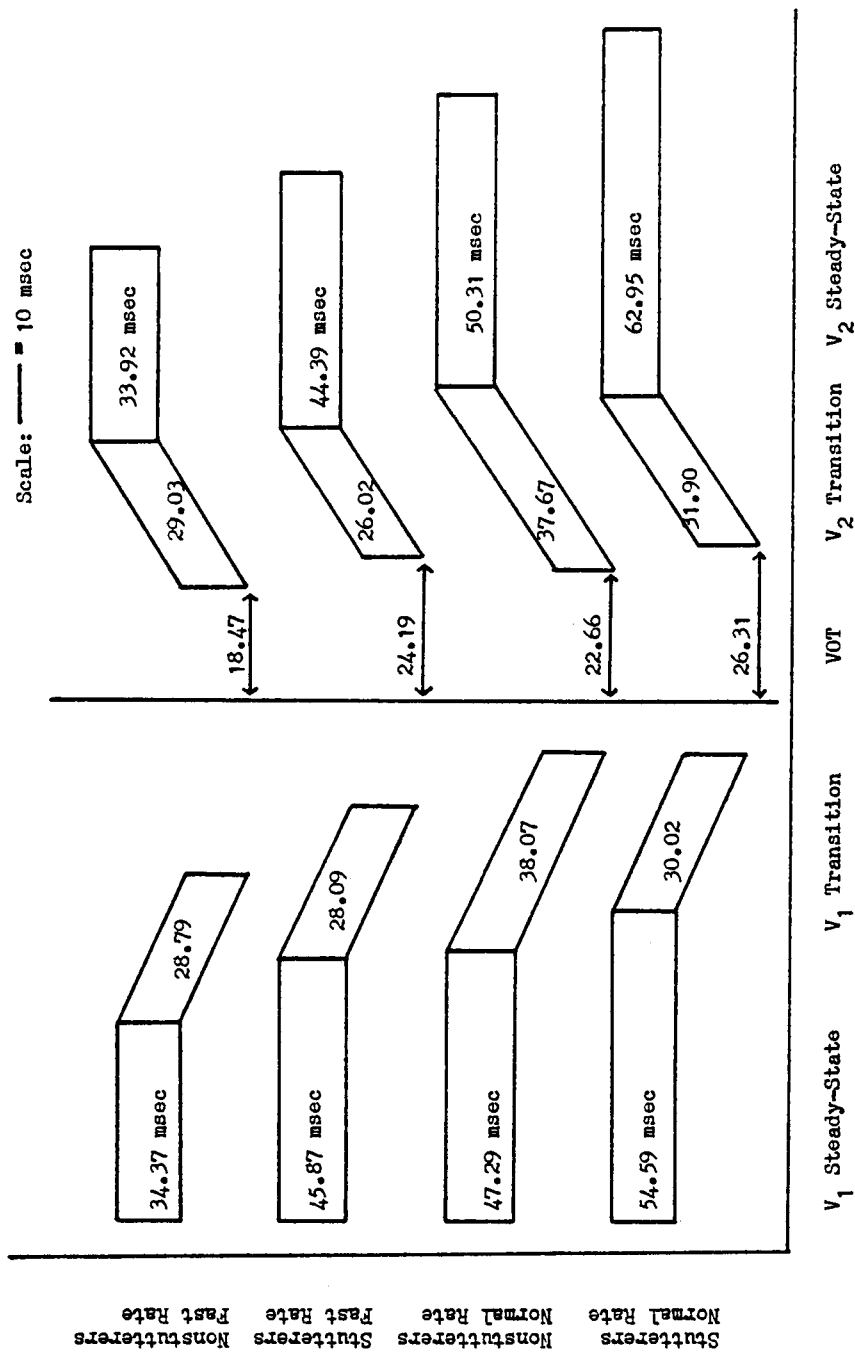


Figure 23. A Schematic of Second Formant Subsegment Durations of Stutterers and Nonstutterers at Two Rates of Speech.

CHAPTER IV

DISCUSSION

Results obtained in this study are discussed with respect to:

(1) group differences between stutterers and nonstutterers, (2) previous data reported in the literature on acoustical aspects of stuttered and nonstuttered speech, and (3) theoretical interpretations of results as related to current hypotheses of the nature of stuttering. Each of these points will be discussed relative to the criterion measures.

I. VOICE ONSET TIME

The group of stutterers involved in the present study displayed significantly longer voice onset times than did nonstutterers. Previous research also has shown stutterers to have longer voice onset times, but often of a greater magnitude than reported here.

The mean VOT for /b/ by stutterers was 18.76 msec and for nonstutterers 14.47 msec. Klatt (1975) used real-word stimuli containing /b/ in the initial position and embedded in carrier phrases. Voice onset times for normal subjects were reported to average 11 msec, over 3 msec less than the results of the present investigation. However Metz, Conture, and Caruso (1978), using stimuli similar to Klatt, obtained mean voice onset times of 13.5 msec for nonstutterers which is similar to the mean VOT of 14.47 msec for nonstutterers in the present study. The mean VOT for stutterers reported by Metz, et al. for /b/ was 27.8 msec, more than 9 msec longer than that found in the present results.

Voice onset times for /g/ averaged 29.19 msec for all subjects combined. The mean VOT for stutterers was 31.75 msec and for

nonstutterers 26.66 msec. These data for nonstutterers are in almost perfect agreement with the 27 msec average reported by Klatt (1975), but less than the 32.7 msec VOT for /g/ reported by Metz, et al. (1978). Likewise the VOT data on /g/ for stutterers are consistently less than the 41.8 msec average reported by Metz, et al.

As shown in Figure 5 (page 40), voice onset time was decreased an average of 13 percent at fast rates. This result agrees with data reported on normal speakers. Gay (1978) measured durations of consonant (stop gap) closure (equivalent in Gay's definition to VOT) for /p/ at normal and fast rates of speech, and reported reductions of 5 to 10 percent, depending on phonetic environment. Lisker and Abramson (1964, 1967) demonstrated, cross-culturally, that VOT varied with speaking rate and linguistic stress. The reason for this variance was hypothesized to be either that plosive closure duration is shorter in rapid speech and the glottis does not have time to fully open, or there may be a reduction in the muscular effort expended to abduct the vocal folds in rapid speech (Klatt, 1975).

Voice onset time among stutterers was significantly longer than among nonstutterers at both rates of speech (see Figure 5, page 40). Stutterers displayed a minimal (8 percent) reduction in VOT at fast rates. One possible explanation is that their speech programming mechanism and/or peripheral muscular execution system (at the larynx) operates under a greater time constraint than do nonstutterers. Such a time constraint may reflect that stutterers are operating at or near their system's reaction time capacity. With specific reference to VOT, stutterers' laryngeal systems may be performing near the limits of their competence level for rapid movement patterns.

Ignoring group differences, it may be seen that bisyllables involving the labial phoneme /b/ had shorter voice onset times than back-of-the-cavity (velar) productions of /g/ (see Figure 6, page 43). Short voice onset times for labial plosives and long voice onset times for velar plosives have been reported previously by Lisker and Abramson (1964), Klatt (1975), and Hillman and Gilbert (1977).

The inherent differences in burst durations for labials and velars have been explained by Klatt (1975) on the basis of the time course of the pressure developed across the oral closure following release. A labial release is rapid and the generated burst spectrum is weak in intensity because there is no resonator in front of the lips (Fant, 1960). Both factors contribute to the acoustic appearance of a short burst. A velar release, on the other hand, involves the entire tongue body. The constriction increases in area more slowly, due in part to the mass involved, and in part to the fact that the release vector of the tongue motion is usually not perpendicular to the long dimension of the acoustic tube formed by the vocal tract (Houde, 1967).

Figure 6 (page 43) displays VOT as a function of the Group and Bisyllable interaction. The figure demonstrates that although stutterers have longer voice onset times, the VOT duration behaves in a "lawful" or normal pattern in that the same consonant trends (/b/ < /g/) and the same vowel-consonant-vowel combination trends are apparent. This may be an indication that the speech programming mechanism (or perhaps the laryngeal system) operates in a lawful or systematic manner, but is delayed in time in stutterers, leading to a lengthened VOT.

II. VOCALIC TRANSITIONS

The mean duration of the V_1C transition was more than 4 msec shorter in stutterers than nonstutterers. Similarly, stutterers' CV_2 transitions averaged more than 10 msec shorter than nonstutterers. In general, the data suggest that stutterers tended to spend less articulatory time in vowel transitions.

The tendency for the present population of stutterers to exhibit shorter transition durations is in direct conflict with the results of Starkweather and Myers (1978). Starkweather and Myers reported that stutterers exhibited lengthened transitions but that steady-state durations were comparable to nonstutterers. The present investigation clearly shows that temporal disruptions cannot be attributed solely to the transitions. While stutterers apparently do not move their laryngeal and supralaryngeal structures as quickly as nonstutterers—this is not the whole problem. Temporal differences existed even in steady-state portions. The results of the present study are, however, in agreement with Zimmermann (1979) who, using cineradiography, reported stutterers took longer time within and between articulatory gestures than did nonstutterers.

The amount of time spent by stutterers in the transitions at fast rates of speech approximated the transition durations of nonstutterers at normal rates of speech. In executing fast speaking rates the two groups exhibited different amounts of transition reduction relative to their respective normal rates. Perhaps stutterers use different strategies for rate changes in that they are operating near their competence limit for rapid transitional movements, even at normal rates.

Trying to produce a faster movement change (i.e. shorter transitional durations) would put an even greater strain on their near competence operating level. This hypothesis would agree with the observed results of a transition duration change of little magnitude ($V_1 = 6$ percent, $V_2 = 18$ percent) in comparison with the magnitude of change exhibited by the nonstutterers ($V_1 = 24$ percent, $V_2 = 23$ percent).

Average transition durations of both the first and second vowels ranged from 26 to 46 msec at normal rates, and 19 to 37 msec at fast rates. At increased speaking rates, the duration of the transition was reduced approximately 5 to 7 msec. Gay (1978) reported that for normal speakers at fast rates, transition time was reduced some 5 to 10 msec. Gay's transition times ranged from 40 to 50 msec at the slow speaking rate and 35 to 45 msec for fast rates. Gay's values appear consistent with the present results.

Transition duration varied significantly with respect to the V_1CV_2 bisyllabic stimuli. In contrast, Gay (1978) stated that transition durations were relatively stable across vowels, when examined in CVC stimuli. The present results seem more in concordance with coarticulatory data (Daniloff and Moll, 1968; Kuehn and Tomblin, 1974) than do Gay's. The transition duration is related to phonetic environment. Some contexts allow for overlapping (nonconflicting) movements to begin at an earlier point in time.

CV_2 transition durations were longer in /bi/ combinations than in /bu/ combinations (see Figure 14, page 63). This is a pattern consistent with previous acoustic literature. Lehiste and Peterson (1961) reported consonant-vowel transition durations (from CVC stimuli) averaged 66 msec for /bi/ and 33 msec for /bu/ in normal speakers. In contrast with

Lehiste and Peterson, shorter transitions were not observed for labial consonant-vowel environments when compared to lingua-velar consonant-vowel environments.

III. STEADY-STATE VOCALIC PORTIONS

Stutterers differed significantly from nonstutterers in the amount of articulatory time spent in the steady-state portions of V_1 . Stutterers' steady-state portions averaged approximately 10 msec longer than nonstutterers. Similarly, the steady-state portions of V_2 averaged 11.55 msec longer in stutterers than nonstutterers. Furthermore stutterers operated consistently with longer steady-state portions at both normal and fast rates of speech. The amount of time spent in steady-states by stutterers at fast rates approximated the steady-state time by nonstutterers at normal speaking rates.

The results reported by Starkweather and Myers (1978) are in conflict with the present finding of longer steady-state vocalic portions in stutterers. Starkweather and Myers studied only one intervocalic interval and reported that speech subsegments corresponding to vocal tract steady-states were comparable in the 12 stutterers and 12 nonstutterers. Zimmermann (1979) however, reported cineradiographic results consistent with the observation of lengthened steady-states in stutterers.

The present data suggest two speculative interpretations. In as much as steady-state vocalic portions represent relatively stable vocal tract configurations, it may be argued that the speech production mechanism in stutterers is temporally upset. Perhaps the time-plan for executing movement onsets is disrupted, resulting in a rather sluggish ability to initiate coarticulatory transitional movements. A somewhat

related explanation may be that there is no initiation problem, but the overall time-plan is just proportionately different per speech subsegment as compared to normal adult behavior.

IV. TOTAL VOWEL DURATIONS

Total vowel durations of stutterers at normal rates averaged 130 msec for V_1 and 135 msec for V_2 . Nonstutterers displayed similar vowel durations in that V_1 averaged 130 msec, and V_2 averaged 122 msec. Group differences were not significant at the two rates of speech. In contrast, Di Simoni (1974) reported that vowel durations in final plosive consonant contexts were 200 msec for nonstutterers and 337 msec for stutterers.

Vowel durations for both V_1 and V_2 at a normal rate of speech ranged from approximately 121 to 144 msec, while the range at fast rates was from 89 to 114 msec. Gay (1978) reported vowel durations to be in the range 105 to 165 msec at slow rates of speech in CVC stimuli, while at fast rates, durations averaged 20 to 35 msec less. Peterson and Lehiste (1960) reported vowel durations in CVC stimuli and spoken at normal rates to be approximately 245 msec. Klatt (1975) reported vowel durations in connected discourse to average 110 msec.

Nonstutterers displayed a 24 percent reduction in vowel durations at fast rates which is consistent with the 26 percent durational decrease reported by Gay (1978). Furthermore, both stutterers and nonstutterers displayed a comparable reduction for V_2 , and this value was also consistent with Gay's data.

Total vowel duration varied as a function of bisyllable. As seen in Figure 12 (page 58), the consonant contributed little to the significant differences obtained. This is consistent with previous research.

House and Fairbanks (1953) provided data on vowel durations in bisyllabic stimuli. Vowel durations in the /g/ environment averaged 239 msec, while durations in the /b/ environment were similar, averaging 237 msec.

Mean comparisons of the same bisyllables indicated however, that the vowel /i/ had a longer duration than /u/. This is in disagreement with Lehiste and Peterson (1961) who classified both /i/ and /u/ as long or tense vowels based on temporal measures and with Lehiste (1970) who reported /u/ to have a longer intrinsic duration than /i/. Gay (1978), in contrast, reported no durational differences in the two vowels. Specifically, Gay stated that the duration of both /i/ and /u/ was 120 msec at a normal rate and 90 msec at a fast rate.

V. VELOCITY OF MOVEMENT

In discussing frequency shifts per unit of time, Liberman, et al. (1956) stated that varying the duration of the transition also varies the rate of change, or velocity, so long as the frequency extent of the transition remains constant. The converse situation would also hold true. The extent of the frequency shifts of the V_1 and V_2 transitions proved nonsignificant between stutterers and nonstutterers; differences averaged 10 Hz for V_1 and less than 1 Hz for V_2 . Subsequently, the velocity during V_1 was significantly lower in stutterers than nonstutterers, but not during V_2 . These equivocal results do not adequately address the issue of stutterers' ability to execute large articulatory velocities. The mean results suggest however that stutterers' velocities are somewhat lower than nonstutterers. This is consistent with results reported by Zimmermann (1979). It may

be said, however that stutterers were able to produce articulatory movements of appropriate speed, at least in the normal rate condition.

Averaged over all subjects, greater articulatory velocities occurred at fast rates of speech. However Figure 19 (page 74) shows that stutterers did not alter their articulatory velocities from one speaking rate to the next in V_1 , while nonstutterers had a 21 percent increase at fast rates. In V_2 , stutterers increased velocity 6 percent and nonstutterers 9 percent at fast rates. Gay (1978) reported that vowel velocities "remained essentially unaffected across the two rates." His data however, based on four normal speakers, show velocity changes of the same magnitude reported here. Gay did not test the significance of the velocity changes.

Velocities associated with the eight bisyllables were significantly different. Sequences involving /b/ typically were associated with greater velocities, possibly because the tongue had farther to move from the V_1 to V_2 position. Production of /b/ is bilabial and has no conflicting tongue command. In contrast, for production of /g/, the tongue is moving into a /g/ position then on to the V_2 position. Since /g/ has a bimodal placement distribution (Halle, Hughes, and Radley, 1957) in that it can assume anterior or posterior articulatory placements of neighboring vowels, the tongue would have a shorter distance to move.

VI. SHIFT OF FREQUENCY

The symmetrical and asymmetrical sequences provide an index of coarticulation across the consonant. The articulatory position, or frequency at the end of the V_1 transition, should reflect the upcoming vowel (forward coarticulation). Likewise, the V_2 initial transition

should reflect the preceding vowel (backward coarticulation). This amount of movement, or shift of frequency, was not significantly different between stutterers and nonstutterers. This suggests therefore that stutterers displayed shifts of frequency indicative of normal patterns of forward and backward coarticulation. This result, considered with durational differences in the speech of stutterers suggests that stutterers eventually executed coarticulatory movements, but that their initiation was delayed.

VII. THEORETICAL IMPLICATIONS

The results of the present investigation do not necessarily support the interpretation that longer voice onset times are an indication of laryngeal dysfunction in stutterers (Adams and Reis, 1971; Hillman and Gilbert, 1977; Starkweather, Hirschman, and Tannenbaum, 1976). The laryngeal dysfunction hypothesis does not appear supported in that durations of many of the speech subsegments studied were aberrant in stutterers and these subsegments represent supralaryngeal events as well as laryngeal events.

The present data also suggested that stutterers tended to spend less articulatory time in vowel transitions. In as much as the transitions presumably reflect the changes in the oral cavities that occur as the articulators alter their positions (Liberman, et al., 1956), this result may suggest that stuttering is indeed a "phonetic transition defect" (Wingate, 1969). Such a definition of stuttering becomes less tenable, however, in that the present results not only showed mean transition differences, but also temporal disruption in other speech subsegments, such as VOT and steady-state portions of vowels.

The finding of no significant vowel durational differences between stutterers and nonstutterers is interesting in light of stutterers displaying longer steady-states but shorter transitions. Perhaps within the speech production mechanism there is some sort of temporal compensation to maintain a constant vowel duration. Temporal compensation was discussed by Allen (1970) as the effect which operates to modify the durations of internal segments of articulatory units in (repeated) productions so that the overall duration of the unit remains relatively constant.

Similarly, Cooper and Allen (1977) discussed a theoretical "neural clock" or timing control process governing speech segment durations. In a repetition task, they observed stutterers to be less accurate speech timers than nonstutterers. Stutterers, as a group, exhibited slower timing programs and greater timing variability. The present results agree somewhat with this notion of a less accurate neural clock among stutterers in that they displayed aberrant speech subsegmental durations. In contrast, however, the concept of a less accurate neural clock was not supported in the data of total vowel durations since stutterers were not significantly different from nonstutterers.

In the first chapter the question was posed: Is the preprogrammed mechanism governing forward coarticulation (1) chronically aberrant in stutterers or (2) just prone to intermittent asynchrony? The results of this study, in as much as it shows timing/ durational aberrations in fluent speech, would provide greater support for the "chronically aberrant" explanation. This hypothesized mechanism apparently operated in a lawful manner in the stutterers in that relatively accurate frequency targets were achieved for the phonemes and that transitions did occur in

the right direction, but these events did not begin and terminate at the point in time expected from the matched normative data.

What is clear, then, from the present study, is that temporal differences exist in the fluent speech of stutterers. Furthermore these temporal differences are not confined to isolated speech subsegments (as only during transitions, or only with vocalization onset), but apparently pervade the entire speech stream. Theoretically, since the temporal aberrations are not confined to a single part of the speech production mechanism, such as the phonatory-articulatory or steady-state vocal tract configurations, the cause of the temporal aberration must be somewhere more central in the nervous system rather than at these peripheral sites. Stutterers were apparently able to produce appropriate articulatory movements but appeared to delay the initiation of these coarticulatory movements. This suggests an involvement in the planning or integration of articulatory movements rather than difficulties in capabilities for the execution of movement.

Perhaps Van Riper (1971) was correct in discussing stuttering as a timing disorder. The results of the study suggest that even during fluency, stutterers exhibit abnormal timing relationships. Possibly this chronic state of temporal aberrations is a precursor to even greater temporal disruptions which are seen as disfluencies.

It is possible that aberrant speech timing is only one aspect of a syndrome of Central Nervous System timing aberrations. This view is supported by research comparing stutterers and nonstutterers on non-speech tasks. Ringel and Minifie (1966) suggest that stutterers have a "receptive" disability in making durational judgments of external stimuli. McFarland (1976) investigated the neural response time by

stutterers and nonstutterers in a reaction time paradigm to rapid lip closure in response to an auditory stimulus. Stutterers displayed significantly longer response times on this task. Similarly, Luper and Cross (1978) observed slower finger reaction times in stutterers when asked to respond as quickly as possible to the onset of pure tones. The data presented in this study do not allow for more than intuitive speculation in this regard. The trends in the data do suggest, however, that differences exist in phoneme subsegments and in certain aspects of the timing of fluent sequences in stutterers.

CHAPTER V

SUMMARY AND CONCLUSIONS

The research attempted to answer questions concerning coarticulatory timing and attainment of frequency targets in perceptually fluent speech of adult, male stutterers and nonstutterers. The specific acoustic characteristics assessed were: voice onset time; transition, steady-state, and total vowel durations; velocity of movement through the transitions; and the amount of the shift in frequency across the consonant in selected V_1CV_2 sequences. These characteristics were assessed in two rate conditions: (1) the speaker's own judgment of a normal rate of speech, and (2) a fast rate of speech. A fast rate was operationally defined as a minimum of two seconds shorter than the time to complete five repetitions of the experimental utterance at a normal rate.

Recordings were made of each subject reading a constant carrier phrase into which a changing medial bisyllable was embedded ("Say the word ___ please"). The bisyllabic stimuli consisted of a vowel-consonant-vowel, in which the voiced plosives, /b, g/, and the vowels, /i, u/, were used. Four symmetric and four asymmetric stimuli were thus constructed.

Wideband, linear-expand spectrograms were made of the recorded stimulus items. Only fluent (medial) repetitions were analyzed for acoustic characteristics.

Temporal delays, as measured at the second formant, occurred within the speech intervals of voice onset time, vocalic transitions, and steady-state portions. The data concerning stutterers' velocity of movement

are equivocal but suggest adequate articulatory speed at normal rates of speech. The specific conclusions, regarding group differences, drawn from the results of this study are:

1. Stutterers differ significantly from nonstutterers in voice onset time. The observed difference was approximately 4 msec at a normal rate of speech and 6 msec at a fast rate.

2. Stutterers, on the average, spent less time in vocalic transitions than did nonstutterers. At normal rates stutterers' transitions averaged 6 to 8 msec less than nonstutterers. At fast rates the two groups performed similarly, as stutterers exhibited up to 3 msec shorter transitions.

3. Stutterers averaged longer steady-state durations than nonstutterers. At normal rates stutterers' steady-state portions averaged 7 to 13 msec longer, while at fast rates differences were approximately 11 to 12 msec longer than those of nonstutterers.

4. The durations of the total vocalic elements were comparable between stutterers and nonstutterers. Greater similarities were observed at normal speaking rates than at fast rates.

5. Results regarding overall velocity of the transitional movement are equivocal. There was a tendency for stutterers to exhibit smaller velocities and this difference was even greater at fast rates of speech.

6. Stutterers did not differ significantly from nonstutterers in the amount of frequency shift across the consonant in the V_1CV_2 sequences.

In as much as physiological movement can be inferred from changes in the acoustic signal, the observed results suggest that temporal disruptions exist in the perceptually fluent speech of stutterers.

These disruptions in timing were observed in articulatory-phonatory and steady-state patterns. It may be hypothesized, since temporal aberrations were observed through-out the speech subsegments, that the cause of the temporal aberrations is a central problem. Stutterers were apparently able to produce transitional shifts appropriate to the phonetic environment, but they appeared to delay the initiation of these coarticulatory movements. This suggests an involvement in the planning or integration of articulatory movements rather than difficulties with movement execution. An alternate hypothesis is that aberrant speech timing is only one aspect of central timing disruption. Reaction time data on nonspeech tasks support such an explanation. Further research should examine this relationship.

Acoustic characteristics of stutterers' speech, as investigated here, should be assessed concurrently with nonspeech reaction times in the same subjects. A reaction time paradigm investigating two types of nonspeech tasks would yield maximal information to address this timing relationship. Nonspeech movements of oral structures, such as done by McFarland (1976), may share neural pathways and centers for planning and integration with those for speech movements. Nonspeech, manual reaction time tasks, such as done by Luper and Cross (1978) with the finger, would yield central timing information on unshared pathways and speech motor planning center.

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APPENDICES

APPENDIX A

DESCRIPTION OF SUBJECTS

TABLE A-1. Chronological Age of Subjects, Self-Rated Severity of Disfluency, and Percentage of Disfluency.

Subject		Age	Self-Rating*	Disfluency**
1	Stutterer	26	Mild	23%
1	Nonstutterer	26	—	3%
2	Stutterer	25	Mild	5%
2	Nonstutterer	25	—	0%
3	Stutterer	29	Mild	27%
3	Nonstutterer	27	—	3%
4	Stutterer	32	Severe	32%
4	Nonstutterer	31	—	0%
5	Stutterer	18	Moderate	22%
5	Nonstutterer	18	—	1%
6	Stutterer	22	Mild	5%
6	Nonstutterer	24	—	3%
7	Stutterer	28	Mild	5%
7	Nonstutterer	27	—	6%
8	Stutterer	26	Moderate	8%
8	Nonstutterer	25	—	0%
9	Stutterer	27	Mild	3%
9	Nonstutterer	27	—	0%
10	Stutterer	25	Moderate	1%
10	Nonstutterer	24	—	1%

* Stutterers were asked to rate the severity of their stuttering "at the present time" in their life, using the scale: mild, moderate, severe.

** Percentage of disfluency in reading the 98-word "Rainbow" passage aloud (see Appendix B), as computed by number of disfluent words divided by total words.

APPENDIX B

MATERIALS USED IN EXPERIMENTAL PROCEDURES

Instructions to the Subjects

The purpose of this study is to measure your ability to speak nonmeaningful syllables at normal and fast rates of speech. You will be seated in this sound-treated booth and a microphone will be placed six inches from your mouth. Please sit comfortably but keep the microphone six inches from your mouth at all times so that the loudness of your voice on the tape recording will not change. Start counting out loud so that I may be sure you are not talking too loudly or softly into the microphone. . . .

You will be handed a series of index cards. The sentence, "Say the word ____ please" appears on each. The blank is filled in with nonmeaningful syllables such as "oogee." Let's practice reading these together so you will know how to pronounce each syllable . . . (correct and model as needed).

What I want you to do today is say each of the sentences five times in a row. First you will do this at what you think is your normal rate of speech. Try one now and let me time what your normal rate is. . . . After you go through the stack of cards, saying each five times in a row at your normal speed, you will repeat the cards again saying each five times but using a fast rate of speech. Try to say the sentence on this card five times at a fast rate while I time it. . . . (Depending on response time, say: Good that was fast enough and I want you to use that same speed when I ask you again, or Let's try that one again just a little faster.)

You can pause, rest, or get a drink of water between cards, but while you are on a particular card you need to say the sentence five times in a row before stopping. Do not be concerned if you stumble in your speech at any time or are disfluent. Raise your hand each time you mispronounce any part of the sentence, or if you feel you are being disfluent, or struggling to speak. I will stay in the booth with you to note these occurrences. I may simply ask you to repeat that card again. Also if your speed of talking changes too much I will let you know and have you try again.

Before we begin, please read and sign this consent form. Then I will have you read a short paragraph into the microphone. Remember to keep the microphone six inches from your mouth at all times.

Passage³ Read Aloud to Determine Percentage of Disfluency

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

³Grant Fairbanks, Voice and Articulation Drillbook (New York: Harper and Row, 1937), p. 127.

TABLE B-1. Score Sheet Used to Code the Occurrence of Disfluencies.

Stimuli	Normal Rate					Fast Rate				
Say the word eebee please.	1	2	3	4	5*	1	2	3	4	5
Say the word eeboo please.	1	2	3	4	5	1	2	3	4	5
Say the word oobee please.	1	2	3	4	5	1	2	3	4	5
Say the word ooboo please.	1	2	3	4	5	1	2	3	4	5
Say the word eegee please.	1	2	3	4	5	1	2	3	4	5
Say the word eegoo please.	1	2	3	4	5	1	2	3	4	5
Say the word oogee please.	1	2	3	4	5	1	2	3	4	5
Say the word oogoo please.	1	2	3	4	5	1	2	3	4	5

*Draw a circle around the number of the utterance which the subject perceived as disfluent and a slash through the number the investigator perceived as disfluent or unacceptable.

APPENDIX C

SUMMARY OF THE STATISTICAL DESIGN

Experimental Factors

A = Group, fixed effect

C = Bisyllable, random effect

B = Rate, fixed effect

D_(A) = Subject(Group), random effect

Experimental Model

$$Y = \mu + A + B + C + D_{(A)} + AB + AC + BC + ABC + e$$

General Variance Expression

$$\sigma_e^2 + nbc\sigma_A^2 + nac\sigma_B^2 + nab\sigma_C^2 + nabc\sigma_{D_{(A)}}^2 + nc\sigma_{AB}^2 + nb\sigma_{AC}^2 + na\sigma_{BC}^2 + n\sigma_{ABC}^2$$

Expected Values of Mean Squares

$$A = \sigma_e^2 + nbc \frac{\sum A^2}{a-1} + nb\sigma_{AC}^2 + nabc\sigma_{D_{(A)}}^2$$

$$B = \sigma_e^2 + nac \frac{\sum B^2}{b-1} + na \frac{\sum BC^2}{(b-1)(c-1)}$$

$$C = \sigma_e^2 + nab\sigma_C^2$$

$$AB = \sigma_e^2 + nc\sigma_{AB}^2 + n\sigma_{ABC}^2$$

$$AC = \sigma_e^2 + nb\sigma_{AC}^2$$

$$BC = \sigma_e^2 + na\sigma_{BC}^2$$

$$ABC = \sigma_e^2 + n\sigma_{ABC}^2$$

$$D_{(A)} = \sigma_e^2 + nabc\sigma_{D_{(A)}}^2$$

Tests of Null Hypotheses

From the formulas, unbiased estimates of all the components of variance were obtained as linear combinations of the mean squares in the analysis of variance. The null hypothesis that any component was zero, was tested using the following as numerators and denominators to obtain the F-ratio:

Factor B by BC interaction

Factor C by Error term

AB interaction by ABC interaction

AC interaction by Error term

BC interaction by Error term

ABC interaction by Error term

For factor A, no single mean square (MS) in the analysis of variance was an appropriate denominator. An approximate F-test was obtained:

$$F' = \frac{MS\ A + MS\ Error}{MS\ D_{(A)} + MS\ AC}$$

The approximate degrees of freedom were:

$$n_1 = \frac{(MS\ A + MS\ Error)^2}{\left(\frac{MS\ A}{df}\right)^2 + \left(\frac{MS\ Error}{df}\right)^2}$$

$$n_2 = \frac{(MS\ D_{(A)} + MS\ AC)^2}{\left(\frac{MS\ D_{(A)}}{df}\right)^2 + \left(\frac{MS\ AC}{df}\right)^2}$$

APPENDIX D

RAW DATA FOR CRITERION MEASURES

TABLE D-1. Voice Onset Time Data for Individual Subjects at Each Rate and for Each Syllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	11.85	39.50	15.80	19.75	7.90	27.65	15.80	15.80	11.85	43.45	20.94
		ubu	23.70	59.25	7.90	7.90	27.65	23.70	19.75	15.80	43.45	23.70	25.28
		ibu	15.80	23.70	11.85	31.60	11.85	11.85	15.80	15.80	23.70	15.80	17.78
		ubi	7.90	11.85	15.80	23.70	23.70	19.75	11.85	11.85	23.70	11.85	16.20
		igi	39.50	55.30	23.70	59.25	55.30	31.60	31.60	23.70	23.70	47.40	39.11
		ugu	31.60	27.65	39.50	63.20	23.70	39.50	11.85	35.55	39.50	35.55	34.76
		igu	39.50	23.70	27.65	31.60	15.80	31.60	31.60	35.55	23.70	19.75	28.05
		ugi	43.45	23.70	15.80	15.80	43.45	23.70	23.70	31.60	31.60	31.60	28.44
		ibi	11.85	7.90	15.80	7.90	7.90	15.80	15.80	11.85	11.85	15.80	12.25
		ubu	11.85	15.80	3.95	23.70	19.75	23.70	35.55	19.75	7.90	27.65	18.96
Nonstutterer	Normal	ibu	3.95	7.90	11.85	11.85	23.70	11.85	11.85	15.80	7.90	15.80	12.25
		ubi	7.90	15.80	11.85	7.90	39.50	11.85	11.85	11.85	11.85	23.70	15.41
		igi	31.60	47.40	15.80	19.75	35.55	23.70	23.70	39.50	35.55	47.40	31.99
		ugu	27.65	39.50	23.70	23.70	27.65	23.70	15.80	27.65	19.75	47.40	27.65
		igu	19.75	23.70	27.65	31.60	27.65	19.75	51.35	31.60	23.70	31.60	28.84
		ugi	39.50	43.45	31.60	35.55	19.75	31.60	47.40	27.65	23.70	39.50	33.97
		ibi	11.85	11.85	11.85	15.80	7.90	15.80	11.85	15.80	19.75	11.85	13.43
		ubu	15.80	55.30	19.75	7.90	15.80	27.65	7.90	15.80	11.85	23.70	20.15
		ibu	15.80	15.80	11.85	35.55	35.55	27.65	15.80	7.90	31.60	15.80	21.33
		ubi	15.80	11.85	19.75	15.80	15.80	23.70	7.90	15.80	7.90	15.80	15.01
Stutterer	Fast	igi	31.60	27.65	31.60	23.70	47.40	47.40	19.75	31.60	35.55	35.55	33.18
		ugu	23.70	23.70	23.70	43.45	15.80	39.50	11.85	31.60	27.65	47.40	28.84
		igu	19.75	19.75	15.80	47.40	43.45	27.65	23.70	31.60	31.60	27.65	28.84
		ugi	15.80	11.85	35.55	15.80	31.60	39.50	27.65	63.20	55.30	31.60	32.79
		ibi	3.95	15.80	7.90	15.80	7.90	15.80	15.80	11.85	11.85	15.80	12.25
		ubu	19.75	19.75	7.90	11.85	31.60	23.70	15.80	11.85	11.85	15.80	16.99
		ibu	11.85	15.80	15.80	7.90	7.90	23.70	27.65	15.80	23.70	23.70	17.38
		ubi	3.95	15.80	7.90	7.90	11.85	15.80	11.85	7.90	7.90	11.85	10.27
		igi	27.65	15.80	19.75	15.80	23.70	55.30	31.60	15.80	27.65	23.70	25.68
		ugu	19.75	15.80	7.90	11.85	31.60	23.70	27.65	31.60	11.85	31.60	21.33
Nonstutterer	Fast	igu	15.80	15.80	15.80	15.80	15.80	23.70	15.80	19.75	27.65	39.50	20.54
		ugi	19.75	31.60	7.90	19.75	27.65	31.60	15.80	19.75	31.60	27.65	23.31

TABLE D-2. V₁C Transition Data for Individual Subjects at Each Rate and for Each Bisyllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	47.40	19.75	31.60	23.70	23.70	27.65	27.65	31.60	47.40	19.75	30.02
		ubu	31.60	15.80	39.50	0.0	75.05	35.55	15.80	39.50	0.0	43.45	29.63
		ibu	39.50	15.80	31.60	35.55	39.50	35.55	47.40	0.0	35.55	23.70	30.42
		ubi	31.60	35.55	27.65	79.00	51.35	67.15	0.0	59.25	23.70	0.0	37.53
		igi	15.80	47.40	31.60	0.0	15.80	47.40	0.0	0.0	35.55	39.50	23.31
		ugu	43.45	47.40	67.15	39.50	0.0	0.0	0.0	71.10	63.20	43.45	37.53
		igu	0.0	39.50	11.85	0.0	0.0	47.40	43.45	39.50	27.65	31.60	24.10
		ugi	23.70	27.65	0.0	35.55	0.0	47.40	0.0	63.20	43.45	35.55	27.65
		ibi	23.70	27.65	23.70	51.35	23.70	47.40	39.50	27.65	19.75	27.65	31.21
		ubu	47.40	39.50	55.30	47.40	47.40	67.15	27.65	35.55	23.70	31.60	42.27
Nonstutterer	Normal	ibu	15.80	27.65	23.70	39.50	43.45	27.65	43.45	27.65	15.80	47.40	31.21
		ubi	67.15	35.55	63.20	35.55	63.20	43.45	23.70	55.30	55.30	0.0	40.69
		igi	51.35	35.55	33.20	39.50	31.60	23.70	19.75	39.50	31.60	39.50	37.53
		ugu	71.10	59.25	35.55	47.40	27.65	35.55	43.45	0.0	43.45	23.70	38.71
		igu	23.70	47.40	39.50	35.55	35.55	23.70	43.45	82.95	23.70	35.55	39.11
		ugi	63.20	43.45	63.20	43.45	27.65	79.00	23.70	27.65	43.45	23.70	43.85
		ibi	0.0	23.70	23.70	15.80	23.70	35.55	27.65	27.65	0.0	0.0	17.78
		ubu	0.0	47.40	39.50	55.30	59.25	31.60	31.60	39.50	39.50	31.60	37.53
		ibu	39.50	15.80	35.55	71.10	0.0	47.40	35.55	23.70	19.75	15.80	30.42
		ubi	15.80	23.70	47.40	86.90	35.55	0.0	23.70	23.70	23.70	55.30	33.58
Stutterer	Fast	igi	0.0	0.0	31.60	31.60	0.0	35.55	51.35	0.0	0.0	0.0	15.01
		ugu	31.60	0.0	0.0	75.05	51.35	0.0	0.0	27.65	55.30	31.60	27.26
		igu	43.45	23.70	31.60	47.40	35.55	43.45	35.55	0.0	31.60	0.0	29.23
		ugi	15.80	51.35	0.0	31.60	0.0	90.85	19.75	35.55	94.80	0.0	33.97
		ibi	43.45	11.85	23.70	31.60	15.80	15.80	19.75	19.75	7.90	31.60	22.12
		ubu	63.20	23.70	11.85	63.20	27.65	23.70	19.75	43.45	31.60	23.70	33.18
		ibu	19.75	19.75	23.70	23.70	15.80	15.80	23.70	27.65	23.70	19.75	21.33
		ubi	55.30	15.80	31.60	59.25	39.50	27.65	39.50	47.40	23.70	19.75	35.95
		igi	0.0	47.40	0.0	39.50	0.0	19.75	35.55	39.50	31.60	23.70	23.70
		ugu	23.70	27.65	55.30	23.70	43.45	15.80	19.75	31.60	23.70	0.0	26.47
		igu	63.20	51.35	39.50	55.30	15.80	35.55	35.55	15.80	51.35	31.60	39.50
Nonstutterer	Fast	ugi	19.75	23.70	67.15	43.45	27.65	0.0	23.70	35.55	19.75	19.75	28.05

TABLE D-3. V_1 Steady-State Data for Individual Subjects at Each Rate and for Each Hissyllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	43.45	79.00	82.95	118.50	79.00	122.45	98.75	51.35	63.20	63.20	60.19
		ubu	59.25	19.75	39.50	39.50	67.15	169.85	51.35	86.90	35.55	75.05	54.39
		ibu	67.15	47.40	39.50	75.05	75.05	102.70	35.55	71.10	79.00	86.90	57.94
		ubi	47.40	47.40	19.75	39.50	86.90	102.70	118.50	79.00	79.00	79.00	49.92
		igi	31.60	71.10	79.00	39.50	51.35	134.30	118.50	98.75	114.55	71.10	50.98
		ugu	47.40	82.95	47.40	51.35	142.20	106.65	79.00	90.85	63.20	94.80	60.58
		igu	31.60	55.30	47.40	130.35	86.90	51.35	43.45	55.30	142.20	79.00	52.29
		ugi	39.50	55.30	23.70	90.85	150.10	67.15	55.30	31.60	55.30	35.55	50.44
		ibi	75.05	39.50	63.20	51.35	35.55	43.45	63.20	51.35	75.05	39.50	53.72
		ubu	23.70	47.40	55.30	59.25	39.50	55.30	47.40	35.55	35.55	71.10	47.01
Nonstutterer Normal	Normal	ibu	55.30	39.50	47.40	35.55	47.40	55.30	59.25	39.50	71.10	31.60	48.19
		ubi	31.60	27.65	39.50	59.25	47.40	39.50	39.50	63.20	71.10	43.45	46.22
		igi	126.40	59.25	31.60	59.25	39.50	39.50	86.90	79.00	59.25	35.55	51.62
		ugu	47.40	39.50	31.60	75.05	31.60	39.50	47.40	31.60	63.20	51.35	45.82
		igu	39.50	35.55	43.45	63.20	39.50	55.30	39.50	39.50	51.35	47.40	45.43
		ugi	27.65	47.40	31.60	55.30	39.50	35.55	27.65	23.70	75.05	39.50	40.29
		ibi	59.25	51.35	102.70	102.70	47.40	55.30	39.50	31.60	94.80	63.20	44.78
		ubu	23.70	71.10	23.70	79.00	79.00	43.45	59.25	47.40	47.40	31.60	50.56
		ibu	23.70	31.60	47.40	71.10	51.35	23.70	31.60	55.30	27.65	55.30	41.87
		ubi	23.70	35.55	51.35	39.50	59.25	90.85	79.00	35.55	27.65	39.50	48.19
Stutterer Fast	Fast	igi	27.65	55.30	86.90	31.60	27.65	55.30	55.30	47.40	59.25	19.75	46.61
		ugu	35.55	31.60	86.90	51.35	67.15	43.45	126.40	63.20	39.50	39.50	48.46
		igu	19.75	47.40	43.45	35.55	31.60	63.20	47.40	23.70	55.30	27.65	39.50
		ugi	35.55	35.55	35.55	43.45	47.40	43.45	27.65	71.10	67.15	63.20	47.01
		ibi	35.55	39.50	31.60	47.50	51.35	15.80	39.50	19.75	67.15	39.50	38.71
		ubu	43.45	39.50	31.60	27.65	31.60	23.70	15.80	39.50	31.60	23.70	30.81
		ibu	39.50	47.40	23.70	47.40	35.55	31.60	43.45	19.75	39.50	43.45	37.13
		ubi	79.00	27.65	47.40	23.70	39.50	11.85	15.80	27.65	39.50	47.40	35.95
		igi	43.45	31.60	71.10	47.40	31.60	15.80	27.65	19.75	31.60	31.60	35.16
		ugu	15.80	27.65	19.75	31.60	27.65	15.80	31.60	39.50	67.15	35.55	31.21
		igu	23.70	27.65	27.65	59.25	27.65	31.60	43.45	23.70	43.45	39.50	34.76
Nonstutterer Fast	Fast	ugi	35.55	19.75	35.55	31.60	27.65	31.60	31.60	39.50	39.50	19.75	31.21

TABLE D-4. V_1 Total Duration Data for Individual Subjects at Each Rate and for Each Bisyllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	118.50	142.20	114.55	142.20	134.30	150.10	126.40	165.90	165.90	134.30	139.44
		ubu	90.85	35.55	79.00	86.90	142.20	205.40	126.40	185.65	67.15	118.50	113.76
		ibu	106.65	110.60	94.80	110.60	158.00	173.80	142.20	165.90	161.95	106.65	133.12
		ubi	79.00	86.90	82.95	173.80	138.25	169.85	118.50	134.30	126.40	126.40	123.64
		ig1	75.05	142.20	110.60	122.45	185.65	181.70	177.75	189.60	150.10	110.60	144.57
		ugu	90.85	169.85	114.55	86.90	142.20	106.65	118.50	213.30	126.40	138.25	130.75
		iqu	67.15	173.80	102.70	130.35	138.25	150.10	126.40	150.10	169.85	161.95	137.07
		uq1	63.20	126.40	110.60	126.40	150.10	114.55	118.50	122.45	158.00	118.50	120.87
		ibi	161.95	134.30	173.80	150.10	98.75	146.15	134.30	142.20	126.40	102.70	137.07
		ubu	158.00	138.25	110.60	161.95	134.30	146.15	102.70	102.70	102.70	158.00	131.54
Nonstutterer	Normal	ibu	154.05	118.50	106.65	142.20	106.65	126.40	102.70	118.50	118.50	126.40	122.06
		ubi	126.40	122.45	102.70	165.90	110.60	138.25	118.50	118.50	126.40	118.50	124.82
		ig1	177.75	209.35	138.25	154.05	110.60	126.40	134.30	146.15	118.50	118.50	143.39
		ugu	118.50	158.00	142.20	158.00	134.30	110.60	130.35	126.40	106.65	110.60	129.56
		iqu	130.35	118.50	150.10	150.10	106.65	150.10	126.40	122.45	114.55	126.40	129.56
		uq1	126.40	134.30	138.25	130.35	94.80	114.55	75.05	134.30	118.50	142.20	120.87
		ibi	86.90	110.60	126.40	118.50	154.05	110.60	114.55	118.50	142.20	102.70	118.50
		ubu	79.00	118.50	106.65	134.30	142.20	114.55	94.80	134.30	150.10	110.60	118.50
		ibu	94.80	98.75	161.95	142.20	134.30	130.35	134.30	181.70	98.75	126.40	130.35
		ubi	63.20	82.95	102.70	126.40	94.80	90.85	102.70	118.50	90.85	138.25	101.12
Stutterer	Fast	ig1	67.15	122.45	114.55	86.90	102.70	130.35	169.85	126.40	126.40	114.55	116.13
		ugu	59.25	102.70	86.90	173.80	158.00	67.15	126.40	146.15	118.50	110.60	114.95
		iqu	90.85	94.80	114.55	82.95	118.50	181.70	126.40	122.45	134.30	98.75	116.53
		uq1	51.35	110.60	75.05	106.65	173.80	134.30	47.40	134.30	161.95	102.70	109.81
		ibi	126.40	110.60	102.70	142.25	106.65	75.05	86.90	102.70	114.55	126.40	107.44
		ubu	106.65	79.00	118.50	126.40	82.95	63.20	94.80	82.95	98.75	102.70	95.59
		ibu	126.40	98.75	79.00	118.50	71.10	71.10	94.80	86.90	118.50	106.65	97.17
		ubi	134.30	63.20	79.00	110.60	79.00	55.30	110.60	94.80	102.70	106.65	95.59
		ig1	138.25	110.60	102.70	122.45	75.05	55.30	90.85	86.90	75.05	118.50	97.57
		ugu	79.00	98.75	75.05	118.50	71.10	75.05	102.70	122.45	90.85	110.60	94.41
		iqu	122.45	118.50	114.55	154.05	94.80	67.15	106.65	82.95	94.80	126.40	108.23
Nonstutterer	Fast	uq1	98.75	82.95	102.70	118.50	90.85	63.20	94.80	106.65	114.55	79.00	95.20

TABLE D-5. CV₂ Transition Data for Individual Subjects at Each Rate and for Each Bisyllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	35.55	0.0	31.60	0.0	15.80	98.75	67.15	102.70	82.95	0.0	33.45
		ubu	31.60	0.0	15.80	47.40	27.65	43.45	43.45	47.40	0.0	0.0	25.68
		ibu	23.70	35.55	35.55	0.0	27.65	23.70	35.55	35.55	47.40	0.0	26.47
		ubi	31.60	31.60	35.55	67.15	31.60	71.10	67.15	118.50	31.60	47.40	43.33
		igi	15.80	75.05	15.80	0.0	27.65	0.0	51.35	110.60	27.65	0.0	22.39
		ugu	27.65	0.0	19.75	71.10	0.0	0.0	0.0	47.40	59.25	27.65	25.28
		igu	47.40	15.80	19.75	15.80	59.25	47.40	31.60	75.05	27.65	51.35	39.11
		ugi	11.85	47.40	43.45	86.90	0.0	39.50	0.0	71.10	67.15	27.65	39.50
		ibi	63.20	47.40	31.60	51.35	35.55	75.05	31.60	71.10	39.50	15.80	46.22
		ubu	27.65	55.30	27.65	35.55	43.45	27.65	31.60	7.90	43.45	23.70	32.39
Nonstutterer	Normal	ibu	7.90	31.60	19.75	35.55	39.50	23.70	23.70	27.65	59.25	11.85	28.05
		ubi	82.95	47.40	19.75	79.00	39.50	51.35	39.50	51.35	47.40	27.65	48.59
		igi	23.70	47.40	27.65	35.55	31.60	23.70	43.45	31.60	15.80	23.70	30.42
		ugu	55.30	27.65	27.65	55.30	11.85	67.15	43.45	27.65	31.60	31.60	37.92
		igu	39.50	11.85	19.75	55.30	27.65	63.20	23.70	35.55	47.40	39.50	36.34
		ugi	47.40	23.70	31.60	51.35	39.50	35.55	43.45	51.35	59.25	31.60	41.48
		ibi	35.55	0.0	31.60	0.0	15.80	98.75	67.15	102.70	82.95	0.0	30.02
		ubu	31.60	0.0	15.80	47.40	27.65	43.45	43.45	47.40	0.0	0.0	20.94
		ibu	23.70	35.55	35.55	0.0	27.65	23.70	35.55	35.55	47.40	0.0	23.70
		ubi	31.60	31.60	35.55	67.15	31.60	71.10	67.15	118.50	31.60	47.40	37.92
Stutterer	Fast	igi	15.80	75.05	15.80	0.0	27.65	0.0	51.35	110.60	27.65	0.0	22.12
		ugu	27.65	0.0	19.75	71.10	0.0	0.0	0.0	47.40	59.25	27.65	11.46
		igu	47.40	15.80	19.75	15.80	59.25	47.40	31.60	75.05	27.65	51.35	44.24
		ugi	11.85	47.40	43.45	86.90	0.0	39.50	0.0	71.10	67.15	27.65	17.78
		ibi	63.20	31.60	35.55	39.50	31.60	43.45	23.70	35.55	31.60	43.45	37.92
		ubu	23.70	27.65	43.45	19.75	11.85	15.80	27.65	23.70	35.55	15.80	24.49
		ibu	23.70	23.70	19.75	23.70	31.60	23.70	15.80	15.80	11.85	23.70	21.33
		ubi	71.10	23.70	23.70	31.60	39.50	43.45	39.50	31.60	47.40	15.80	36.74
		igi	43.45	19.75	31.60	23.70	19.75	15.80	15.80	31.60	15.80	23.70	24.10
		ugu	27.65	23.70	11.85	43.45	15.80	27.65	35.55	0.0	23.70	47.40	25.68
Nonstutterer	Fast	igu	35.55	31.60	27.65	47.40	23.70	39.50	27.65	19.75	11.85	35.55	30.02
		ugi	31.60	39.50	51.35	15.80	19.75	39.50	23.70	31.60	35.55	31.60	31.99

TABLE D-6. V_2 Steady-State Data for Individual Subjects at Each Rate and for Each Syllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	47.40	90.85	86.90	23.70	55.30	63.20	47.40	51.35	110.60	122.45	69.92
		ubu	35.55	75.05	47.40	75.05	31.60	134.30	11.85	39.50	106.65	71.10	62.81
		ibu	39.50	43.45	23.70	94.80	51.35	67.15	51.35	55.30	39.50	71.10	53.72
		ubi	31.60	79.00	71.10	35.55	39.50	79.00	90.85	51.35	35.55	71.10	58.46
		igi	11.85	47.40	142.20	67.15	23.70	189.60	98.75	94.80	82.95	63.20	82.16
		ugu	39.50	47.40	35.55	86.90	71.10	90.85	94.80	55.30	47.40	31.60	60.04
		igu	15.80	31.60	23.70	35.55	23.70	55.30	35.55	71.10	23.70	59.25	37.53
		ugi	31.60	31.60	79.00	63.20	90.85	158.00	59.25	94.80	122.45	59.25	79.00
		ibi	79.00	39.50	47.40	43.45	39.50	47.40	39.50	43.45	114.55	31.60	52.54
		ubu	55.30	51.35	27.65	43.45	47.40	39.50	47.40	23.70	47.40	47.40	43.06
Nonstutterer	Normal	ibu	71.10	82.95	19.75	43.45	31.60	55.30	27.65	31.60	63.20	19.75	44.64
		ubi	63.20	43.45	47.40	43.45	43.45	67.15	55.30	35.55	122.45	39.50	56.09
		igi	154.05	79.00	63.20	55.30	63.20	71.10	55.30	63.20	79.00	23.70	70.71
		ugu	23.70	122.45	23.70	35.55	55.30	31.60	39.50	39.50	23.70	31.60	42.66
		igu	27.65	134.30	27.65	43.45	27.65	39.50	15.80	19.75	55.30	23.70	41.48
		ugi	47.40	43.45	55.30	63.20	51.35	67.15	39.50	51.35	75.05	19.75	51.35
		ibi	31.60	63.20	55.30	23.70	39.50	35.55	71.10	43.45	63.20	98.75	52.54
		ubu	19.75	31.60	43.45	0.0	27.65	71.10	55.30	27.65	47.40	55.30	37.92
		ibu	43.45	27.65	35.55	19.75	23.70	43.45	43.45	39.50	63.20	43.45	38.32
		ubi	23.70	31.60	35.55	23.70	27.65	51.35	27.65	27.65	55.30	55.30	35.95
Stutterer	Fast	igi	31.60	39.50	94.80	31.60	55.30	51.35	43.45	71.10	118.50	75.05	61.23
		ugu	19.75	55.30	31.60	23.70	35.55	55.30	55.30	31.60	47.40	47.40	40.29
		igu	43.45	23.70	15.80	35.55	15.80	63.20	23.70	35.55	31.60	55.30	34.37
		ugi	19.75	98.75	27.65	63.20	31.60	67.15	43.45	67.15	47.40	79.00	54.51
		ibi	47.40	51.35	35.55	23.70	47.40	55.30	23.70	23.70	47.40	23.70	37.92
		ubu	63.20	47.40	23.70	39.50	11.85	59.25	15.80	23.70	35.55	31.60	35.16
		ibu	31.60	31.60	23.70	23.70	35.55	19.75	23.70	19.75	23.70	23.70	25.68
		ubi	35.55	31.60	15.80	27.65	31.60	51.35	15.80	31.60	55.30	15.80	31.21
		igi	47.40	35.55	55.30	39.50	71.10	35.55	23.70	39.50	102.70	55.30	50.56
		ugu	31.60	31.60	19.75	39.50	15.80	27.65	15.80	27.65	47.40	15.80	27.26
		igu	23.70	39.50	27.65	31.60	27.65	19.75	15.80	15.80	15.80	23.70	24.10
Nonstutterer	Fast	ugi	55.30	23.70	55.30	35.55	55.30	43.45	23.70	23.70	43.45	35.55	39.50

TABLE D-7. V_2 Total Duration Data for Individual Subjects at Each Rate and for Each Bisyllable.

Group	Rate	Syllable	Subject Number						Mean				
			1	2	3	4	5	6		7	8	9	10
Stutterer	Normal	ibi	102.70	110.60	114.55	118.50	102.70	161.95	110.60	173.80	193.55	122.45	131.14
		ubu	106.65	130.35	63.20	165.90	114.55	177.75	98.75	150.10	154.05	126.40	128.77
		ibu	98.75	118.50	98.75	154.05	126.40	205.40	130.35	161.95	150.10	165.90	141.02
		ubi	90.85	110.60	106.65	165.90	114.55	146.15	205.40	197.50	67.15	150.10	135.49
		igi	82.95	122.45	158.00	150.10	79.00	189.60	205.40	268.60	110.60	146.15	151.29
		ugu	94.80	126.40	86.90	158.00	118.50	90.85	94.80	146.15	154.05	165.90	123.64
		igu	86.90	98.75	63.20	142.20	110.60	161.95	114.55	146.15	94.80	173.80	119.29
		ugi	63.20	114.55	122.45	197.50	142.20	197.50	59.25	229.10	189.60	185.65	150.10
		ibi	165.90	146.15	102.70	130.35	106.65	158.00	86.90	114.55	154.05	47.40	121.27
		ubu	158.00	150.10	75.05	122.45	126.40	98.75	110.60	55.30	138.25	94.80	112.97
Nonstutterer	Normal	ibu	165.90	146.15	71.10	118.50	114.55	134.30	110.60	110.60	122.45	126.40	122.06
		ubi	161.95	122.45	94.80	142.20	106.65	118.50	110.60	114.55	169.85	67.15	120.87
		igi	177.75	126.40	118.50	126.40	110.60	150.10	98.75	110.60	158.00	71.10	124.82
		ugu	161.95	150.10	134.30	138.25	110.60	134.30	118.50	118.50	126.40	94.80	128.77
		igu	158.00	146.15	134.30	126.40	106.65	142.20	82.95	110.60	150.10	102.70	126.01
		ugi	173.80	122.45	118.50	158.00	118.50	126.40	79.00	102.70	134.30	94.80	122.85
		ibi	59.25	90.85	86.90	71.10	98.75	110.60	118.50	90.85	114.55	177.75	101.91
		ubu	79.00	59.25	90.85	102.70	94.80	130.35	150.10	79.00	98.75	158.00	104.28
		ibu	82.95	63.20	75.05	59.25	55.30	110.60	110.60	114.55	102.70	134.30	90.85
		ubi	71.10	86.90	98.75	43.45	90.85	126.40	102.70	63.20	126.40	134.30	94.41
Stutterer	Fast	igi	86.90	75.05	94.80	110.60	79.00	126.40	118.50	150.10	118.50	114.55	107.44
		ugu	63.20	82.95	102.70	75.05	94.80	138.25	142.20	94.80	86.90	118.50	99.94
		igu	102.70	82.95	82.95	110.60	79.00	165.90	102.70	102.70	98.75	118.50	104.68
		ugi	63.20	98.75	98.75	126.40	110.60	126.40	71.10	102.70	114.55	142.20	105.47
		ibi	142.20	82.95	71.10	86.90	94.80	118.50	63.20	67.15	94.80	94.80	91.64
		ubu	118.50	98.75	67.15	110.60	43.45	118.50	55.30	71.10	71.10	79.00	83.35
		ibu	114.55	86.90	75.05	106.65	102.70	79.00	55.30	71.10	71.10	47.40	80.98
		ubi	138.25	75.05	67.15	86.90	86.90	110.60	71.10	63.20	102.70	71.10	87.30
		igi	150.10	71.10	118.50	94.80	114.55	71.10	47.40	71.10	114.55	94.80	94.80
		ugu	130.35	79.00	59.25	79.00	86.90	82.95	71.10	47.40	71.10	82.95	79.00
Nonstutterer	Fast	igu	110.60	102.70	94.80	94.80	102.70	94.80	43.45	51.35	86.90	86.90	86.90
		ugi	134.30	79.00	126.40	71.10	102.70	98.75	82.95	71.10	122.45	63.20	95.20

TABLE D-8. V_1 Transition Velocity Data for Individual Subjects at Each Rate and for Each Bisyllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	4.14	4.96	3.72	4.14	6.62	7.09	5.67	6.21	4.14	4.96	5.17
		ubu	10.55	2.48	6.45	0.0	3.66	7.17	8.69	3.97	0.0	4.06	4.70
		ibu	4.47	4.96	5.58	6.62	6.95	3.86	3.72	0.0	3.31	4.96	4.44
		ubi	9.93	4.22	7.09	5.15	9.93	5.26	0.0	2.65	4.14	0.0	4.84
		igi	6.21	3.31	2.48	0.0	6.21	2.90	0.0	0.0	4.96	2.98	2.91
		ugu	3.61	3.31	3.50	6.95	0.0	0.0	0.0	2.76	7.45	2.71	3.03
		igu	0.0	1.99	13.24	0.0	0.0	3.72	4.06	3.97	3.55	2.48	3.30
		ugi	4.96	4.25	0.0	3.86	0.0	4.55	0.0	2.79	3.61	8.82	3.28
		ibi	4.96	5.67	7.45	4.20	9.10	2.07	3.47	5.67	7.94	6.38	5.69
		ubu	4.96	7.94	4.91	4.01	9.10	6.29	5.39	5.52	4.96	3.60	5.67
Nonstutterer	Normal	ibu	7.45	11.35	6.62	7.45	3.61	4.96	3.61	4.96	11.17	4.96	6.61
		ubi	4.38	5.52	3.55	2.21	4.65	4.81	2.36	5.32	4.96	0.0	3.78
		igi	4.58	3.31	1.86	1.99	3.10	3.31	2.98	4.47	2.48	3.47	3.16
		ugu	4.96	1.65	2.21	1.65	2.13	8.27	3.43	0.0	1.81	3.31	2.94
		igu	3.31	2.48	1.99	2.21	3.31	3.31	3.61	2.13	3.31	3.31	3.92
		ugi	4.03	1.81	3.97	6.77	4.96	3.72	3.93	2.84	1.35	5.79	3.92
		ibi	0.0	6.62	6.62	6.21	5.79	3.31	6.38	12.06	0.0	0.0	4.70
		ubu	0.0	5.23	6.95	4.25	9.27	5.58	6.21	5.46	9.33	10.55	6.28
		ibu	13.40	4.96	3.86	1.93	0.0	2.90	7.17	3.31	9.93	6.21	5.37
		ubi	5.89	2.48	6.62	5.60	6.62	0.0	4.14	8.27	4.14	7.80	5.16
Stutterer	Fast	igi	0.0	0.0	4.96	4.34	0.0	3.31	3.44	0.0	0.0	0.0	1.61
		ugu	2.48	0.0	0.0	2.87	1.53	0.0	0.0	13.47	2.48	5.58	2.84
		igu	3.16	3.31	4.96	4.14	3.31	4.96	3.86	0.0	3.72	0.0	3.14
		ugi	0.0	5.35	0.0	1.24	0.0	3.02	6.95	4.41	5.17	0.0	2.61
		ibi	4.06	13.24	4.96	8.07	8.69	6.21	5.96	8.94	9.93	5.58	7.56
		ubu	6.21	6.62	4.72	1.47	6.38	8.27	6.60	5.87	2.48	10.76	5.94
		ibu	5.96	4.96	4.14	10.76	11.17	6.21	2.48	10.64	4.14	10.92	7.14
		ubi	6.74	7.45	4.72	1.99	3.47	6.38	2.36	6.62	3.31	3.97	4.70
		igi	0.0	7.03	0.0	3.97	0.0	5.96	3.86	6.45	3.72	5.79	3.68
		ugu	7.45	3.55	3.90	2.48	2.26	6.21	5.66	4.34	5.79	0.0	4.16
Nonstutterer	Fast	igu	4.03	5.73	2.48	2.84	2.48	2.21	3.86	13.65	2.29	3.72	4.33
		ugi	1.99	4.96	4.32	10.24	6.38	0.0	2.36	3.31	4.96	3.97	4.25

TABLE D-9. V_2 Transition Velocity Data for Individual Subjects at Each Rate and for Each Syllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	12.13	0.0	4.96	0.0	8.69	2.98	4.96	7.06	4.25	0.0	4.50
		ubu	4.34	0.0	7.45	2.90	3.55	2.71	3.16	4.55	0.0	0.0	2.87
		ibu	6.62	2.21	3.86	0.0	4.25	6.62	2.76	3.86	3.31	0.0	3.35
		ubi	4.34	4.34	6.62	3.21	4.96	4.69	8.47	6.78	3.72	4.96	5.21
		igi	4.96	2.09	4.96	0.0	1.42	0.0	0.76	1.42	3.55	0.0	1.92
		ugu	4.25	0.0	3.97	1.93	0.0	0.0	0.0	4.96	6.62	3.55	2.53
		igu	7.03	4.96	7.94	4.96	7.28	4.96	6.21	7.05	6.38	6.49	6.33
		ugi	6.62	4.14	3.16	2.71	0.0	5.46	0.0	1.93	2.63	3.55	3.02
		ibi	4.34	3.31	3.72	4.96	3.86	3.66	4.34	3.86	3.47	4.96	4.05
		ubu	4.25	3.55	4.96	2.76	4.51	4.96	2.95	12.41	3.61	3.31	4.73
Nonstutterer	Normal	ibu	7.45	5.58	3.97	2.76	2.48	5.79	2.36	2.13	1.99	4.96	3.95
		ubi	19.41	4.14	5.96	2.98	5.46	4.96	5.46	4.58	3.31	6.38	6.26
		igi	1.65	3.31	3.55	2.76	1.86	2.48	2.26	2.48	2.48	4.96	2.78
		ugu	4.96	3.55	2.84	3.55	8.27	2.34	1.29	2.13	3.72	6.21	3.89
		igu	5.46	8.27	5.96	5.32	4.25	5.27	8.89	7.17	2.48	6.95	6.00
		ugi	2.48	2.48	3.10	1.53	2.48	2.76	2.71	2.67	2.65	3.10	2.60
		ibi	0.0	4.96	3.72	8.27	6.83	4.06	6.38	12.82	0.0	3.47	5.05
		ubu	7.45	0.0	0.0	4.96	4.96	0.0	3.72	4.25	4.96	2.90	4.73
		ibu	5.46	2.48	0.0	3.97	0.0	0.0	5.79	1.91	7.32	2.76	2.97
		ubi	4.14	4.41	4.47	9.93	5.58	3.40	5.79	13.47	4.96	5.96	6.21
Stutterer	Fast	igi	0.0	0.0	0.0	3.97	0.0	2.90	4.41	2.98	0.0	2.98	1.72
		ugu	0.0	0.0	0.0	4.47	4.96	0.0	0.0	5.96	5.79	7.45	2.86
		igu	5.32	4.30	8.44	4.41	9.93	3.59	4.96	8.07	9.34	5.67	6.40
		ugi	9.93	0.0	8.27	0.0	2.48	1.99	0.0	3.97	2.48	0.0	2.91
		ibi	3.41	4.34	3.31	6.45	3.72	4.51	5.79	6.62	3.72	3.16	4.50
		ubu	1.65	4.96	1.71	4.96	4.96	2.48	4.72	5.79	4.41	4.96	4.06
		ibu	3.31	4.14	11.76	0.83	3.10	5.79	4.78	4.96	4.96	3.31	4.69
		ubi	4.41	4.14	8.27	4.34	4.96	4.96	4.96	5.58	4.14	9.93	5.57
		igi	3.16	6.95	2.48	6.62	3.97	4.96	4.96	4.34	2.48	3.31	4.32
		ugu	5.67	4.14	1.65	4.51	4.96	4.96	2.62	0.0	7.45	2.90	3.89
Nonstutterer	Fast	igu	6.07	6.21	6.38	6.21	7.45	5.46	6.74	11.91	8.27	6.07	7.08
		ugi	2.48	2.48	2.67	4.96	4.96	2.48	5.79	3.72	2.76	3.72	3.60

TABLE D-10. Shift of Frequency Data for Individual Subjects at Each Rate and for Each Bisyllable.

Group	Rate	Syllable	Subject Number										Mean
			1	2	3	4	5	6	7	8	9	10	
Stutterer	Normal	ibi	215.69	98.04	58.82	196.08	98.04	137.25	254.90	666.67	117.65	39.22	188.24
		ubu	39.22	196.08	19.61	274.51	58.82	137.25	137.25	78.43	117.65	294.12	135.29
		ibu	803.92	627.45	647.06	176.47	529.41	686.27	1000.00	1196.08	764.71	647.06	707.84
		ubi	372.55	855.88	784.31	661.76	862.74	529.41	686.27	196.08	372.55	19.61	534.12
		igi	647.06	98.04	19.61	176.47	39.22	176.47	78.43	0.0	98.04	196.08	152.94
		ugu	58.82	235.29	0.0	19.61	196.08	98.04	431.37	411.76	470.59	313.73	223.53
		igu	490.20	568.63	647.06	215.69	431.37	431.37	588.24	647.06	196.08	176.47	439.22
		ugi	333.33	1117.65	725.49	411.76	647.06	921.57	705.88	1215.69	509.80	784.31	737.25
		ibi	98.04	137.25	39.22	98.04	0.0	98.04	39.22	156.86	78.43	117.65	86.28
		ubu	313.73	98.04	95.10	150.98	215.69	226.47	186.27	0.0	0.0	152.94	143.92
Nonstutterer	Normal	ibu	431.37	254.90	901.96	745.10	313.73	470.59	901.96	764.71	411.76	960.78	615.69
		ubi	686.27	274.51	862.75	764.71	431.37	875.49	816.67	666.67	176.47	1076.47	663.14
		igi	58.82	19.61	235.29	176.47	58.82	19.61	156.86	117.65	98.04	58.82	99.99
		ugu	666.67	176.47	19.61	235.29	176.47	392.16	186.27	98.04	58.82	352.94	236.27
		igu	352.94	196.08	392.16	960.78	294.12	254.90	1000.00	529.41	117.65	705.88	480.39
		ugi	960.78	137.25	1133.33	823.53	235.29	705.88	764.71	607.84	98.04	1039.22	650.59
		ibi	137.25	39.22	0.0	39.22	78.43	98.04	176.47	450.98	58.82	156.86	123.53
		ubu	117.65	93.14	78.43	19.61	78.43	235.29	156.86	156.86	113.73	39.22	108.92
		ibu	274.51	705.88	372.55	509.80	568.63	568.63	921.57	862.75	823.53	549.02	615.69
		ubi	627.45	705.88	705.88	447.06	196.08	235.29	901.96	196.08	607.84	529.41	515.29
Stutterer	Fast	igi	98.04	39.22	196.08	117.65	117.65	117.65	39.22	156.86	39.22	58.82	98.04
		ugu	196.08	98.04	137.25	235.29	39.22	176.47	19.61	549.02	39.22	333.33	182.35
		igu	490.20	529.41	647.06	431.37	392.16	529.41	1333.33	568.63	333.33	274.51	552.94
		ugi	450.98	529.41	1196.08	352.94	19.61	725.49	882.35	941.18	78.43	313.73	549.02
		ibi	117.65	58.82	39.22	0.0	19.61	39.22	19.61	98.04	58.82	58.82	50.98
		ubu	215.69	78.43	37.25	112.75	235.29	117.65	0.0	78.43	392.16	0.0	126.77
		ibu	431.37	156.86	1134.31	725.49	215.69	235.29	882.35	490.20	313.73	921.57	550.69
		ubi	647.06	254.90	1165.69	725.49	490.20	411.76	873.53	607.84	176.47	1000.00	635.29
		igi	98.04	39.22	156.86	39.22	0.0	78.43	19.61	39.22	58.82	0.0	52.94
		ugu	450.98	117.65	176.47	98.04	156.86	313.73	204.90	98.04	39.22	235.29	189.12
Nonstutterer	Fast	igu	470.59	117.65	725.49	941.18	137.25	0.0	1016.67	666.67	235.29	901.96	521.28
		ugi	725.49	294.12	1250.98	725.49	431.37	607.84	1037.26	529.41	0.0	784.31	638.63

APPENDIX E

ANALYSIS OF VARIANCE FOR FREQUENCY DIFFERENCES IN THE TRANSITIONS

TABLE E-1. Analysis of Variance Summaries for the Mean Frequency Differences of V_1 Midpoint and V_1 End of Transition.

	SS	df	MS	F
<u>Between</u>				
Group	8157.87	1	8157.87	1.06
Subject (Group)	195028.43	18	10834.91	
<u>Within</u>				
Syllable	405086.11	7	57869.44	.001*
Rate	3236.29	1	3236.29	.70
Group x Rate	5736.48	1	5736.48	.50
Group x Syllable	50689.63	7	7241.38	.65
Rate x Syllable	32461.74	7	4637.39	.42
Group x Rate x Syllable	80452.96	7	11493.28	1.04
Error	2986283.66	270	11060.31	

*Significant at the .0001 level

TABLE E-2. Analysis of Variance Summaries for the Mean Frequency Differences of V₂ Onset of Transition and Midpoint.

	SS	df	MS	F
<u>Between</u>				
Group	31.85	1	31.85	.25
Subject (Group)	769730.22	18	42762.79	
<u>Within</u>				
Syllable	1389053.63	7	198436.22	14.71*
Rate	62482.51	1	62482.51	3.84
Group x Rate	81.78	1	81.78	.02
Group x Syllable	72867.62	7	10409.66	.77
Rate x Syllable	114034.51	7	16290.64	1.21
Group x Rate x Syllable	29888.57	7	4269.80	.32
Error	3642267.40	270	13489.88	

*Significant at the .0001 level

VITA

Carrie Rebekah Hand was born in Greensboro, North Carolina on August 30, 1953. She received her elementary and secondary education in Greensboro and was graduated from Grimsley Senior High School in 1971. In 1975 she graduated summa cum laude from East Carolina University with a Bachelor of Science degree in Speech, Language, and Auditory Pathology. She continued her education at the Graduate School of East Carolina University. In 1976 she graduated with Highest Distinction and received the Master of Science degree in Speech, Language, and Auditory Pathology.

In September, 1976, she entered the Graduate School of the University of Tennessee and received the Doctor of Philosophy degree with a major in Speech and Hearing Science in December, 1979. Upon completion of her studies in Speech and Hearing Science, she accepted the position of Assistant Professor of Speech Communication at Auburn University, Auburn, Alabama.