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Speed and Variability of Voice Reaction Times of Stuttering and Nonstuttering Children and Adults

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To the Graduate Council:

I am submitting herewith a dissertation written by Douglas Edward Cross entitled "Speed and Variability of Voice Reaction Times of Stuttering and Nonstuttering Children and Adults." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

Harodl J. Luper, Major Professor

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H. Alan Lasater, Harold A. Peterson, Carl W. Asp

Accepted for the Council:

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(Original signatures are on file with official student records.)

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Harold L. Luper, Major Professor

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and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

SPEED AND VARIABILITY OF VOICE REACTION TIMES

OF STUTTERING AND NONSTUTTERING

CHILDREN AND ADULTS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Douglas Edward Cross

June 1978

DEDICATION

This endeavor is dedicated to Dr. E. Thayer Curry in an expression of this author's sincere appreciation of his caring, inspiration, and insatiable love for early morning coffee and donuts.

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Sincere appreciation is extended to Dr. Harold L. Luper for his continued patience in guiding both this author's academic and personal growth. The author also wishes to thank his committee members: Drs. H. Alan Lasater, Harold A. Peterson, and Carl W. Asp for their guidance in the preparation of this dissertation. Special gratitude is extended to the author's parents and Janet Brogan for their unyielding faith and confidence during the pursuit of academia.

ABSTRACT

The mean and intrasubject response variability of voice reaction time to auditory stimuli was investigated for five year old, nine year old and adult stutterers and nonstutterers. The subjects who participated in this study were twenty-seven stutterers and twenty-seven nonstutterers matched for age and sex. There were nine stutterers and nine nonstutterers at each of the three age levels. All of the stutterers had been reported to have exhibited the onset of stuttering behavior by no later than five years of age.

Each of the subjects was presented with a total of fifty-five pre-recorded 1000 Hz tones bilaterally through stereo earphones at 80 dB SPL. The stumuli were divided into five equal sets of eleven tones each. Data analysis was based on responses two through eleven for each set for a total of fifty responses per subject. The duration of each tone was one second and the silent interval between each of the tones varied randomly among three, four, five, and six seconds. A one minute rest period was provided between each set. The subjects were instructed to respond to the onset of each tone as quickly as possible by initiating the neutral vowel sound /ʌ/ with what they considered to be their natural conversational loudness and effort and to hold it until the tone ended. A training period was provided for the five year old and the nine year old subjects until the investigator determined that they understood and could consistently perform the task. Each of the subjects was then given ten practice trials in order to become familiar with the test procedures. Voice reaction time (VRT) was measured with an electronic digital counter triggered

by the onset of the pure tones. Vocal onset from the subject was transduced by a condenser microphone two inches from the subject's lips. When the voltage level of the acoustic signal exceeded 460 mVolts (approximately 80 dB SPL vocal intensity level) the circuit to the counter was broken and stopped the clock.

Two three-factor analyses of variance with repeated measures on one factor (Set) were utilized to investigate the effects of the three experimental variables of Age (five, nine, and adult), Group (stutterers and nonstutterers), and Set (one through five) on both the mean and intrasubject response variability (calculated from the log of the variance) of voice reaction time. Conclusions drawn from these analyses may be summarized as follows:

1. Both the stutterers and the nonstutterers exhibited a significant decrease in mean voice reaction time with an increase in age. The five year old subjects for both groups exhibited significantly longer VRTs than the nine year olds and the adults. The VRTs for the nine year olds were longer than those of the adults; however, the differences were not significant.
2. Similarly, the intrasubject response variability decreased significantly with an increase in age for both the stutterers and the nonstutterers with significant differences found between each of the age groups. Thus, while the mean VRT approximated that of the adults by nine years of age, the intrasubject variability continued to decrease through adulthood.
3. Between group comparisons revealed that the mean VRTs for the stutterers were significantly longer than those of the matched

nonstutterers at each of the three age levels. The largest difference between the means for the two groups of subjects was found for the five year olds (60 msec.), decreasing to 50 msec. for the nine year olds and 30 msec. for the adults. The Group x Age interaction, however, was nonsignificant.

4. The intrasubject response variability for the stutterers was also significantly greater than that for the nonstutterers at each of the three age levels. As with mean VRT, the greatest difference in response variability between the two groups occurred for the five year olds, progressively decreasing as age increased.

5. The Age x Set interaction for the mean voice reaction time was nonsignificant indicating that age had little or no effect on the rate or degree of adaptation for the mean VRT across response sets. The stutterers as a group, however, demonstrated a pattern of adaptation for mean VRT which was dissimilar to that of nonstutterers. The stutterers exhibited a decrease in mean VRT from set one to set two of 19 msec. This decrease was followed by a progressive increase in VRT with each additional set, attaining a maximum value for est five which was 6 msec. longer than set one. The nonstutterers showed little or no change in mean VRT across sets, attaining a minimum value on set one.

6. The Age x Set interaction for intrasubject response variability was nonsignificant indicating that age had little

effect on the rate or degree of adaptation with respect to response variability.

7. Similarly, the Group x Set interaction for intrasubject response variability was also nonsignificant. This indicates that the stutterers and the nonstutterers exhibited similar patterns of change in variability across sets.

8. The combined intrasubject response variability for both the stutterers and the nonstutterers decreased from set one to set two. This was subsequently followed by an overall increase in subject variability with sets three, four, and five.

The results of this study suggest that the slower, more variable voice initiation ability for stutterers may not result from factors associated with the development of the stuttering disorder with age. Difficulty in promptly initiating voicing, on the other hand, may contribute to early disruption in the timing relationship between respiratory, phonatory, and articulatory processes needed for fluent speech production. The results of this study as well as those reported from previous investigations might be interpreted to suggest that the slow voice initiation ability, at least in some individuals, may result from disruption in the development of motor programming involved in early stages of speech production. This disruption also appears to be exhibited in nonspeech as well as speech related motor tasks and may reflect factors involved in central processing, such as lack of hemispheric dominance.

TABLE OF CONTENTS

CHAPTER PAGE

I. INTRODUCTION AND REVIEW OF THE LITERATURE AND STATEMENT OF THE PROBLEM 1

Introduction 1

Review of the Literature 3

Adaptation Studies 5

Temporal Patterns in Stuttering. 8

Phonatory Disfunction in Stuttering. 11

Voice Reaction Time Studies. 18

Summary of Physiological-Aerodynamic Correlates of Stuttering 23

Components of Motor Reaction Time. 26

Development of Motor Reaction Time 29

Normal Patterns of Motor Speech Development 31

Statement of the Problem 39

II. METHODS. 41

Subjects 41

Auditory Test Stimuli. 44

Stimulus Tape Preparation. 48

Instrumentation. 50

Presentation of the Stimulus Tones 50

Monitoring of Subjects' Vocal Responses. 52

Measurement of Voice Reaction Time 52

Determining Stimulus and Response Gate Threshold Levels 54

CHAPTER PAGE

Calibration of Instrumentation Prior to Subject Testing 58

Procedure 59

Repeatability 60

III. RESULTS. 63

Mean Voice Reaction Time 64

Age Effect on VRT Performance. 64

Set Effect on VRT Performance. 70

Group Effect on VRT Performance. 72

Variability of Voice Reaction Time 72

Age Effect on Intrasubject VRT Variability 73

Set Effect on Intrasubject VRT Variability 78

Group Effect on Intrasubject VRT Variability 82

IV. DISCUSSION 83

Age and Voice Reaction Time Performance. 83

Set Effect on Voice Reaction Time Performance. 88

Differences Between Stutterers and Nonstutterers. 90

V. SUMMARY AND CONCLUSIONS. 101

Implications for Further Research. 104

BIBLIOGRAPHY 107

APPENDICES 117

VITA 127

LIST OF TABLES

TABLE PAGE

1. Chronological age of the stutterers and nonstutterers as well as the mean for each age level. Age is expressed in years-months for the five and nine year olds and years only for the adults 42

2. Randomized durations of silent intervals (SI) between the offset of each stimulus tone and the onset of the following tone for each of six response sets 45

3. Intrasubject test-retest analysis with respect to the difference between the mean voice reaction time for test 1 and test 2 for each of five response sets. 62

4. Mean voice reaction times (msec.) for the stutterers and nonstutterers as a function of age (5 years, 9 years, and adults) and response sets (one through five). 65

5. Summary of the analysis of variance for the factors age, group, and set with repeated measures on set with respect to the mean voice reaction time. 67

6. Analysis of the difference between the mean voice reaction times for each of three ages (collapsed across groups) utilizing the Bonferroni method for multiple comparisons (Neter and Wasserman, 1977). 69

7. Mean log of the variance (MLV) for the stutterers and nonstutterers as a function of age (5 years, 9 years, and adults) and response sets (one through five) 74

8. Summary of the analysis of variance for the factors age, group, and set, with repeated measures on set with respect to the log of the variance of voice reaction time 76

9. Analysis of the difference between the mean log of the variance (MLV) for each of the three ages (collapsed across groups) utilizing the Bonferroni method for multiple comparisons 79

TABLE PAGE

10. Analysis of the differences between the mean log of the variance (MLV) for each of the five response sets (collapsed across age and group) utilizing the Bonferroni method of multiple comparisons 81

11. Summary of raw data for the mean voice reaction times (msec.) for all subjects as a function of group (stutterers and nonstutterers), age (5 years, 9 years, and adults), and set (one through five) 121

12. Summary of the log of the variances of reaction times in msec. for all subjects as a function of group (stutterers and nonstutterers), age (5 years, 9 years, and adults), and set (one through five) 124

LIST OF FIGURES

FIGURE PAGE

1. Block diagram of the instrumentation utilized for construction of the stimulus tape 49

2. Block diagram of the instrumentation utilized to present the stimulus tones, transduce the subject's vocalizations, and measure the resulting voice reaction times. 51

3. Block diagram of the two channel comparator NAND gate logic circuit and electronic digital counter utilized to measure voice reaction time. The gate is shown in the "ready" position prior to onset of the pure tone stimulus cue. 53

4. Block diagram of the instrumentation utilized to record a calibration tape consisting of ten stimulus-response pairs 55

5. Block diagram of the instrumentation utilized to calibrate the stimulus and response comparator voltage threshold levels for measurement of voice reaction time 56

6. Mean voice reaction time (VRT) for the five year old (○ ●), nine year old (△ ▲), and adult (□ ■) stutterers (open symbols) and nonstutterers (filled symbols) for response sets one through five. 66

7. Overall mean voice reaction times (VRT) for the five year old, nine year old, and adult stutterers and nonstutterers (sets combined). 68

8. Mean voice reaction times (VRT) for stutterers and nonstutterers (all ages combined) for each of the five response sets. 71

9. Mean log of the variance of voice reaction times for the five year old (○ ●), nine year old (□ ■), and adult (△ ▲) stutterers and nonstutterers for response sets one through five. 75

FIGURE PAGE

10. Mean log of the variance for the five year old, nine year old, and adult stutterers and nonstutterers collapsed across sets, as well as the mean log of the variance for each age level collapsed across groups and sets. 77

11. Mean log of the variance for the stutterers and nonstutterers (collapsed across ages) for sets one through five, as well as the mean log of the variance for each set collapsed across groups and ages. 80

12. Overall mean voice reaction times for the five year old, nine year old, and adult stutterers and nonstutterers, as well as the mean finger tap reaction times reported by Goodenough (1935) for subjects of the same age 85

CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE AND STATEMENT OF THE PROBLEM

I. INTRODUCTION

Research evidence indicating that the disfluent speech of stutterers might in part be attributable to phonatory behavior which differs from that of nonstutterers has resulted from numerous investigations (for example: Wingate, 1970; Besozzi and Adams, 1969; Adams and Reis, 1971, 1974; Freeman and Ushijima, 1974; and Agnello, 1974). Adams and Reis (1971), for example, measured the frequency of stuttering and the rate of adaptation of stutterers while reading two passages, one containing all voiced phonemes and the other containing both voiced and voiceless phonemes. Less stuttering and a faster adaptation rate were observed for the all voiced passage which required less off/on adjustments of the vocal folds. A similar difference in adaptation rate was observed in a replication of this study (Adams and Reis, 1974), although it did not confirm the difference in frequency.

Recent investigations have utilized the reaction time paradigm* in an attempt to identify more precisely the nature of the phonatory behavior differences between stutterers and nonstutterers. Adams and Hayden (1976) compared the voice initiation times (VIT) and the voice termination times (VTT) of adult stutterers and nonstutterers. The

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*Studies utilizing the reaction time paradigm have also referred to their resultant measurements as "voice initiation time," or VIT. Therefore, both VIT and VRT refer to the same behavioral phenomenon and are used interchangeably in accordance to the author's terminology.

subjects responded as quickly as possible to the onset and offset of an auditory stimulus cue (1000 Hz pure tone) by initiating and terminating phonation of the isolated vowel /ɑ/. Although both groups improved with repeated phonatory responses, the stutterers' VITs and VTTs were both significantly longer than those of the nonstutterers.

Starkweather, et al. (1976) also found that stutterers had longer VITs than nonstutterers when subjects responded to a visual stimulus cue (flash of a light on a screen) by initiating various syllable or syllable combinations. The stutterers' VITs were significantly longer than those of the nonstutterers with both groups improving with practice.

Cross and Shadden (1977) investigated the optimum voice reaction times (VRT) of adult stutterers and nonstutterers as a function of which ear received the auditory stimulus cue. The subjects responded to one hundred 4000 Hz pure tones by initiating the vowel /ʌ/. Results indicated that the stutterers had significantly longer VRTs and exhibited greater response variability in initiating voicing than the nonstutterers when operating at what appeared to be their optimum voice reaction ability for the task. No differences were observed between the left and right ears with respect to VRT for either group.

The results of these investigations on voice reaction time indicate that one focal point of difficulty for the adult stutterer might be in a slow, extremely variable ability to initiate vocal fold vibration irrespective of supraglottal articulatory gesturing. However, whether the slow voice initiation ability observed for stutterers as a group contributes to early disruption in the speech production process or possibly results from the individual's history of stuttering development is

presently unknown. For example, the stuttering behavior which has developed from its early stages to that observed in the adult may contribute to the slow VRTs for the stutterers. On the other hand, if the delay in initiating voicing originally contributes to disruption of fluent speech, then longer VRTs might be expected for the young stutterer than for the nonstutterer. No studies have been found which investigated the development of voice reaction ability of either stutterers or nonstutterers.

The purpose of this study was to investigate the effects of the three experimental variables of Age (five year olds, nine year olds, and adults), Group (stutterers and nonstutterers), and Set (practice) on both the mean and intrasubject response variability of voice reaction times to a pure tone auditory stimulus cue.

II. REVIEW OF THE LITERATURE

The conceptualization that stuttering is at least in part identifiable as a disruption in the precise coordination of the respiratory, phonatory, and/or articulatory processes of speech has been postulated since the early 19th century. Serre d'Alais (1829) for example, attributed the source of stuttering to a chronic "spasm of the glottis," while Sir Charles Bell (1832), Becquerel (1847) and Coen (1875) hypothesized that stuttering results from the pathological incoordination of the respiratory system. Recent research efforts have attempted to identify more specifically the level in the speech production process at which disruption in temporal coordination of the respiratory, phonatory, and articulatory processes may occur.

Study of the normal speech processes has demonstrated that fluent speech is dependent upon the precise temporal coordination of respiratory forces, phonatory processes, and upper airway modification of the vocal tract. The laryngeal and upper airway structures move in an effort to modify the essentially constant air pressure provided by the respiratory system. One determiner of fluent speech is the maintenance of air flow in conjunction with the onset and offset of voicing. The precise timing of voice initiation needed for speech is dependent upon a number of factors. For example, partial adduction of the vocal folds is necessary in order to create glottal resistance prior to voicing. Initiation of vocalization is dependent upon the expiratory forces creating subglottic pressure large enough to overcome the glottal and supraglottal resistances. Optimally, glottal stiffness and supraglottal pressures will be sufficiently low to require only minimal increase in expiratory forces to initiate smooth vocal fold vibration. Disruption in the balance of pressures and flows anywhere along the speech mechanism may result in the disruption of phonation. For example, disruption in the initial laryngeal adductory effort would delay voicing onset and force the supraglottal articulators to either prolong or repeat movements in an attempt to allow the phonatory system time to establish a sufficient vocal tone for voicing. This compensatory supraglottal activity, however, may also create excessive pressures behind the articulators increasing glottal resistance and further disrupting the onset of phonation. Therefore, as noted by Adams (1974), initial disruption in any one of the systems might be reflected in disruption at any other level.

Wingate (1966) postulated that the focal defect in stuttering ". . . lies in the matter of a difficulty in making quick shifts in

the highly integrated coordination of phonation and articulation demanded in the simple function of verbal expression." He identified this problem as a "phonetic transition defect" characterized by difficulty in proceeding from one phone to another (Wingate, 1969). He suggested that the observed increase in fluency during such activities as singing, imposed rhythm, and choral speaking results from the individual initiating changes in the manner of phonation from his usual mode of speaking. Changes in phonation during fluency enhancing situations such as delayed auditory feedback (DAF) and auditory masking have been identified as increases in both the fundamental frequency and vocal intensity as well as increased syllable duration (Wingate, 1970).

An increasing number of research efforts have attempted to identify correlates of stuttering associated with the disruption in timing between the respiratory, phonatory, and articulatory processes. Indirect evidence has been provided through studies of stuttering adaptation. Others have attempted to identify specific temporal patterns associated with stuttering behavior. More direct evidence of stuttering as a disruption in the phonatory processes has been provided through studies utilizing fiberoptic and electromyographic techniques as well as through the investigation of voice onset time and voice reaction time.

Adaptation Studies

Wingate (1966) attributed stuttering adaptation in successive readings of the same passage to increased practice with the prosody of the passage. To test this assumption he had sixteen young adult male stutterers read a 207-word passage five times in succession under two conditions. In one condition the passage was punctuated in five different

ways, thus requiring an altered pattern of intonation and melody in each reading. In the second condition, punctuation of the prose passage was the same in all five readings. Significantly greater adaptation was observed on the passages containing the same prosodic patterns. Wingate hypothesized a two-factor explanation of stuttering adaptation consisting of: (1) a general organismic adaptation to the situation, and (2) increasing familiarity with the prosody resulting in increased proficiency in making articulatory movements and coordinating articulation and phonation.

Besozzi and Adams (1969) believed that if Wingate's assumption were correct then the more oral reading practice provided the stutterer, the more he should adapt. They had sixteen stutterers read matched 300 word passages under two conditions. In the control condition, the subjects orally read the same passage five consecutive times. In the experimental condition, the subjects read a matched passage orally on trials 1 and 5, and silently on trials 2, 3, and 4, limiting oral reading practice and hence prosodic adaptation. Significantly greater adaptation occurred when subjects were provided with the additional oral reading practice supporting Wingate's assumption that practice in coordinating the physiological activities for speech reduces stuttering.

Brenner, Perkins, and Soderberg (1972) attempted to identify factors contributing to decreased stuttering observed under conditions of increased practice suggested by Wingate (1966) and Besozzi and Adams (1969). Brenner, et al. had twelve stutterers recite 10-syllable sentences from memory after conditions of silent rehearsal, lipped rehearsal (silent rehearsal where motor movements were performed for speech without producing sound), whispered rehearsal, rehearsal aloud, and no rehearsal.

Fewer disfluencies were observed after the stutterers had practiced aloud than after any other condition. Although both the lipped rehearsal and whispered rehearsal contained motoric components, they were distinguished from the rehearsal-aloud condition by not utilizing vocalization. Since the aloud rehearsal condition provides more practice in integrating the intricate motor functions of phonation and articulation, the authors suggested that stutterers have more difficulty coordinating phonatory with articulatory movements than controlling articulatory movements without voice.

Adams and Reis (1971) examined the role of phonation in stuttering adaptation by altering the number of "off-on" adjustments of vocal fold vibration required during oral reading. They had fourteen stutterers perform five massed oral readings of each of two passages, one containing both voiced and voiceless sounds, and the other containing voiced sounds only. Thus, the voiced-voiceless passage required more "off-on" phonatory adjustments than the all voiced passage. Results showed significantly less stuttering and more rapid adaptation was associated with the all-voiced passage material. In a replication of their study, Adams and Reis (1974) again reported faster adaptation with the all-voiced passage. The authors also observed that the loci of blocks in these studies indicated that most disfluencies occurred at points in the passage where phonation had to be initiated quickly, as on rapid transitions from voiceless to voiced sounds. One third of the total number of disfluencies occurred on the first sound in a sentence, on the first sound after a juncture, or on transitions from voiceless to voiced speech sounds. The authors also noted that many stutterings that did not "adapt out" appeared during the

production of syllable initial voiced stops. From these findings Adams and Reis (1974) suggested that the amount of adaptation will increase as the number of requirements for prompt onset of phonation, and complete articulatory constriction in a passage decreases. To further test this assumption, Adams, et al. (1975) had fourteen adult stutterers perform massed oral readings of each of three separate, specially constructed passages. The largest amount of adaptation occurred between the first and second readings for each of the three passages. However, more adaptation occurred during an all-voiced-continuants-only passage than on an all-voiced-stops-and-continuants passage. The least amount of adaptation occurred on the passage that contained both voiced and voiceless sounds, stops, and continuants. Thus, stuttering appeared to decrease with the decrease in the level of motor complexity characterized by the number of requirements for prompt onset of vocalization and complete articulatory constriction.

The results of these adaptation studies indicate that stuttering decreases with repeated motor practice. These studies also suggest that the number of disfluencies decreases as the motor complexity required for the coordination of respiratory, phonatory, and articulatory activity decreases.

Temporal Patterns in Stuttering

Disruption in timing between the laryngeal and supralaryngeal activity may result from an inability to make adjustments of the vocal folds rapidly during speech. Adams (1974) proposed that fluency is dependent upon smooth coordination of the respiratory, phonatory, and articulatory systems. He also suggested the possibility that each

level could serve as a focus of difficulty that triggers discoordination with other levels of the system. Studies utilizing aerodynamic and electromyographic techniques have attempted to identify patterns of discoordination during fluent and disfluent speech production of stutterers.

Hutchinson and Ringel (1973) compared aerodynamic patterns of stuttered speech production with the perceptual categorization of the disfluency type. Measurements of air flow and pressure were obtained during the oral reading of a prose passage by eight adult stutterers. No one-to-one relationship was observed between the perceptual categorization of the disfluency and its physiological condition. It was also found, however, that each stutterer displayed one or two characteristic aerodynamic patterns more frequently than others, inferring an individualization in the patterns of disrupted coordination between the respiratory, phonatory, and supraglottal processes.

Conture and Colton (1976) analyzed the prephonatory adjustment of stutterers' respiratory and laryngeal systems during disfluent and fluent speech production. Two adult male stutterers and one nonstutterer read 34 isolated monosyllabic and bisyllabic words. Temporal relationships with respect to the onset of chest wall diminution and onset of adductory activity were obtained by means of a magnetometer and EMG readings from the lateral cricoarytenoid muscle (LCA). Results indicated that 94 percent of all fluent production was characterized by onset of the LCA activity preceding the onset of chest wall diminution. Seventy-five percent of the disfluent productions, however, were characterized by LCA onset lagging behind chest wall diminution by 25 to 875 msec. The disfluencies were also characterized by cessation

of the chest wall diminution and inappropriate inspiratory gestures. The authors hypothesized that the improper timing relationship in the respiratory-phonatory process associated with stuttering resulted from inappropriate contraction of the laryngeal abductor musculature. They further suggested that the laryngeal mechanism is the locus of peripheral timing control for speech.

Ford (1975) investigated the temporal relationship among the onsets of subglottic and intraoral air pressure, phonation, and labial EMG activity during stuttered and fluent productions of single words beginning with bilabials by three adult stutterers. From the analysis of the data she concluded that perceived stuttering was partially attributable to a failure to use a consistent sequence of speech production events. Moreover, the location of disruption in the speech production mechanisms appeared to differ among subjects indicating an individualization of aerodynamic-physiological patterns. It was also observed that incoordination of the speech production process sometimes preceded, accompanied, or followed the onset of phonation.

The results of these studies investigating the temporal patterns in stuttering indicate that stuttering behavior is characterized by disrupted patterns of motor timing between the respiratory, phonatory, and articulatory systems. It has also been shown that stutterers may demonstrate individual patterns of disrupted motor timing even though they result in similar perceptual judgements of disfluency type (i.e., prolongation, repetition, etc.). Finally, these studies suggest that a primary focal point of stuttering may be in difficulty in effecting appropriate timing relationships between respiratory events and phonation.

This difficulty appears to be characterized by delayed onset of vocal fold vibration with respect to onset of respiratory exhalation activity.

Phonatory Disfunction in Stuttering

Several authors have hypothesized that stuttering results from a disruption in laryngeal muscle activity prior to or during the onset of phonation for speech. Wyke (1969, 1970) for example, proposed that there are two different types of stuttering associated with phonatory difficulty. One type of "voluntary" stuttering results from abnormally slow or inaccurate voluntary presetting of the laryngeal and respiratory musculature. The second type, "reflex stuttering," supposedly results when voluntary presetting of adductor tone (tension) is performed accurately but intrinsic laryngeal reflex systems fail to maintain the musculature in the appropriate preset phonatory position. Thus, during expiration the vocal folds are randomly deviated from the desired position and tension.

Moravek and Langová (1967) and Lastovka (1970) considered the central problem of stuttering to be excessive tension in the laryngeal musculature during the prephonation or the "initial tonus" stage of speech production. Excessive tension would preclude smooth initiation of phonation. Lastovka (1970), for example, attributed the excessive initial laryngeal tonus in stuttering to increased excitability of the spinal motoneurons facilitated by an increased emotional state. He observed that the resting monosynaptic spinal cord reflex in stutterers is normal but that there is a significantly greater facilitation of the reflex prior to stuttering.

Fibiger (1971) also suggested that stuttering may result from excessive initial tonus of the speech musculature. He observed that, prior to stuttering, individuals demonstrated exaggerated amplitude of

normal physiological tremor (8 Hz) in facial muscles. This tremor was not present prior to fluent speech or in the speech of nonstutterers.

Schwartz (1974) suggested that stuttering results from an inappropriate, vigorous, abduction of the vocal folds in response to subglottal pressures required for speech. The lack of inhibition of the abductory response (airway dilation reflex) at the level of the medulla supposedly results in contraction of the posterior cricoarytenoid (PCA) placing the vocal folds in a posture incompatable with the phonation required for speech. Schwartz related this inappropriate PCA contraction to psychological stress which, when present, increased the possibility of loss of supramedullary control (Vickers, 1968; Teichner, 1968).

More recently, Perkins, et al. (1976) hypothesized that due to the highly complex nature of phonatory adjustments needed for speech the most likely focal point of stuttering is in disruption at the laryngeal level. If this were in fact the case, they suggested that systematically simplifying the complexity of laryngeal adjustments without varying articulatory activity should result in less stuttering. To test this hypothesis, Perkins and his associates had thirty adult stutterers who stuttered when whispering read three 130-syllable exerpts from the "Rainbow Passage" under three conditions of systematically changing phonatory-respiratory complexity: voiced, whispered, and articulated without phonation. Results showed that syllable disfluencies were progressively reduced in number as the complexity of phonatory and respiratory coordinations was simplified. Speaking rates were also observed to increase progressively with simplification of phonation. The authors concluded that stuttering appears to be a function of complexity of

phonatory coordination with articulatory and respiratory processes. Moreover, since the complexity of the phonatory adjustments was the only variable altered systematically in the study, the authors also suggested that the primary location of disruption in fluent speech production is in phonation.

Direct observation of the vocal folds has also been utilized to investigate phonatory activity during fluent speech and stuttering. Chevrie-Muller (1963) observed the vocal folds of 27 stutterers by means of glottographic techniques. Laryngeal abberations in the form of a fluttering of the folds, arhythmical vocal fold vibration, unpredictable glottal openings and partial or complete absence of voicing during rapid glottal activity were observed during stuttering. Similar observations were reported by Freeman and Ushijima (1974a) who utilized fiberoptic methods to view the vocal folds during stuttering. They reported that the primary feature of laryngeal activity during stuttering moments was tight closure of the laryngeal aperture. This was observed primarily at the level of the true vocal folds, but also frequently involved the ventricular folds and/or the tuberculum of the epiglottis. They also reported an irregular, intermittent opening and closing of the glottis.

Conture, McCall, and Brewer (1974) utilized flexible fiberoptic nasolaryngoscopes to view the laryngeal activity accompanying 120 disfluencies produced by six adult stutterers. Vocal fold activity was observed during sustained phonation, diadochokinesis, informal conversation, and reading of a prose passage. Sound-syllable repetitions were characterized by the vocal folds being held in a relatively fixed,

partially-abducted position. While in this position the folds were seen to oscillate slowly. Sound prolongations were characterized by holding the vocal folds in a relatively fixed, completely adducted position. The authors suggested that the partially abducted position characterized by the sound-syllable repetitions may result in some degree of interference in the reciprocal contraction and relaxation of the antagonistic adductory-abductory muscles of the vocal folds. Temporal disruption in the timing relationship between the primary adductory-abductory laryngeal musculature was also observed by Freeman and Ushijima (1974b). They observed the electromyographic (EMG) activity of four laryngeal muscles during stuttering. Hookwire electrodes were used to measure activity from the posterior cricoarytenoid (PCA), lateral cricoarytenoid (LCA), the vocalis, and the cricothyroid muscles of a severe male stutterer. Comparisons were made of the subject's fluent and stuttered utterances of the same words. Results showed that fluent productions were characterized by a precise balance in timing of the abductory-adductory PCA and the LCA muscles similar to the pattern of reciprocity that has been observed in the laryngeal muscle activity of normal speakers (Hirose and Gay, 1971, 1973). Freeman and Ushijima, however, indicated that reciprocity of antagonistic muscle activity was not present during stuttering. Disfluencies were characterized by simultaneous activity of both the adductory and abductory musculature with a high level of activity in the lateral cricoarytenoid. The level of the activity of the LCA (adductory) appeared to be positively correlated with the severity of the block with marked decrease in activity accompanying the termination of the block.

Freeman and Ushijima (1974a) also compared the EMG activity from four intrinsic laryngeal muscles of three stutterers during the fluent and disfluent readings of sentences. Results were similar to their previous study with high levels of both adductory and abductory muscles during stuttering. Disfluent productions were characterized by asynchronous activity between the adductors as well as the disruption in the normal reciprocity between the antagonistic abductory-adductory musculature.

Direct observation of the vocal fold activity through fiberoptic and electromyographic techniques indicates that stuttering is characterized by excessive tension and a lack of synchronous adductory-abductory activity in the laryngeal musculature. These findings lend support to previous theories and research indicating that the focal point of difficulty in the smooth coordination of the respiratory, phonatory, and articulatory systems lies at the level of phonation. However, as noted by Ford (1975), these studies ". . . provide limited information on an isolated aspect of speaking without demonstrating the influence of other speech production events." That is, infra or supraglottal articulatory or aerodynamic activity may contribute to the observed disruption in the phonatory processes. This seems likely in view of the fact that all observations in the studies cited above were made during speech production requiring the precise timing of these complex motor activities.

Acoustic studies have investigated the precise timing relationship required between voicing onset and offset activity with supraglottal articulatory gestures. Specifically, studies measuring voice onset time

(VOT) have identified the time lag or lead between articulatory release and voicing onset as the cue which serves as the primary distinction between voiced and unvoiced cognates (Lisker and Abramson, 1964, 1970). Agnello (1974) hypothesized that the primary site of difficulty in the stutterer is at the crucial transitional boundaries characterized by the precise coordination of phonatory onset with articulatory movements from one sound to another. He reported the voice onset times and voice termination times for three fluent productions of each of the CV and VC test syllables /pa, ba, ap, and ab/. VOTs and VTTs as measured on the Agnellograph (1973) which combined intraoral air pressure (indicating articulatory constriction and release) and acoustic information (voicing onset and offset) on spectrograms. VOT was defined as the time from which the point of pressure makes its greatest drop to the point of the first glottal pulse. VTT was the time from glottal arrest (last glottal pulse) to the point of maximum excursion of the pressure trace from its baseline. Results indicated that stutterers, as a group, employed significantly longer VOTs and VTTs than the nonstutterers during fluent productions. Voice onset time after the voiceless consonant /p/ averaged 12 msec. for normal speakers and 20 msec for the stutterers. Phonation preceded release for the /b/ by an average of 10 msec. for normal speakers and 7 msec. for the stutterers. It should be noted, however, that the values obtained in this study were much lower than the voice onset times for normal speakers reported by Lisker and Abramson (1964, 1967). The differences in reported values between these studies may be attributable to differences in measurement techniques since Lisker and Abramson used the spectrographic information for the identification of

both articulatory release and glottal onset. What is important to observe, however, is the relative difference in VOT and VTT between the stuttering and nonstuttering groups when utilizing the same measurement procedures. These results indicate that stutterers were slower in initiating vocal fold vibration in coordination with basic articulatory events.

Agnello, Wingate, and Wendall (1974) also studied the VOTs of normal speaking children and those who stutter. The ages of the children ranged from 5.5 years to 9.5 years. Longer VOTs were again observed for the disfluent group than for the matched group of normal speakers. It was also noted that the VOTs for the children as a group were longer than those for the adults. Agnello (1974) suggested that the difficulty most likely experienced by the stutterer is in the closing down phase of the glottis during the initiation of phonation.

The observations that stutterers demonstrate slower VOTs and VTTs than normal speakers is consistent with the findings of Adams and Reis (1971, 1974) that stutterers demonstrate difficulty in "off-on" adjustments of phonation during speech. The asychronies in adductory-abductory musculature during stuttering noted by Freeman and Ushijima (1974) further suggest that disruption in motor timing of the speech processes may originate in the vocal folds. This difficulty would appear to lie in the stutterer's inability to smoothly initiate glottal vibration within the temporal constraints needed for speech.

Voice Reaction Time Studies*

The reaction time experiment has been utilized to determine the speed with which an individual can initiate a predetermined behavioral response following the onset of a cueing stimulus. This type of experiment usually involves a warning signal (in the form of a light or sound) preceding a stimulus cue which elicits the subject's behavioral response. Reaction time (RT) is then defined as the time interval between the onset of the cueing stimulus and the onset of the subject's response.

Hayden (1975) utilized a reaction time procedure to compare the ability of stutterers and nonstutterers to quickly initiate phonation for sentences. He had ten adult stutterers and ten matched nonstutterers initiate the oral reading of each of ten sentences as soon as possible after hearing the onset of a 1000 Hz pure tone. Each sentence was constructed such that the first word began with the syllable /ʌ/ (i.e., "Almonds are nuts."). Results indicated that the stutterers were significantly slower than the nonstutterers in initiating phonation for speech.

Adams and Hayden (1976) attempted to identify a "direction of causation" relationship between stuttering and observed difficulty in initiation of vocal fold vibration. They speculated that the observed slowness in initiating phonation reported in previous studies might be the result of the presence of stuttering behavior such as the excessive tension in the laryngeal musculature reported by Freeman and Ushijima (1974), Fibiger (1971), and others. The opposite "direction of causation" would

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*The term voice initiation time (VIT) has been utilized interchangeably with voice reaction time (VRT) in a number of studies. Any investigation under this heading utilized the reaction time paradigm.

suggest that the delay in voicing caused the individual to repeat and prolong his oral articulatory gestures until a stable vocal tone had been achieved. Thus, the slow phonatory initiation would result in compensatory behaviors observed as stuttering. To investigate these two hypotheses they employed a voice reaction time task which was independent of running speech and, presumedly, stuttering. They suggested that if the slowness in observed initiation of phonation was dependent on the presence of stuttering then elimination of stuttering from the task should eliminate the slowness. Ten adult stutterers and ten matched nonstutterers were instructed to start and stop phonation of "ah" as quickly as possible upon hearing a 1000 Hz pure tone cueing signal appear and then disappear. The experimenters used the "ah" sound based on Van Riper's (1971) assumption that stuttering behavior is not likely to occur when the individual is doing nothing more than phonating. The prerecorded tones were presented in three groups or "trains" with three tones in each train. Each train consisted of a tone, an interval, the second tone, another interval, and the third tone. The length of the tones varied randomly from 1.5 to 4.5 seconds while the silent intervals ranged from 1.5 to 2.5 seconds in duration. The three responses for each train were produced on one breath lasting approximately thirteen seconds. Responses were recorded on an optical oscillograph. Data were analyzed with respect to the summed value for each of the three tones in a train for both the voice initiation and voice termination times. Results indicated that both VITs and VTTs decreased from train to train for both groups of subjects. This progressive improvement in reaction time scores is consistent with

observations of other reaction time experiments demonstrating a "practice effect" characterized by faster reaction times with repeated responses within the same task. It was also observed that the stutterers were significantly slower than the nonstutterers in both initiating and terminating phonation. The authors interpreted these results as indicating that the slowness in voice initiation ability is independent of the presence of stuttering behavior and may be a significant contributing factor in the disruption of phonatory-articulatory coordination. As noted by the authors, however, the obtained reaction time values probably do not accurately reflect the optimum voice initiation and voice termination times for either the stuttering or nonstuttering group. This is evident in that both the VITs and VTTs were continuing to decrease by the end of the third train. A total of only nine responses were elicited for each subject in the study. Generally, reaction time experiments utilizing simple motor responses such as finger pressing have indicated that reaction times continue to decrease with up to fifty to one hundred responses of the same task (Woodworth and Schlosberg, 1954). Moreover, factors such as anxiety and increased excitability, as well as generalized muscle tension have been observed to contribute to slower reaction time scores (Luria, 1932; Goodenough, 1934). Thus, although overt stuttering may have been eliminated from the phonatory task the slower voice initiation times for the stutterers might have been due to situational anxiety associated with the task.

Starkweather, Hirshman, and Tennenbaum (1976) investivated the hypothesis that the slow phonatory reaction times for stutterers may be attributable to disparities in the auditory feedback of speech resulting

from improperly functioning middle-ear muscles as has been hypothesized by Webster (1974). Instead of using an auditory cue to elicit phonation they had eleven stutterers and matched controls produce as quickly as possible twenty-six different monosyllables and bisyllables following a visual cueing stimulus. Three trials were given with each syllable appearing once in each trial. Results indicated that stutterers were slower than the nonstutterers by an average of 65 msec. in initiating vocalization across the wide variety of syllables. A practice effect similar to Adams and Hayden (1976) was observed for both the stuttering and nonstuttering groups with voice initiation times progressively decreasing with increased number of responses. Moreover, the mean initiation time of the stutterers progressively approximated that of the nonstutterers. No significant difference was observed between trials II and III for the non stuttering group. This would suggest that the nonstutterers approached their optimum voice initiation time ability by the end of the second trial. The stutterers, however, continued to significantly decrease their initiation times through trial III. Thus, it would appear that the stutterers were continuing to decrease their reaction times at a different rate than the nonstutterers and that the values do not fully reflect the optimum phonatory capability of the disfluent group. If all contributing stuttering behavior had been eliminated by the nature of the task, as Adams and Hayden assumed, then the overall shape of the "practice" or "adaptation" curves should have been similar for both the stutterers and the nonstutterers. Starkweather, et al. interpreted their results as suggesting that auditory dysfunction was not a cause for the slower voice initiation times in

stutterers. They further suggested that central factors such as a lack of cerebral dominance might be responsible for these differences.

Cross and Shadden (1977) investigated the phonatory reaction times of ten adult stutterers and ten matched nonstutterers as a function of which ear received the auditory stimulus cue. Subjects responded to the onset of a 4000 Hz pure tone by phonating the neutral vowel /ʌ/ as quickly as possible with "natural loudness and effort." The tones were presented to each ear separately, alternating back and forth. A total of one hundred tones was presented to each subject in five sets with twenty tones in each set. There was a two minute rest period between each set. Results indicated that there was no significant difference in reaction times with respect to which ear received the cueing stimulus. Between group comparisons revealed that the mean voice reaction times were significantly longer with a greater degree of response variability for the stutterers than the nonstutterers. These slower and more variable reaction times were observed for each of the five sets of responses. Moreover, no significant differences in mean reaction times were observed between any combination of sets for either the stuttering or the nonstuttering group. It thus appeared that both groups of subjects approximated their optimum reaction time for the experiment by the conclusion of the first set of responses. The results of this study appear to indicate more conclusively that adult stutterers are generally slower and more variable than nonstutterers in initiating voicing and that this delay is observed when operating at what appears to be an optimal capability for a basic phonatory task.

Summary of Physiological-Aerodynamic Correlates of Stuttering

A summary of the studies investigating the physiological-aerodynamic correlates of stuttering indicates that stuttering is characterized by a discoordination of the timing relationship between the respiratory, phonatory, and articulatory processes for speech production. These studies suggest that the focal point of difficulty for the stutterer might be in his ability to consistently make the quick adjustments in the phonatory mechanism needed for fluent speech production. Specifically, stutterers appear slower and more variable than nonstutterers in their ability to initiate phonation.

Voice onset time studies have indicated that stutterers are slower than nonstutterers in initiating voicing in conjunction with supraglottal articulatory release from consonants. Voice reaction time (or "voice initiation time") studies have indicated that stutterers are slower than nonstutterers in their ability to initiate voicing independent of supraglottal articulatory movements and overt stuttering behavior. Adams and Hayden (1976) observed that stutterers had slower voice reaction times than nonstutterers when initiating phonation for an isolated vowel. Since stutterers' voice reaction times were slower than the nonstutterers independent of observable stuttering behavior, the authors proposed that stuttering results from the disruption in timing of the speech production events originating from the delay in voicing onset. This delay supposedly causes the individual to repeat or prolong articulatory movements while attempting to establish a stable glottal tone for voicing.

It is difficult to assume from these voice reaction time studies that the delay in voicing precipitates stuttering since each of the

experiments used only adult subjects. Although stuttering may have been supposedly eliminated from the response task, other factors resulting from the individual's history of stuttering development may have contributed to slow initiation of voicing.

From studies investigating developmental patterns of stuttering, it appears that the features of stuttering are acquired through a process of development which typically begins in early childhood between the ages of two and six years (Morley, 1957; Andrew and Harris, 1964). Stuttering observed in its earliest form seems to differ from that characteristically found in older children and adults. Bluemel (1932) first differentiated between "primary" and "secondary" stuttering based on symptoms exhibited by stutterers when they were just beginning to stutter as compared to the symptoms in its advanced form. Bluemel characterized "primary" stuttering as the easy repetition of the first word or syllable of a sentence unaccompanied by signs of effort or emotional reaction. "Secondary" stuttering, however, was defined as ". . . the child's consciousness of his impediment, physical effort, the use of starters, synonyms and other attempts to control or conceal stuttering." Van Riper (1963) added a "transitional" stage to Bluemel's classification in an attempt to more fully describe the development from primary to secondary stuttering.

Bloodstein (1960) described four major phases of stuttering development. His classifications were based upon observation of 418 stutterers, aged 2-16 years. The criteria identifying a child as belonging to a particular phase include analysis of both his overt speech characteristics and the reaction he has to speaking. Generally, the early phase of stuttering (preschool years) is characterized by easy repetitions of syllables

and nonsyllabic words with few hard contacts and tension. These children display little or no emotional reaction of fear or embarrassment as a stutterer and speak freely in all situations. Later development of stuttering is characterized by more hard contacts or associated struggle behaviors occurring with the blocks. Increasing awareness on the part of the child as being a stutterer is also observed. By the fourth phase of stuttering the child has fully developed symptomotology characterized by tension and struggle with blocks, avoidance of particular sounds, words, and speaking situations, postponement, and starting and releasing devices. The child has developed vivid and continual anticipation of stuttering and demonstrates definite emotional reactions such as fear or embarrassment. Obviously, developmental patterns of stuttering reported are not all inclusive and independently distinguishable from one another. What is important from these studies, however, is the observation that stuttering is a nonstatic, changing behavior. Fully developed stuttering observed in the older child and adult is often distinguishable from its early form by increased muscle tension, struggle, anticipation, and strong emotional reaction on the part of the stutterer to speaking.

The slow voice reaction times observed for adult stutterers may be attributed to a number of factors. For example, the slow initiation times may result from an individual's history of stuttering development characterized not only by overt stuttering behavior but also by a learned anticipatory fear of speaking. This learned fear and resulting muscle tension may also have generalized to other speech related situations as well, such as simply phonating under the pressured involved in

a reaction task. On the other hand, the slow voice reaction times may have been present during the early period of motor speech development. If this latter assumption is correct, the slow voice initiation ability may originally contribute to disruption in the child's ability to accurately time the respiratory, phonatory, and articulatory processes needed for fluent speech production. These two explanations might be tested by comparing the developmental patterns of voice reaction time for stutterers and nonstutterers at different age levels. The age level where the slow voice initiation times become apparent may provide information as to its relationship with the onset and development of stuttering.

Components of Motor Reaction Time

The reaction time paradigm involves the quantitative measurement of the time differential between the onset of a uniform stimulus and the initiation of a single behavioral response. This total response latency is based on the timing relationship among several neurophysiological events. Reaction time (RT) may be divided into two fundamental component processes: (1) neural response time (NRT), and (2) mechanical response time (MRT). The NRT is characterized as the latency of neural impulse transmission from the onset of the external stimulus to the arrival of the efferent motor command at the muscle identified by the initiation of the muscle action potential. The mechanical response time is the latency between the onset of muscle activity and the initiation of the overt response as defined by experimental design.

The neural response processes may be further subdivided into three sequential events involving sensory input, central processing,

and motor output. The sensory time (ST) is the latency of afferent neural impulse transmission from the initiation of the external stimulus in the periphery to the onset of the corresponding evoked potential in the sensory cortex. Motor time (MT) is the time between the electrical discharge in the motor cortex to the arrival of the efferent neural impulses at the muscle. Central processing time (CPT), then is the resulting latency between the arrival of the afferent sensory impulse and the initiation of the motor command. Since neural reaction time is based on the sequential occurrence of these processes in time, the timing relationship between them is additive and may be expressed as NRT = ST + CPT + MT (Botwinick and Thompson, 1966). Both the sensory and motor processes are accessible to quantitative laboratory investigation whereas the mediating perceptual-motor integration system involved in central processing is not and is often times left to investigative inference. The relative time involved in central processing for a given reaction task, however, can be derived from the formula where CPT = NRT - (ST + MT). Based further on the overall additivity of the response processes the total reaction time can be expressed as RT = (ST + CPT + MT) + MRT.

The locus of variation for simple motor reaction tasks for the normal subject has been investigated to determine which component of the neurophysiological system involved in RT accounts for variation in reaction time. Weiss (1965) for example, investigated the mechanical response time and neural response time for a finger lift response to auditory stimuli as a function of the preparitory interval (PI). He reported that of the average total RT of 200 msec., 140 msec. were

accountable for NRT while 60 msec. involved mechanical response time. Weiss also reported that the MRT showed little or no variation across responses and was not functionally related to variation in either the total RT or the PI. The neural response time, however, was in the same functional relation to PI as was RT. Weiss concluded that variation in reaction time was functionally related to the PI and could be attributed primarily to central processing characterized by the subject's states of expectancy or readiness to respond. Botwinick and Thompson (1966) reported similar results where the variance in the NRT for finger lift response was significantly longer than that for the mechanical response time. Neural response times were also highly correlated with both the PI and the total reaction time (r = .96) while mechanical response time and RT were not (r = .10).

Although these studies indicate that variation in reaction time for the normal subject is functionally related to premotoric processes, there is still a distinction to be made between the relative contribution of central processing and sensory-motor transmission factors. Both the sensory time and motor time for simple reaction tasks have been investigated and indicate that, given a uniform stimulus cue, neither ST or MT contribute to variance in reaction time (Netsell and Daniel, 1974; Evarts, 1966). The sensory time in these studies for simple reaction tasks to auditory stimuli ranged from 30 to 35 msec. while motor time varied between 35 and 40 msec. Neither ST nor MT were shown to correlate with variation in the total reaction time. The remaining time spent in central processing, however, was approximately 60 to 70 msec. accounting for approximately one-third of the total reaction time and was highly correlated with RT.

Development of Motor Reaction Time

Several investigators have studied the development of simple motor response time in children (Luria, 1932; Bellis, 1937; Goodenough, 1937; Jones, 1937; Woodworth and Schlosberg, 1954; Czudner and Rourke, 1972; Rourke and Czudner, 1972; and Elliott, 1970). Goodenough (1937) for example, investigated changes in a motor reaction time task as a function of age, sex, intelligence, and socioeconomic status. Two hundred forty-six children ranging from two-and-a-half to eleven-and-a-half years of age and 56 college students served as subjects. Each subject was asked to respond to the onset of a buzzer which initiated an electronic clock by depressing a finger key as quickly as possible. Twenty responses were made by each subject. Correlations between intelligence and reaction time were based on scores from the Minnesota Preschool Tests, the Merrill-Palmer Tests, the Arther Performance Scale, or the Stanford Binet. Results indicated that a regular, progressive decrease in the median reaction time was observed between all age levels. At three-and-a-half years of age the average child's reaction times were 34.9 percent of the adult speed. A substantial decrease in the intrasubject reaction time variability was also observed with increasing age. This decrease in variability was much more marked than the improvement in average speed. Slight sex differences were observed for both the median reaction times and the intrasubject variability. Although differences were small with much overlapping between the sexes, the males were generally faster with lower variability than the females at all age levels. These sex differences are consistent with the findings of Bellis (1931) and Luria (1932). Little or no correlation was observed between intelligence and reaction time supportive of similar

findings by Farnsworth, Seashore, and Tinkers (1927). Also, comparison of the median reaction speed of children from the upper socioeconomic classes with that of children from the lower social classes revealed no consistent differences between groups. The authors, however, gave no indication as to how they defined socioeconomic level in their study.

A similar pattern of decreasing reaction time with age was reported by Jones (1937) who observed significant decreases in mean reaction time of 200 children in grades 6 to 10 when performing a finger pressing task in response to an auditory stimulus cue. The data also revealed marked gains in reaction time speed from 4.5 years through the preadolescent period when a slower rate of improvement in early adolescents and only slight gains after 12.5 years of age.

More recent studies have supported earlier findings that reaction time decreases with age. Czudner and Rourke (1972) and Rourke and Czudner (1972) found that reaction times of "young" (6-9 years) children were significantly slower than "old" (10-13 years) children on a finger pressing reaction task using both auditory and visual stimulus cues. Similar results were obtained by Elliott (1970) who reported the reaction times of 216 children between the ages of 5 and 13 years and 72 young adults. Significant differences were reported among the age groups with reaction time decreasing with increasing age.

The results of these studies indicate that the speed with which an individual can respond to either an auditory or visual cue with a simple motor task increases with age approximating adultlike patterns by about 11 to 12 years of age. The intrasubject reaction time variability is also observed to decrease markedly with increasing age and oftentimes

is more pronounced than the actual decrease in the speed of the reaction time itself. The pattern of faster, more stable reaction time ability with increased age appears to parallel the development of motor speech control.

Normal Patterns of Motor Speech Development

Kent (1976) summarized the acoustic literature investigating the anatomical and neuromuscular development of the speech mechanism. Studies have been concerned primarily with identifying maturational patterns associated with changes in fundamental frequency (Fo), formant patterns of vocalic sounds, and temporal properties of speech, such as voice onset time (VOT).

A review of studies investigating relative values of fundamental frequency indicates a developmental pattern with age. Generally, it has been found that Fo increases from about the third week of life to four months, where it stabilizes for a period of approximately five months (Prescott, 1975). A sharp decrease is then observed for both males and females from about the first to the third year of life (McGlone, 1966; Van Oordt and Drost, 1963). This decrease is followed by a more gradual reduction in Fo from about three years to the onset of puberty at eleven or twelve years of age (McGlone and McGlone, 1972). Characteristically, nondistinguishable differences in the Fo are observed between sexes from birth until approximately 11 to 13 years of age (Fairbanks, 1949a, 1949b); however, upon entering puberty the Fo for females appears to stabilize (Hollien and Paul, 1969) while males further reduce their values by approximately one more octave until about seventeen to eighteen years of age (Curry, 1940; Hollien and Malcik, 1967; Hollien and Paul, 1969).

Generally, the decrease in Fo from infancy to adulthood is approximately one octave for females and on the order of two octaves for males. The most rapid changes in Fo occur during the first four months, one to three years for both males and females, and again between thirteen and seventeen years for males. This developmental change in fundamental frequency is consistent with the pattern of laryngeal growth reported by Kaplan (1960), who observed that laryngeal growth occurs primarily during the first three years of life and during puberty.

As well as identifying the relative values of Fo as a function of age, Eguchi and Hirsh (1969) identified patterns of intrasubject variability for fundamental frequency. Analysis of Fo and intrasubject variability was made from spectrograms of 84 children ranging in age from three to thirteen years at one-year intervals. Each subject repeated the two sentences "He has a blue pen" and "I am tall" five times with acoustic measurement taken for the vowels /i, æ, u, e, a, and ɔ /. Intrasubject variability was determined with respect to standard deviations for Fo measurements for each age group. Results indicated patterns of decreasing Fo similar to those reported in previous studies. It was also observed, however, that intrasubject variability decreased with increasing age until approximately ten or twelve years. The three year olds showed a standard deviation of about 40 Hz decreasing to a minimum value of 12 Hz at ten or twelve. Little or no decrease in variability was observed after this age. It would appear, then, that the decrease in Fo variability with age reflects a pattern of laryngeal accuracy and control for vowels which improves continuously over a period of seven to nine years.

Peterson and Barney (1952) were first to investigate the spectrographic analysis of the formant patterns of men, women, and children. Analyses were made from a total of 1520 words containing the vowels /i, I, e, æ, ɑ, ɔ, ʊ, u, ʌ, ɝ/ produced by 76 speakers. Results indicated that the formant frequency values for children were higher than those of the adult females, with the adult males having the lowest values. The authors concluded that specific vowel perception is not dependent on an exact formant frequency value for all subjects but is dependent on the ratio of one formant to another. The specific formant values for each subject were dependent more upon the relative size of the vocal tract of each individual speaker as well as on the fundamental frequency.

Few studies, however, have investigated intrasubject variability for formant frequency values. Eguchi and Hirsh (1969) suggested that the measurement of formant variability may serve as an index of repeatability of precise articulatory gesturing during the production of vowel sounds. From the acoustic data reported in the previous section they calculated the mean values and intrasubject standard deviations for formant one (F1) and formant two (F2) for the five vowels produced in the two sentences. Each sentence was repeated five times by each subject. Results indicated a steady decrease in the standard deviations of F1 and F2 from approximately the age of three to eleven years. This decrease in formant variability was observed for both the absolute values of the formants and the ratio of each SD to its only mean. The authors proposed that the observed greater formant variability at the younger age levels is due to inaccurate positioning of the articulators for the same vowels

in repetition of the same sentences. The increased accuracy of articulatory movements with age, then, might be attributed to the development of the child's neuromuscular processes for speech production.

Malot and Schneiderman (1976) obtained similar results when investigating the variability in the production of F1 and F2 of specific vowels in a CVC context. One hundred and twelve children ranging in age from three to nine years at one-year intervals and adults served as subjects. A single word picture naming task was utilized for the production of each of the vowels /i, æ, o, ʊ/. The single word task was used to eliminate possible difficulty that the three year old children might encounter repeating sentences. As found in the Eguchi and Hirsch study, an overall decrease in formant variability with increasing age was observed. The largest decrease in standard deviation occurred between the ages of three and four. Reduction in variability was more gradual between four years and adulthood.

Specific attention has been given to voice onset time (VOT) for stop plosive cognates which identifies the timing relationship between voicing onset and supraglottal articulatory release. VOT has been measured from spectrograms and is defined as the time interval between release of the stop consonant (identified by a noise burst on the spectrogram) and the onset of voicing for the following vowel. Values of VOT are presented in both positive and negative time magnitudes with the point of release representing a zero referent point. Therefore, voicing onset prior to articulatory release is presented in negative values and voice onset after the release is presented in positive values.

Lisker and Abramson (1964, 1967) investigated the VOTs for voiced and voiceless cognates for the stop plosives /b, d, g, p, t, and k/ for

adult speakers. Results indicated that the two phoneme categories could be effectively differentiated on the basis of VOT. Specifically, for isolated words voiceless plosives were characterized by relatively long voicing lag times in the range of +40 to +75 msec. Conversely, the voiced cognates were characterized by very short VOTs in the range of zero to +10 msec. It was also observed that for some speakers negative VOTs were observed in the range of -100 msec. indicating that these individuals initiated voicing prior to articulatory release.

Preston and his colleagues at Haskins Laboratory have identified the VOTs for stop plosive consonants of children of various age levels (Preston, Yeni-komshian, and Stark, 1967; Preston and Port, 1968, 1969). Measurements of VOT for most of these studies were taken from the recordings of the spontaneous vocalizations and speech of children produced during thirty minute sessions. Results from these and other studies have been summarized by Kent (1976). Generally, all of the child's early productions of stop plosives fall within a short unimodel range of VOT characteristic of voiced sounds in the range of zero to +30 msec. By about the second to the fourth year the greatest concentration of VOT values is still in the short 0 to +30 msec. range but an increasing proportion of longer voicing lag times are observed. Thus, a differential, yet overlapping bimodel pattern begins to emerge by four years of age. Voiced plosives fall within the 0 to +30 msec. range and voicless plosives fall within the +20 to +50 msec. range. By six years of age a bimodal distribution of VOTs is clearly observed. However, more overlap between voiced and voiceless cognates is observed than for adults. As previously noted, VOTs for adult speakers are characterized by distinctly bimodal distributions with little or no overlap between them.

Zlatin and Koenigstnecht (1976) investigated the VOTs in ten two-year old children, ten six-year old children, and twenty adults. VOT measurements were made from recorded utterances of the words bees, bean, pear, dime, time, goat, and coat. Each word was produced thirty times in random order by each subject. Results were similar to those reported in previous studies with VOT values for the voiced and voiceless stops differing as a function of age. VOT values for the voiced sounds ranged between 0 and +20 msec., for /b/ and /d/ and +10 to +40 msec. for /g/. Voiceless labials ranged from +50 to +100 msec. with apicals and velars falling between +60 and +110 msec.

In each of these studies intrasubject variability for VOTs was observed to decrease with age, approximating adultlike stability by about eight to ten years. For example, Preston and Port (1969) reported significantly greater variance values for the VOTs of two-and-a-half and four-and-a-half year old children when compared with adults. Zlatin and Koenigstnecht (1976) also reported that within category comparisons VOTs showed significantly smaller standard deviations with increasing age.

Port and Preston (1972) suggested that one explanation for the delay in the production of longer VOTs results from the more complex timing relationship between laryngeal and supralaryngeal events needed for the production of voiceless stop plosives. They indicated that voiceless stop plosives are produced with the glottis open at the time of articulatory release (Lisker, et al., (1970). Approximately 100 to 200 msec. is needed to adduct fully the vocal folds from the initial open position (Kim, 1970). Therefore, the individual must leave the glottis open throughout articulatory closure and then promptly initiate vocal fold vibration at the

moment of stop release, having maintained velopharyngeal closure throughout. However, for voiced plosives the adduction of the vocal folds can take place any time prior to or during articulatory closure (approximately 100 msec.) and oscillation will still begin upon release. It would appear, then, that the longer VOTs needed for voiceless stop plosives do not occur until the child has developed sufficient neuromuscular control to accurately time the laryngeal and supralaryngeal events.

Tinley and Allen (1975) investigated the extent to which speech motor timing control improves in consistency with age. They had subjects at four levels (5, 7, 9, and 11 years) repeat the phrase, "Twinkle, twinkle little star, how I wonder where you are" thirty times and tap their finger on a force gauge transducer for two minutes, as steadily as possible. Measurements of intrasubject variance were taken with respect to the time of occurrence of nine articulatory events made within each repetition of the speech sample. Results indicated that intragroup (age) variances were significantly different, with relative variance decreasing to within the adult range by 11 years of age. Similar trends of decreasing variance were observed for the finger tapping task. These results suggest that the speech timing control mechanism has a developmental component similar to other motor tasks. The authors hypothesized that a timing control mechanism or "neural clock" is at least partially responsible for speech timing control and may be common for all motor timing abilities.

In summary, studies investigating speech development indicate that precision of speech motor control and timing increases with age. This development of motor control has been observed for both speech and non-speech tasks. A primary characteristic associated with increased motor

development is the progressive decrease in intrasubject variability from about the age of three to eleven years where it assumes adultlike stability (Eguchi and Hirsh, 1969). A decrease in variability of motor control has been observed for speech production processes involving phonatory adjustments (Fo), precision of vocal tract configuration (formant patterns), and the timing relationship between voicing onset and supraglottal articulatory movements (VOT). Tingley and Allen (1975) also found that variability in the timing of speech motor events decreases with age approximating adult patterns by eleven years.

Similarly, reaction time studies have found that the speed and stability with which an individual can initiate a simple motor task such as finger pressing progressively increases with age. Intrasubject variability for these reaction time tasks decreases markedly with age, oftentimes to a greater extent than the reaction time speed itself. As with speech motor development, the greatest decrease in the mean reaction times and intrasubject variability occurs between the ages of three and seven years diminishing more gradually until assuming adultlike responses by about eleven years of age.

It would appear from these studies that motor control ability for both speech and nonspeech tasks increases with the neurophysiological development of the child. Studies of brain development observed as changes in electroencephalographic (EEG) patterns have supported this assumption. Generally, an adult EEG pattern is not reached until approximately ten to thirteen years of age (Lindsley, 1952) Dustman and Beck, 1966; Novikova, 1961). It seems that the cortex undergoes a slow change toward stability with maturation and that younger children do not

perform as uniformly as older children in tasks involving neural control mechanisms.

Whether the slower, more variable voice reaction times observed for adult stutterers result from the development of the stuttering problem with age or contribute as a disruptive factor in the early development of fluent speech production is presently undetermined. The level in the speech development process at which disruption in phonatory ability occurs might be investigated by comparing the developmental patterns of voice reaction time between stutterers and nonstutterers at several age levels. If slow voicing initiation ability originally contributes to early disruptive behavior then the voice reaction times of children who stutter might be longer and more variable than those of fluent children at early periods in the speech development processes. These differences in voice reaction time might be observed to continue or even increase in magnitude as the individual's stuttering problem develops with age. Conversely, if the slow voicing initiation ability results from the development of stuttering then differences between the two groups might not be observed until later in the development of the individual's stuttering problem. At present, no studies have been found which investigate development of VRT performance of stutterers and non-stutterers as a function of age.

III. STATEMENT OF THE PROBLEM

The purpose of this study was to compare the performance ability of stutterers and nonstutterers of three different age levels on a voice reaction task involving initiation of the neutral vowel sound /ʌ/ in

response to pure tone stimulus cues. The effects of the three experimental variables of Age (five year olds, nine year olds, and adults), Group (stutterers and nonstutterers), and Set (practice) on both the mean and intrasubject response variability of voice reaction time was investigated.

CHAPTER II

METHODS

Subjects

Twenty-seven stutterers and twenty-seven nonstutterers matched for age and sex participated as subjects in this study. Both the stuttering and nonstuttering groups were comprised of nine subjects at each of the three age levels of five years, nine years, and adults (defined in this study as fifteen years or older). Seven of the five year old subjects for both groups were male and two were female. Six of the nine year olds were male and three were female while all of the adult subjects were male. Table 1 displays the summary of the chronological ages of the matched stutterers and nonstutterers as well as the respective mean for each age level. The adult nonstutterers were matched for age with the stutterers within two years, while the children were matched within six months.

Each of the twenty-seven subjects comprising the stuttering group were selected on the basis of the following criteria:

1. Had been evaluated by a speech pathologist certified by the American Speech and Hearing Association as exhibiting stuttering behavior sufficient in frequency and degree to warrant therapeutic intervention either directly with the individual or indirectly with the child's parents at the date of testing.
2. Exhibited no pathological structural anomolies of the speech mechanisms as determined by an oral peripheral examination by the experimenter.

TABLE 1

CHRONOLOGICAL AGE OF THE STUTTERERS AND NONSTUTTERERS AS WELL AS THE MEAN FOR EACH AGE LEVEL. AGE IS EXPRESSED IN YEARS-MONTHS FOR THE FIVE AND NINE YEAR OLDS AND YEARS ONLY FOR THE ADULTS.

Five Year Olds		Nine Year Olds		Adults	
Stutterers	Nonstutterers	Stutterers	Nonstutterers	Stutterers	Nonstutterers
5-1	5-1	8-8	9-2	15	16
5-2	5-2	8-8	9-2	17	18
5-2	5-6	8-11	9-3	19	21
5-3	5-6	9-4	9-4	21	22
5-4	5-6	9-6	9-6	22	23
5-4	5-10	9-7	9-6	23	25
5-6	5-11	9-8	9-6	26	27
5-8	5-11	9-10	9-10	30	30
5-9	5-11	10-5	9-11	30	28
$\overline{X}$ = 5-4	$\overline{X}$ = 5-7	$\overline{X}$ = 9-4	$\overline{X}$ = 9-5	$\overline{X}$ = 22	$\overline{X}$ = 23

3. Exhibited normal voice quality, pitch, and loudness while counting from one to ten and prolonging the vowel sound /ʌ/ for two seconds.
4. Exhibited normal bilateral hearing, defined as pure tone air conduction thresholds not in excess of 20 dB SPL in both ears at 500, 1000, 2000, and 4000 Hz and no greater than 10 dB threshold difference between ears at each frequency.
5. Had an onset of stuttering behavior prior to five years of age as determined by an evaluation by a speech pathologist or presented in a case history report.

Each of the twenty-seven subjects comprising the nonstuttering group were selected on the basis of the following criteria:

1. Were matched for sex with subjects at each age level of the stuttering group.
2. Did not exhibit at the time of this study nor had been previously evaluated by a certified speech pathologist as exhibiting a speech or language disorder sufficient in degree to warrant therapeutic intervention.
3. Exhibited no pathological structural anomolies of the speech mechanism as determined by an oral peripheral examination by the investigator.
4. Exhibited normal voice quality, pitch, and loudness while counting from one to ten and prolonging the vowel sound /ʌ/ for two seconds.
5. Exhibited normal bilateral hearing, defined as pure tone air conduction thresholds not in excess of 20 dB SPL in both ears

at 500, 1000, 2000, and 4000 Hz and no greater than 10 dB threshold difference between ears at each frequency.

Auditory Test Stimuli

The test cues utilized to initiate the subject's vocal responses consisted of a series of 1000 Hz pure tone pulses of one second duration. The pure tones were prerecorded on channel one of a magnetic audio tape at equal intensity levels. The stimulus tape consisted of a total of ninety tones divided into six equally balanced sets of fifteen tones each. The duration of the silent interval (SI) between the offset of one tone and the onset of the following tone varied randomly between three, four, five, and six seconds. Table 2 displays the order of the silent intervals for each of the tones for sets one through six. The first set of tones was utilized as a practice set to familiarize the subject with the test procedures. The experimental procedures, then, utilized the remaining five sets of tones and will henceforth be referred to as sets one, two, three, four, and five, respectively. The phrase, "This is the beginning of set number ___" preceded the onset of the first tone in each set by approximately five seconds. A broadband white noise calibration signal was recorded at an intensity level equivalent to that of the stimulus tones at the beginning of the stimulus tape. Although there were fifteen tones recorded for each set only eleven responses were elicited from each subject. The remaining four tones were utilized as extra stimulus cues in the event of an inappropriate response from a subject.

The nature of the stimulus cues utilized in this study were determined on the basis of previous research utilizing the simple motor

TABLE 2

RANDOMIZED DURATIONS OF SILENT INTERVALS (SI) BETWEEN THE OFFSET OF EACH STIMULUS TONE AND THE ONSET OF THE FOLLOWING TONE FOR EACH OF SIX RESPONSE SETS.

Interval Between Tones	Duration of SI (sec.) for Response Sets					
	Practice	1	2	3	4	5
1-2	3	4	4	3	4	5
2-3	6	3	3	3	3	5
3-4	3	6	6	6	4	3
4-5	6	4	6	3	5	5
5-6	4	3	4	5	5	6
6-7	4	3	4	5	5	6
7-8	6	4	4	5	4	3
8-9	4	6	4	4	3	6
9-10	3	6	5	4	4	4
10-11	5	3	3	3	4	6
11-12	3	2	4	4	3	2
12-13	2	5	6	2	3	3
13-14	6	6	4	3	5	5
14-15	3	2	3	4	4	6

reaction time paradigm. Simple reaction time has been shown to be affected by factors such as the nature of a ready signal, the stimulus modality, stimulus intensity, and the number of trials used.

Traditionally, the ready signal in the form of a light or sound prior to the onset of each stimulus cue has been assumed to maximize the subject's state of readiness and thus lower the threshold of responding. When the ready signal is utilized, manipulating the time interval (often referred to as the preparatory interval, or PI) between its onset and the initiation of the stimulus cue has been shown to have marked effects on reaction time (RT) (Weiss, 1965; Davis and Green, 1969; Kofeld, 1969; Elliott, 1970; Czudner and Rourke, 1972; Henriksen and Holmes, 1973; Algerial and Delhaye-Rembaux, 1975; and Possamai, Granjon, Reynard, and Requin, 1975). Generally, when the PI is the same for all responses, longer PIs result in longer RTs. However, when the PI is randomly altered between responses the shorter PIs result in longer reaction times. These shorter reaction times with longer PIs in the randomly presented intervals have been assumed to result from the increased probability of the occurrence of the response cue with time. Henriksen and Holmes (1973) investigated the ready signal effects as a function of experimental design for a simple reaction time task. In their between-subjects design, 20 subjects had a visual ready signal presented on each trial, while for another 20 subjects the ready signal was always absent. For the within-subject design, 40 subjects experienced both ready signal conditions in random order. They observed that there were no significant differences with respect to reaction times when the ready signal was either present or absent for the

between-subjects design. However, in the within-subject experiment, the reaction times were longer when the ready signal was absent indicating its presence was important for lowering reaction time only when the subject has experienced it within the same session. The authors concluded that when the subjects had never received a ready signal the preceding response cue itself served as the preparatory stimulus for the next cue. It would appear that for reaction time tasks involving young children the presence of both a ready signal and a response cue might serve more to confuse than aid the subject. The ready signal was eliminated from the reaction task in this study to simplify the nature of the task presumably having little or no effect on the resulting reaction time scores.

Effects of the modality through which the stimulus cue is presented and the intensity of the stimulus have also been investigated. It has been found that response cues presented through the auditory modality result in faster reaction times than when presented through visual stimulation (Woodworth and Schlosberg, 1954; Kofeld, 1969; Davis and Green, 1969). The shorter auditory RTs have been attributed to shorter neural transmission latencies than those observed for the visual modality. Intensity of the response cue has also been shown to affect reaction time (Chochile, 1945; Woodrow, 1914; Kofeld, 1969; Grice and Hunter, 1964; and Murry, 1969). Auditorily presented pure tones have been observed to achieve minimum reaction times at medium to high intensity levels ranging from 60 to 90 dB SPL. As a consequence, most reaction time experiments have employed auditory stimulus intensities of 80 to 85 dB SPL to insure minimal effects of stimulus strength on resulting reaction times.

Finally, as noted in the review of the literature on reaction time experiments, a practice effect is observed for reaction tasks. The speed of the response progressively increases with an increased number of responses. Cross and Shadden (1977) observed that for a voice reaction task both adult stutterers and nonstutterers attained what appeared to be their fastest reaction times during the first twenty responses, although within-set comparisons indicated the stutterer took more response trials to reach this level than the nonstutterer. Whether a similar decrease in reaction time is observed with children's voice reaction performance is presently unknown. In order to avoid factors such as fatigue and loss of attention from contributing to variation in voice reaction time a maximum of fifty-five trials were elicited from each subject during the experimental condition.

Stimulus Tape Preparation

Instrumentation utilized in the preparation of the stimulus tape is shown in Figure 1. A broadband white noise calibration signal was produced by a noise generator (Grason-Stadler, model 455C) and routed to channel one of an Ampex (model AG 440B) tape recorder. The recording level for channel one was adjusted to 0 VU for the white noise signal. Thirty seconds of the calibration signal followed by thirty seconds of silence was recorded on magnetic audio tape (Scotch, model 206). The noise generator was then disconnected and the output of a timing generator (custom equipment), electronic switch (Grason-Stadler, model 1287B), and tone generator (Wavetek, model 136) were routed to the input of channel one of the tape recorder. With the circuit open, the tone generator was adjusted to produce a 1000 Hz sine wave with a rise and decay

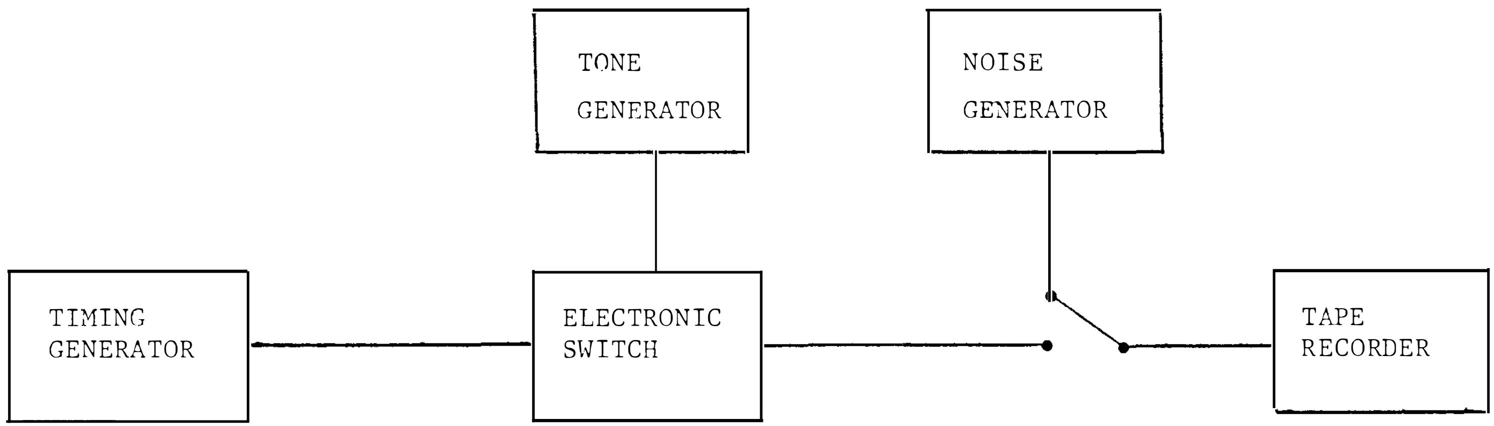

Figure 1. Block diagram of the instrumentation utilized for construction of the stimulus tape.

time of 10 msec. at a level peaking at 0 VU on the recorder. Thus, the white noise calibration signal and the stimulus tones were recorded at the same level. The timing generator was then adjusted so that manually depressing a trigger key produced a one second electrical impulse opening the electronic switch and allowing the 1000 Hz tone of one second duration to be routed to channel one of the tape recorder. The six sets of stimulus tones were then recorded on the stimulus tape by the experimenter manually triggering the timing generator at intervals equivalent to the predetermined silent interval (See Table 2, p. 45) plus one second (tone duration) for each of the stimulus cues. Thirty seconds of white noise calibration signal were recorded at the end of the stimulus tape. The phrase, "This is the beginning of set number ___" was recorded approximately five seconds prior to the onset of the first tone of each set. The signal-to-noise ratio for the pure tone stimuli was 40 dB as measured on an oscilloscope and graphic level recorder.

Instrumentation

A block diagram of the instrumentation used to present the stimulus tones, monitor the subjects' vocal responses, and measure the resulting voice reaction times is shown in Figure 2.

Presentation of the Stimulus Tones. The pure tone stimulus cues were reproduced from the stimulus tape by means of a Wollensak (model 1520AV) tape recorder. The output of the tape recorder was routed to an amplifier (custom equipment) and two attenuators (custom equipment) before being routed bilaterally to Koss K-6 stereo earphones. The output level of each earphone was adjusted independently by means of the

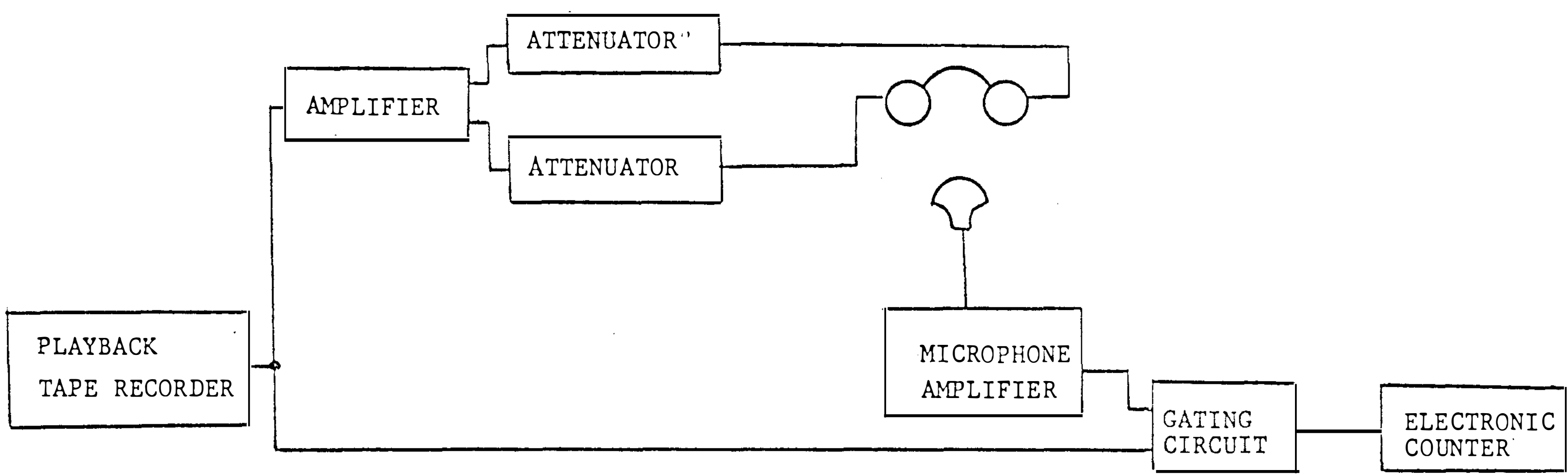

Figure 2. Block diagram of the instrumentation utilized to present the stimulus tones, transduce the subject's vocalizations, and measure the resulting voice reaction times.

amplifier and attenuators. The output from the tape recorder was also routed to the stimulus gate of a two channel comparator gate logic circuit.

Monitoring of Subjects' Vocal Responses. The Subject's vocalizations were transduced by a Sony uni-directional condenser (model ECM 19B) microphone. The microphone was held in place two inches in front of the subject's lips by means of a lavelier neck microphone holder attached to a four- by six-inch metal plate allowing for freedom of movement without varying microphone positioning. The output from the microphone was amplified and routed to the response gate of the comparator gate circuit.

Measurement of Voice Reaction Time. Voice reaction time was measured by means of a two channel comparator NAND gate logic circuit (custom equipment) and an electronic digital counter (Heathkit, model 1B-101). A block diagram of the circuit design involving the comparator gates, counter, and clock mechanism is shown in Figure 3. The electronic digital counter consisted of an internal 1000 Hz clock mechanism which was routed through two comparator logic gate circuits. The stimulus logic gate was controlled by the onset of the rectified signal from the stimulus tones while the response gate was controlled by the onset of the rectified signal from the vocal response. The logic circuits were designed to gate when the rectified voltage level for the stimulus or response signals exceeded a predetermined threshold which could be manually adjusted and lock by two potentiometers. The system was designed such that in the "ready" state prior to stimulus onset, the stimulus circuit was not gated and the response circuit was, breaking the circuit to the clock mechanism. When the voltage level for each stimulus tone exceeded 200 mVolts, the stimulus circuit was gated and the clock began running. When the subsequent voltage level for the subject's

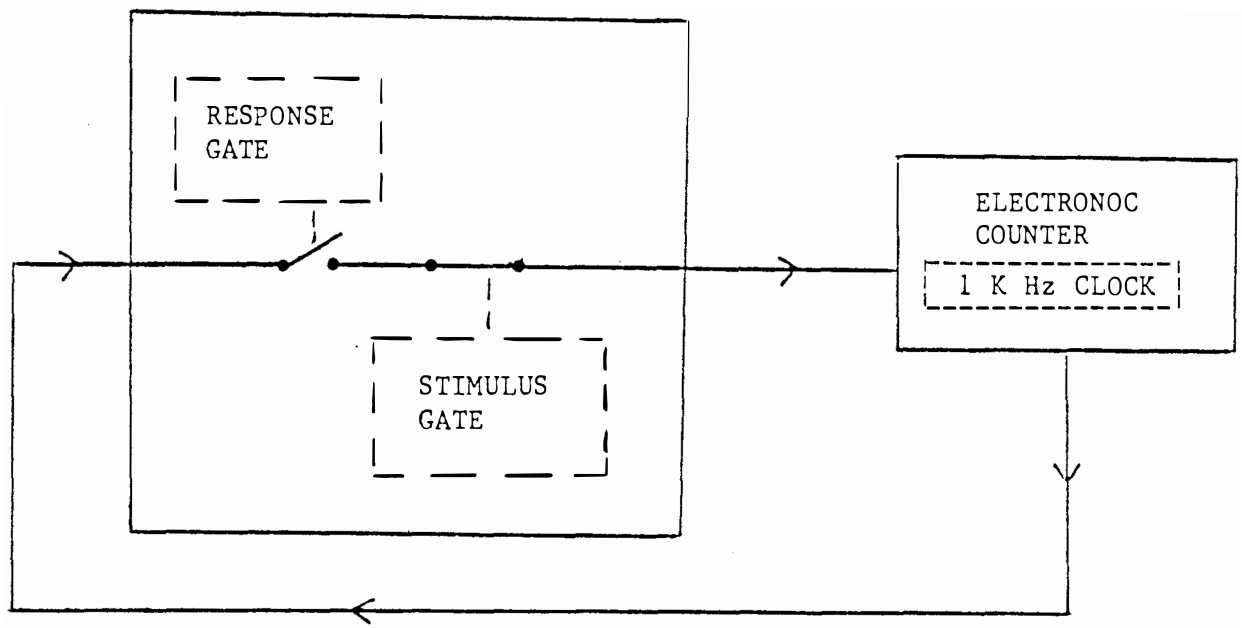

Figure 3. Block diagram of the two channel comparator NAND gate logic circuit and electronic digital counter utilized to measure voice reaction time. The gate is shown in the "ready" position prior to onset of the pure tone stimulus cue.

vocal response exceeded 460 mVolts, the response circuit also gated breaking the circuit to the clock mechanism. The 460 mVolt threshold level corresponded to a vocal intensity level of approximately 80 dB SPL as measured with a sound level meter two inches from the microphone. Voice reaction time, then, was operationally defined as the latency in milliseconds between the moment when the voltage level for the stimulus tone exceeded 200 mVolts and the subject's vocal response exceeded 460 mVolts as measured on the electronic digital counter.

Determining Stimulus and Response Gate Threshold Levels

The voltage threshold levels for both the stimulus and response comparator gate circuits which provided the largest degree of test-retest reliability for measurement of voice reaction time was determined. Figure 4 shows a block diagram of the instrumentation used to prepare a calibration tape consisting of ten stimulus-response pairs. The stimulus tape consisting of the 1000 Hz tones was reproduced on an Ampex (model 445B) playback unit and routed to channel one of the Ampex tape recorder. The output of the Sony microphone and microphone amplifier (custom equipment) were routed to channel two of the recorder. The ten stimulus-response pairs were then recorded as the experimenter responded as quickly as possible to the onset of each of ten stimulus tones by phonating the sound /ʌ/ and holding it until the tone stopped.

Figure 5 displays the instrumentation used to determine the voltage threshold levels for both the stimulus and response gates. The stimulus-response calibration tape was reproduced on a two channel Sony (model TC-377) stereo tape recorder. Channel two of the calibration tape consisting of the experimenter's vocal responses was routed to an amplifier

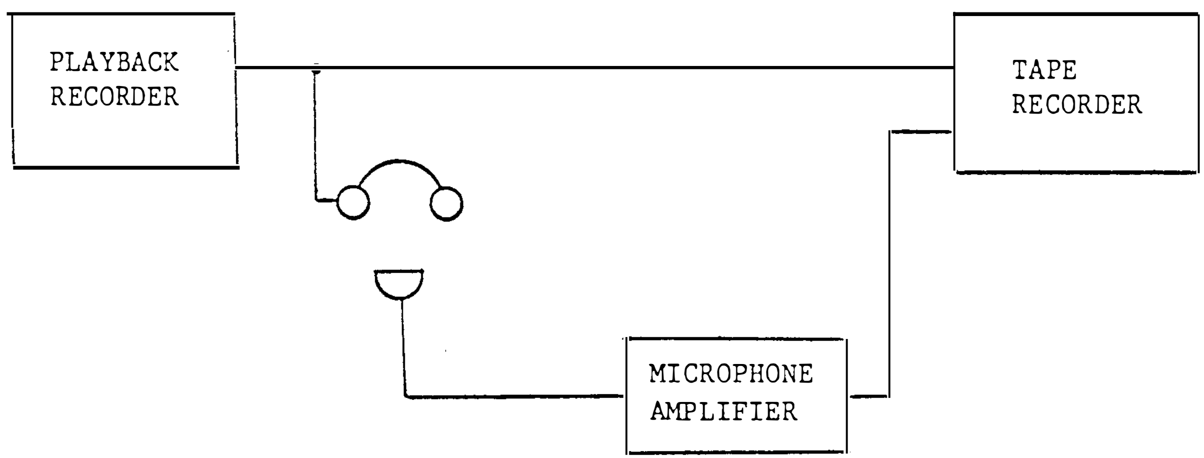

Figure 4. Block diagram of the instrumentation utilized to record a calibration tape consisting of ten stimulus-response pairs.

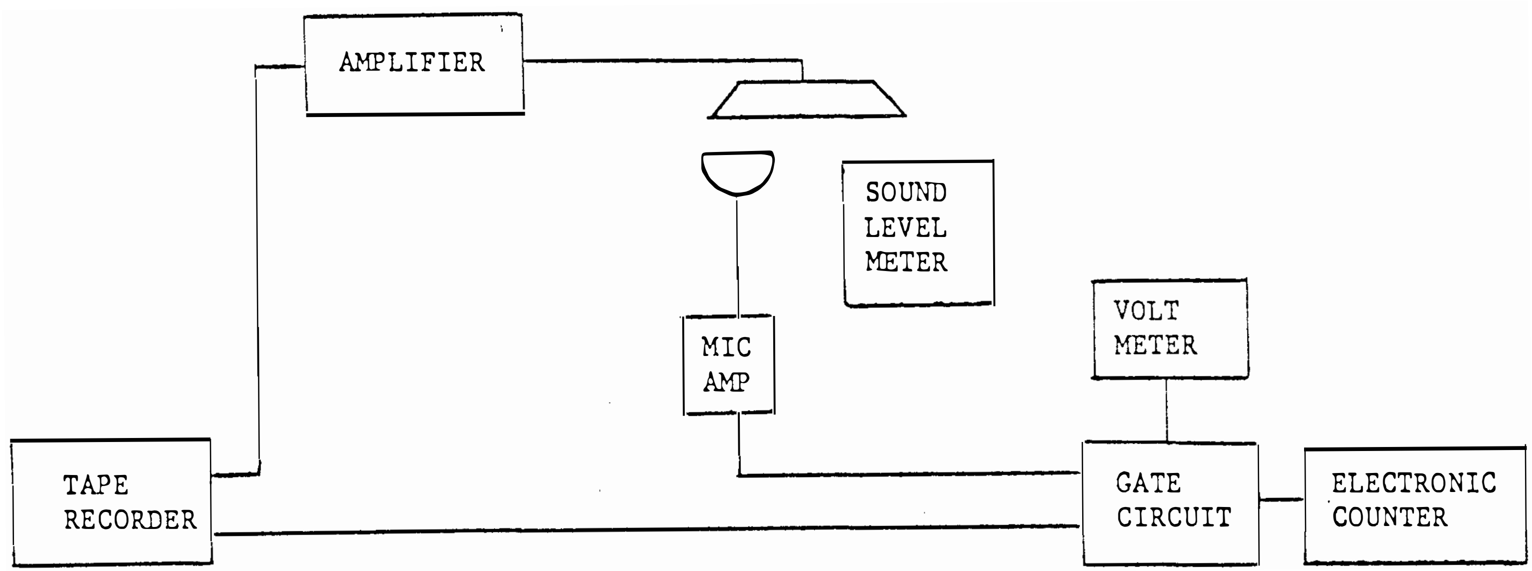

Figure 5. Block diagram of the instrumentation utilized to calibrate the stimulus and response comparator voltage threshold levels for measurement of voice reaction time.

(custom equipment) and then to a six inch loudspeaker. The acoustic output of the loudspeaker was transduced by the Sony condenser microphone with the output level monitored by a sound level meter (Bruel and Kjaer, model 2203). Both the microphone and sound level meter were positioned two inches directly in front of the loudspeaker. The output of the microphone amplifier was routed to the response gate of the comparator logic circuit. The pure tone stimuli from channel one of the calibration tape were routed to the stimulus gate of the comparator circuit. The output from the logic circuit was then routed to the electronic digital counter. A digital voltmeter (Heathkit, model IM102) monitored the voltage output from both the stimulus and response gates.

A potentiometer was used to adjust the microphone amplifier to approximately two-thirds maximum gain and was then locked. Since the rise time of the stimulus tones was consistent and relatively instantaneous (10 msec.) the stimulus gate was set to trigger at 200 millivolts and locked. The output level of the vocal responses at the loudspeaker were then set at 80 dB SPL measured by the sound level meter. The test-retest reliability for measurement of voice reaction time at different response gate voltage threshold levels was investigated by measuring voice reaction time for the ten stimulus-response pairs on three consecutive trials using a single response gate voltage threshold level. This procedure was then repeated systematically advancing each time the response gate threshold level in five millivolt steps. The mean difference between each of the ten stimulus-response pairs was calculated with respect to trials, one, two, and three for each of the voltage threshold levels. The lowest mean difference between the three trials was 3.3 msec. observed for the 460 mVolt

threshold level. The potentiometer for the response gate was then locked in at this voltage threshold level. The voice reaction times for the ten stimulus-response pairs measured under these conditions were recorded and used as future calibration referent values (Appendix A).

Calibration of Instrumentation Prior to Subject Testing

Prior to each testing situation the instrumentation was arranged in the same manner as previously described for determination of the logic gate threshold levels as shown in Figure 5. The output of the vocal responses for the ten stimulus-response calibration pairs was again adjusted to 80 dB SPL as measured by the sould level meter two inches from the microphone. The voice reaction times for the ten calibration stimulus-response pairs were then measured with the electronic digital counter. If the mean difference between these VRTs and those previously measured as calibration referent values exceeded four milliseconds, the gain on the microphone amplifier was adjusted slightly and the procedure repeated. In this manner the instrumentation was calibrated to provide consistent measures of voice reaction time from one test time to another.

When the gate circuits and the microphone amplifier had been calibrated, the instrumentation was arranged for presentation of the experimental condition to the subject as shown in Figure 2 (p. 51). With the reproduce level of the tape recorder set to zero VU for the white noise calibration signal, both the left and right earphones were independently calibrated to an output level of 80 dB SPL for the pure tone stimuli by means of a flat plate coupler (Bruel and Kjaer, model 4147), artificial ear (Bruel and Kjaer, model 4152), condensor microphone (Bruel and Kjaer, model 4144), and sound level meter (Bruel and Kjaer, model 2203).

Procedure

All testing was conducted in rooms with ambient noise levels not in excess of 65 dB SPL as measured by a sound level meter. The subject was seated at a table directly across from the experimenter. All instrumentation with the exception of the electronic digital counter was situated so as not to be in direct view of the subject in order to minimize distraction during testing. The counter was on the table facing away from the subject.

The microphone was positioned on the lavelier microphone holder around the subject's neck and adjusted to two inches from the lips. The specific procedural instructions depending on whether the subject was a child (Appendix B) or an adult (Appendix C) were given prior to initiating the experimental task. Generally, the subject was informed that the purpose of the task was to investigate how quickly he could begin phonating the sound /ʌ/ after hearing the onset of a 1000 Hz tone through the earphones. The subject was instructed that as quickly as he could after hearing the onset of the tone he was to initiate the /ʌ/ sound and hold it until the tone ended, which would be about one second. The subject was informed that he would respond to fifty-five tones in all with a one minute rest period after every eleven tones. Several practice tones were then provided first through a loudspeaker and then through the earphones. Verbal reinforcement was provided by the experimenter when he judged that the subject understood the nature of the task by attempting to initiate phonation of the correct sound as quickly as he could. The practice session was then discontinued when the experimenter judged that the subject understood and could repeatedly perform the task. The experimenter

then set the electronic counter to zero, asked the subject if he was ready, and started the tape recorder at the first set of experimental stimulus tones. The measurements of the voice reaction times were recorded by the experimenter on a data sheet after each stimulus-response pair and the counter was reset to zero. Responses which were judged by the experimenter to be inappropriate due to observable stuttering behavior,* swallowing, coughing, or obvious distraction were marked on the data sheet and eliminated from data analysis. The next appropriate response was then recorded in its place. Stimulus tones were presented until the subject had produced eleven appropriate responses in each set.

Repeatability

Six subjects. one stutterer and one nonstutterer from each of the three age levels, were randomly selected in order to investigate intra-subject test-retest repeatability of VRT measurement. Each of the six subjects was readministered the entire experimental procedure (Test 2) not less than one week following the administration of the original test (Test 1). The Bonferroni method for multiple comparisons (Neter and Wesserman, 1977) was utilized to determine if the mean VRT obtained in Test 2 for each of the six subjects differed significantly at the five percent level of confidence from that obtained in Test 1 for each of the five response sets. The difference between the mean VRT for Test 1 and

*None of the fifty-four subjects exhibited observable stuttering behavior during phonation of any of the vocal responses.

Test 2 was analyzed with respect to the overall mean variance calculated for sets one through five for Test 1. Table 3 displays the results obtained from the test-retest analysis. No significant differences were found between the mean VRT for Test 1 and Test 2 for any of the six subjects. The measurements of VRT obtained in this study were therefore considered to be reliable.

TABLE 3

INTRASUBJECT TEST-RETEST ANALYSIS WITH RESPECT TO THE DIFFERENCE BETWEEN THE MEAN VOICE REACTION TIME FOR TEST 1 AND TEST 2 FOR EACH OF FIVE RESPONSE SETS.

Subject	Set	Difference (Test 1 minus Test 2) Between the Means (msec.)	t-Statistic*
JT (Adult Nonstutterer)	1	12	0.63
	2	-18	0.94
	3	-12	0.63
	4	-25	1.30
	5	-24	1.25
SB (9 Year Nonstutterer)	1	0	0.00
	2	19	0.81
	3	-44	1.88
	4	-11	0.47
	5	3	0.13
BR (5 Year Nonstutterer)	1	19	0.49
	2	-38	0.98
	3	-25	0.65
	4	-102	2.01
	5	-57	1.47
KP (Adult Stutterer)	1	-22	1.69
	2	21	1.61
	3	-3	0.23
	4	17	1.31
	5	11	0.84
SC (9 Year Stutterer)	1	50	1.33
	2	57	1.51
	3	-13	0.34
	4	36	0.95
	5	-5	0.13
CJ (5 Year Stutterer)	1	-51	1.28
	2	-42	1.05
	3	20	0.50
	4	-26	0.65
	5	-32	0.80

*Any value greater than 2.88 is significant at the .05 level.

CHAPTER III

RESULTS

Previous research (Cross and Shadden, 1977) has indicated that a substantial decrease in voice reaction time is observed between responses one and two for each set for both stutterers and nonstutterers. The longer VRTs for the first response in each set is interpreted as the result of a lesser state of readiness to respond due to the absence of a preceding stimulus cue to serve as a preparatory warning signal. The first response in each set in this study, therefore, was excluded from data analysis. The mean voice reaction time and variability for each subject were based on responses two through eleven in each set. This yielded a total of fifty responses per subject. The data were analyzed to investigate the effects of three experimental variables of Age (five years old, nine years old, and adults), Group (stutterers and nonstutterers), and Set (one through five) on voice reaction time performance. Analysis of variance procedures were employed to investigate if there were significant differences among the three experimental variables with respect to both (1) mean voice reaction time performance, and (2) intrasubject response variability of voice reaction time. The probability level of .05 was selected as a criterion for statistical significance in all analysis. The data on which the analysis procedures were based for both mean reaction time and intrasubject response variability are displayed in Appendices D and E, respectively.

Mean Voice Reaction Time

The mean, range, and standard deviation of voice reaction time for the stutterers and the nonstutterers for each of the three ages for sets one through five are displayed in Table 4. The graphic representation of these means is shown in Figure 6. A three-factor analysis of variance with repeated measures on one factor, sets, (Winer, 1969) was utilized to investigate the effects of Age, Group, and Set on the mean voice reaction time. The results of the analysis of variance are summarized in Table 5 and reveal a nonsignificant Age x Group x Set interaction ($F = 0.96$, $df = 8$, $p = .47$). Subsequent analysis of the data is presented with respect to the Age, Group, and Set effects on mean voice reaction time.

Age effect on VRT performance. Examination of Table 5 reveals that voice reaction time significantly decreased as the subjects increased in age ($F = 80.65$, $df = 2$, $p = .0001$). The Age x Set interaction was nonsignificant ($F = 1.04$, $df = 8$, $p = .41$) indicating that the pattern of VRT from one set to another was similar for each of the three age groups. Figure 7 displays the overall mean VRT for the stutterers and nonstutterers of each age and shows that both groups demonstrated similar patterns of reduction in VRT from one age to the next. The Age x Group interaction was also nonsignificant ($F = 0.67$, $df = 2$, $p = .52$).

The Bonferroni method for multiple comparisons (Neter and Wasserman, 1977) was utilized to investigate the differences between the mean VRT for each of the three ages. These results are displayed in Table 6. The overall mean VRT for the five year old subjects was 522 msec. The mean VRTs for the nine year old and adult subjects were 321 msec. and 283 msec., respectively. The voice reaction times for both the nine year olds and

TABLE 4

MEAN VOICE REACTION TIMES (MSEC.) FOR THE STUTTERERS AND NONSTUTTERERS AS A FUNCTION OF AGE (5 YEARS, 9 YEARS, AND ADULTS) AND RESPONSE SETS (ONE THROUGH FIVE).

		5 YEARS OLD			9 YEARS OLD			ADULTS			
		MEAN (msec.)	RANGE (msec.)	SD (msec.)	MEAN (msec.)	RANGE (msec.)	SD (msec.)	MEAN (msec.)	RANGE (msec.)	SD (msec.)	MEAN (msec.)
STUTTERERS	SET										
	1	570	468-814	102	350	259-414	51	312	237-394	47	411
	2	536	422-811	113	342	260-386	48	298	224-353	35	392
	3	552	465-712	78	345	285-393	37	300	256-357	33	399
	4	569	432-770	100	350	261-420	57	287	238-387	43	402
	5	581	469-782	100	367	268-452	62	304	261-449	59	417
	MEAN	562			351			300			404
NONSTUTTERERS	SET										
	1	480	351-611	67	295	267-322	19	264	203-312	31	346
	2	476	373-647	83	288	226-337	33	272	226-311	28	345
	3	492	398-767	114	295	227-346	33	265	228-291	26	351
	4	488	364-672	98	293	267-339	23	261	192-302	33	347
	5	479	307-627	98	287	243-337	36	276	208-304	29	347
	MEAN	483			292			268			348

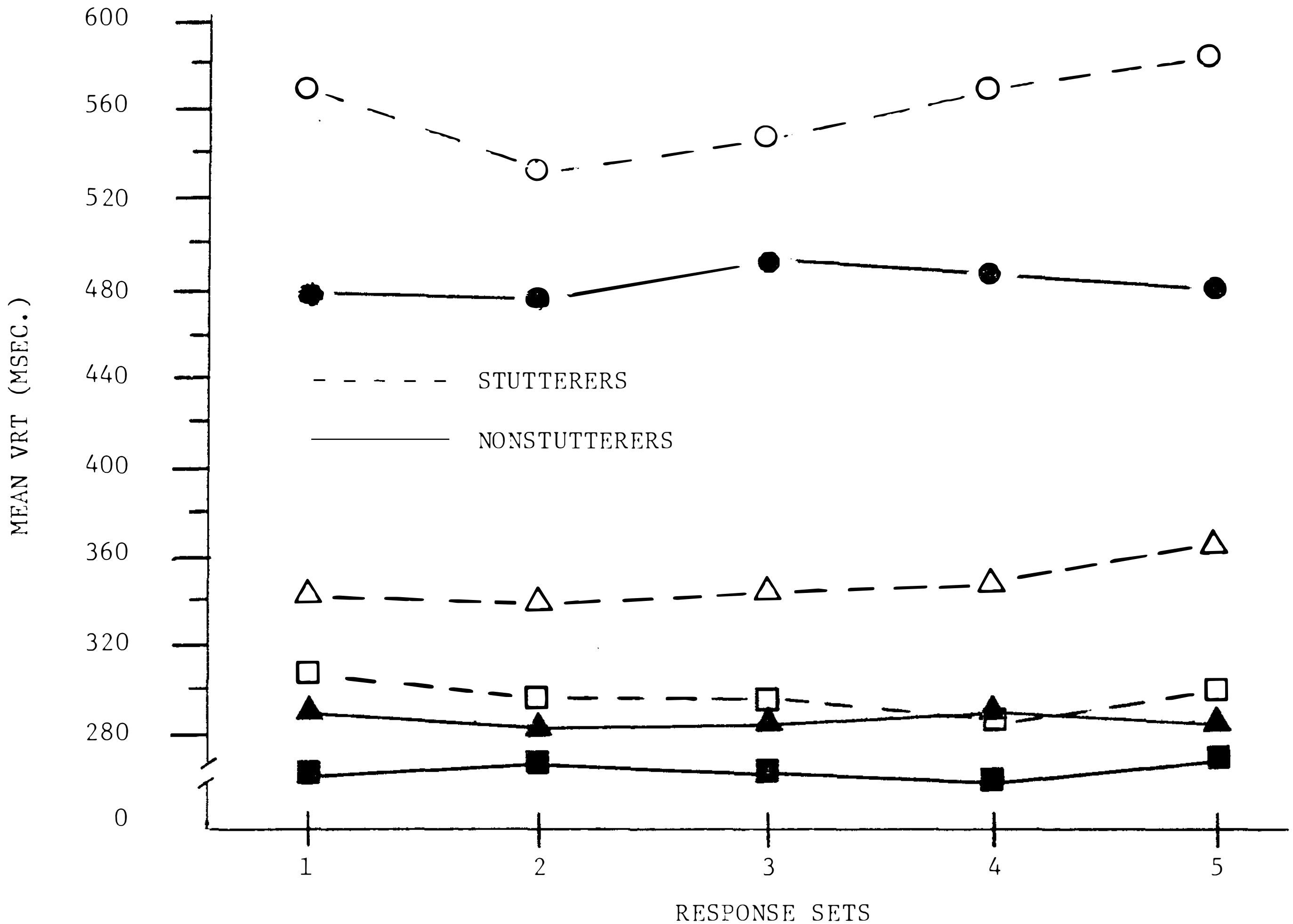

Figure 6. Mean voice reaction time (VRT) for the five year old (○ ●), nine year old (△ ▲), and adult (□ ■) stutterers (open symbols) and nonstutterers (filled symbols) for response sets one through five.

TABLE 5

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE FACTORS AGE, GROUP, AND SET WITH REPEATED MEASURES ON SET WITH RESPECT TO THE MEAN VOICE REACTION TIME.

	SS	df	MS	F	P
BETWEEN SUBJECTS	4086341.73	53			
AGE	2962251.73	2	1481125.87	80.65	.0001
GROUP	218134.87	1	218134.87	11.88	.0012
AGE x GROUP	24443.08	2	12221.54	0.67	.52
SUBJECT (AGE x GROUP)	881512.04	48	18364.83		
WITHIN SUBJECTS	141058.55	216			
SET	5559.99	4	1398.99	2.24	.07
AGE x SET	5194.02	8	649.25	1.04	.41
GROUP x SET	5605.65	4	1401.41	2.24	.07
AGE x GROUP x SET	4813.10	8	601.64	0.96	.47
SUBJECT x SET (AGE x GROUP)	119885.79	192	624.41		

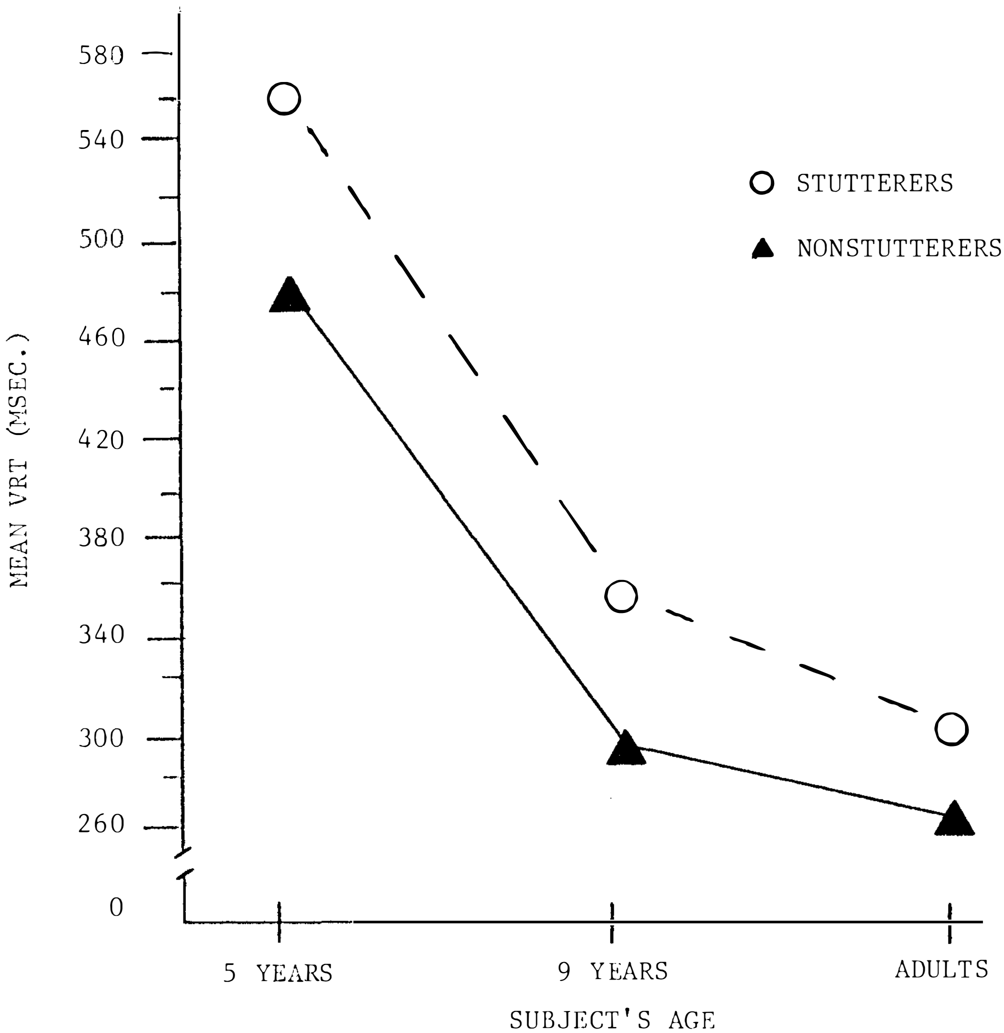

Figure 7. Overall mean voice reaction times (VRT) for the five year old, nine year old, and adult stutterers and nonstutterers (sets combined).

TABLE 6

ANALYSIS OF THE DIFFERENCE BETWEEN THE MEAN VOICE REACTION TIMES FOR EACH OF THREE AGES (COLLAPSED ACROSS GROUPS) UTILIZING THE BONFERRONI METHOD FOR MULTIPLE COMPARISONS (NETER AND WASSERMAN, 1977)

	MEAN	df****	t-Statistic
5 YEAR OLDS	522		
vs.		48	4.46***
9 YEAR OLDS	321		
5 YEAR OLDS	522		
vs.		48	5.30***
ADULTS	283		
9 YEAR OLDS	321		
vs.		48	1.00
ADULTS	283		

*Significant at the .05 level
**Significant at the .01 level
***Significant at the .001 level
****The 48 degrees of freedom were calculated using the mean square error from the analysis of variance.

the adults were significantly shorter than those of the five year olds. Although, the difference between the nine year olds and adults was nonsignificant, the nine year olds exhibited VRTs which were consistently longer than those of the adults. The decrease in mean VRT between the five year old and the nine year old subjects was 200 msec. accounting for 84 percent of the total reduction in VRT across all ages (238 msec.) whereas the difference between the nine year olds and adults was only 38 msec., or 16 percent of the total decrease in VRT. Thus, the most substantial decrease in VRT occurred between the ages of five and nine years with less of a decrease in VRT between the nine year olds and adults.

Set effect on VRT performance. As noted in the previous section, the Age x Set interaction proved to be nonsignificant indicating that age had little demonstrable effect on the pattern of mean VRT across response sets. Figure 8 displays the mean VRT for both the stutterers and the nonstutterers (collapsed across Age) for each of the five sets. Although the Group x Set interaction was statistically nonsignificant ($F = 2.24$, $df = 4$, $p = .07$) inspection of Figure 8 indicates that the stutterers appeared to demonstrate a response pattern different from that of the nonstutterers. The stutterers, as a group, demonstrated a decrease in mean VRT from set one (mean = 411 msec.) to set two (mean = 392 msec.) of 19 msec. This initial decrease in VRT was subsequently followed by a gradual increase in response time with set three (mean = 399 msec.), set four (mean = 402 msec.) and set five (mean = 417 msec.). The nonstutterers, however, demonstrated little or no variation in mean VRT across response sets. Thus, while the nonstutterers appeared to

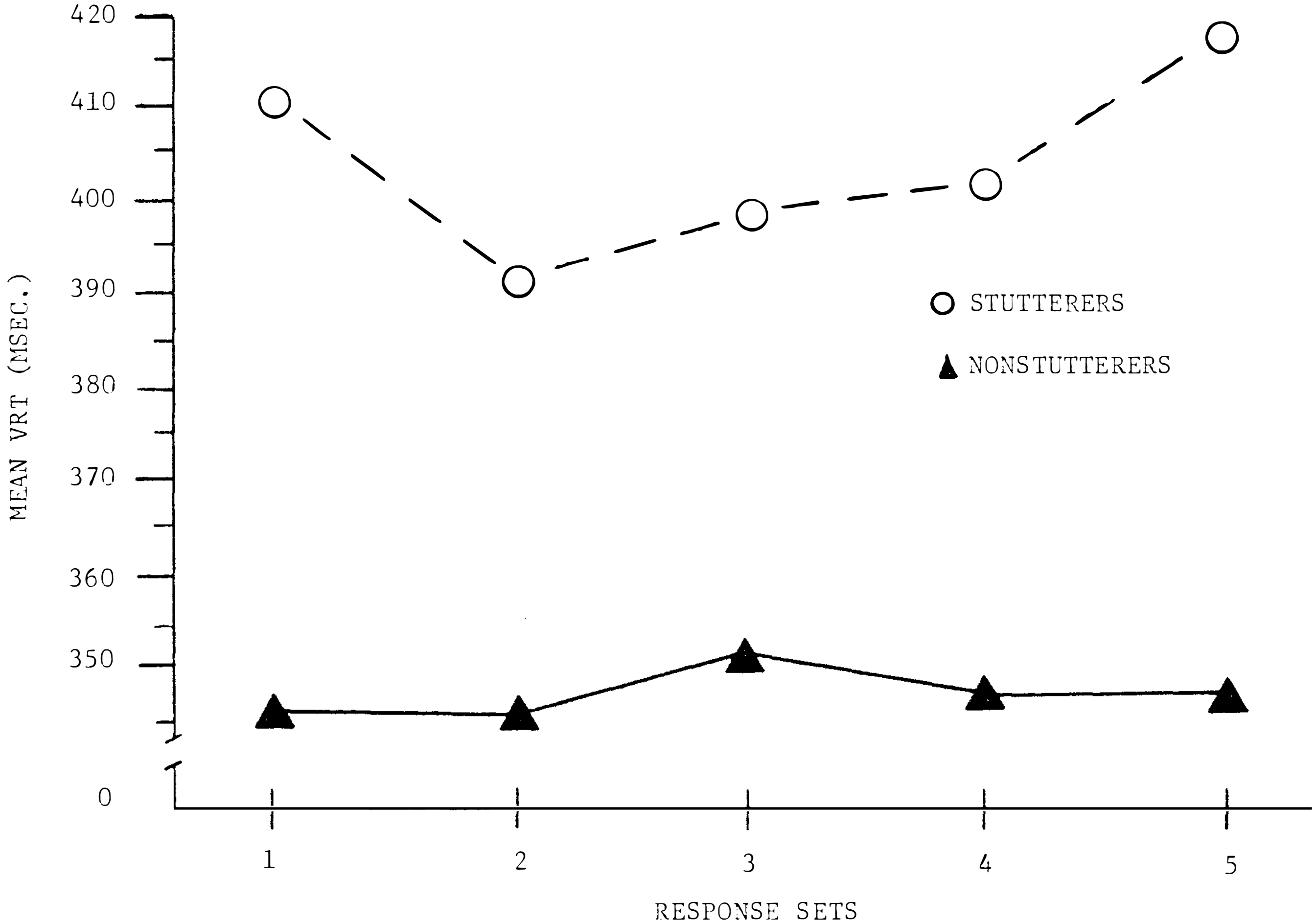

Figure 8. Mean voice reaction times (VRT) for stutterers and nonstutterers (all ages combined) for each of the five response sets.

attain their most efficient mean VRT by set one the stutterers did not reach this level until set two and then demonstrated a consistent increase in VRT with each additional response set.

In view of the observed differences with respect to the response trends between the stutterers and the nonstutterers the main effect for Set should be approached with caution ($F = 2.24$, $df = 4$, $p = .07$). Although the F ratio and the probability value for Set are similar to those for the Group x Set interaction the primary source of variation for the main effect appears to originate with the stutterers.

Group effect on VRT performance. Examination of Table 5 and Figure 7 reveals that the stutterers, as a group, demonstrated slower VRTs than the nonstutterers and that the difference was significant ($F = 11.88$, $df = 1$, $p = .0012$). A nonsignificant Age x Group interaction ($F = 0.67$, $df = 2$, $p = .52$) further indicates that the stutterers exhibited slower VRTs than the nonstutterers at each of the three ages. Although no significant Age x Group interaction was observed in the data, further examination of Figure 7 indicates that the difference in VRT between the five year old stutterers and nonstutterers was 79 msec. while the difference between the nine year olds was 59 msec. The adults showed an even smaller difference of 32 msec. Thus, although the stutterers exhibited significantly slower VRTs than the stutterers at all age levels the respective difference between the two groups decreased as the subjects increased in age.

Variability of Voice Reaction Time

A three factor analysis of variance (ANOVA) with repeated measures on one factor, Set, (Winer, 1969) was utilized to investigate the effects

of the factors of Age, Group, and Set on the intrasubject response variability of voice reaction time. The criterion measure used in the ANOVA procedure was the log of the variance (Neter and Wasserman, 1977) calculated from the ten responses produced by each subject for each of the five response sets, providing an estimate of each subject's response variability. Since variance is noted to be wide distributed and not heterogeneous a transformation of the data to the log of the variance was conducted in order to more closely approximate a normal distribution. Table 7 displays the mean log of the variance for each of the five response sets. These data are also displayed graphically in Figure 9. The summary of the ANOVA is shown in Table 8 and reveals a nonsignificant Age x Group x Set interaction (F = 1.77, df = 8, p = .09). Subsequent analysis of the data is presented with respect to Age, Group, and Set effects on variability of voice reaction time.

Age effect on intrasubject VRT variability. Inspection of Table 7 and Figure 9 reveals that intrasubject variability of VRT decreased as an inverse function of age. The computed ANOVA (see Table 8) revealed a nonsignificant Age x Set interaction (F = 0.71, df = 8, p = .68) suggesting that change in response variability across sets was similar for each of the three age groups. Figure 10 displays the mean log of the variance (MLV) collapsed across sets for the five year old, nine year old, and adult stutterers and nonstutterers as well as the overall MLV for each age level. The ANOVA also revealed a nonsignificant Age x Group interaction (F = 1.36, df = 2, p = .27) indicating that both the stutterers and the nonstutterers exhibited similar patterns of decrease in response variability from one age to the next. The subsequent test for the main effect for Age was significant (F = 90, df = 2, p = .0001).

TABLE 7

MEAN LOG OF THE VARIANCE (MLV) FOR THE STUTTERERS AND NONSTUTTERERS AS A FUNCTION OF AGE (5 YEARS, 9 YEARS, AND ADULTS) AND RESPONSE SETS (ONE THROUGH FIVE).

	5 YEAR OLDS (MLV)	9 YEAR OLDS (MLV)	ADULTS (MLV)	MEAN (MLV)
STUTTERERS				
SET				
1	3.9248	3.7089	3.3348	3.6561
2	3.8386	3.6564	2.9967	3.4972
3	3.9090	3.6978	3.1847	3.5972
4	3.8985	3.6347	3.0225	3.5185
5	4.0191	3.6797	3.1402	3.6129
MEAN	3.9180	3.6755	3.1358	3.5762
NONSTUTTERERS				
SET				
1	3.8116	3.4035	2.9305	3.3818
2	3.6634	3.2593	3.0173	3.3133
3	3.8493	3.3163	2.7746	3.3135
4	3.8559	3.4199	2.9337	3.4031
5	3.7838	3.4286	3.2282	3.4802
MEAN	3.7928	3.3658	2.9769	3.3784

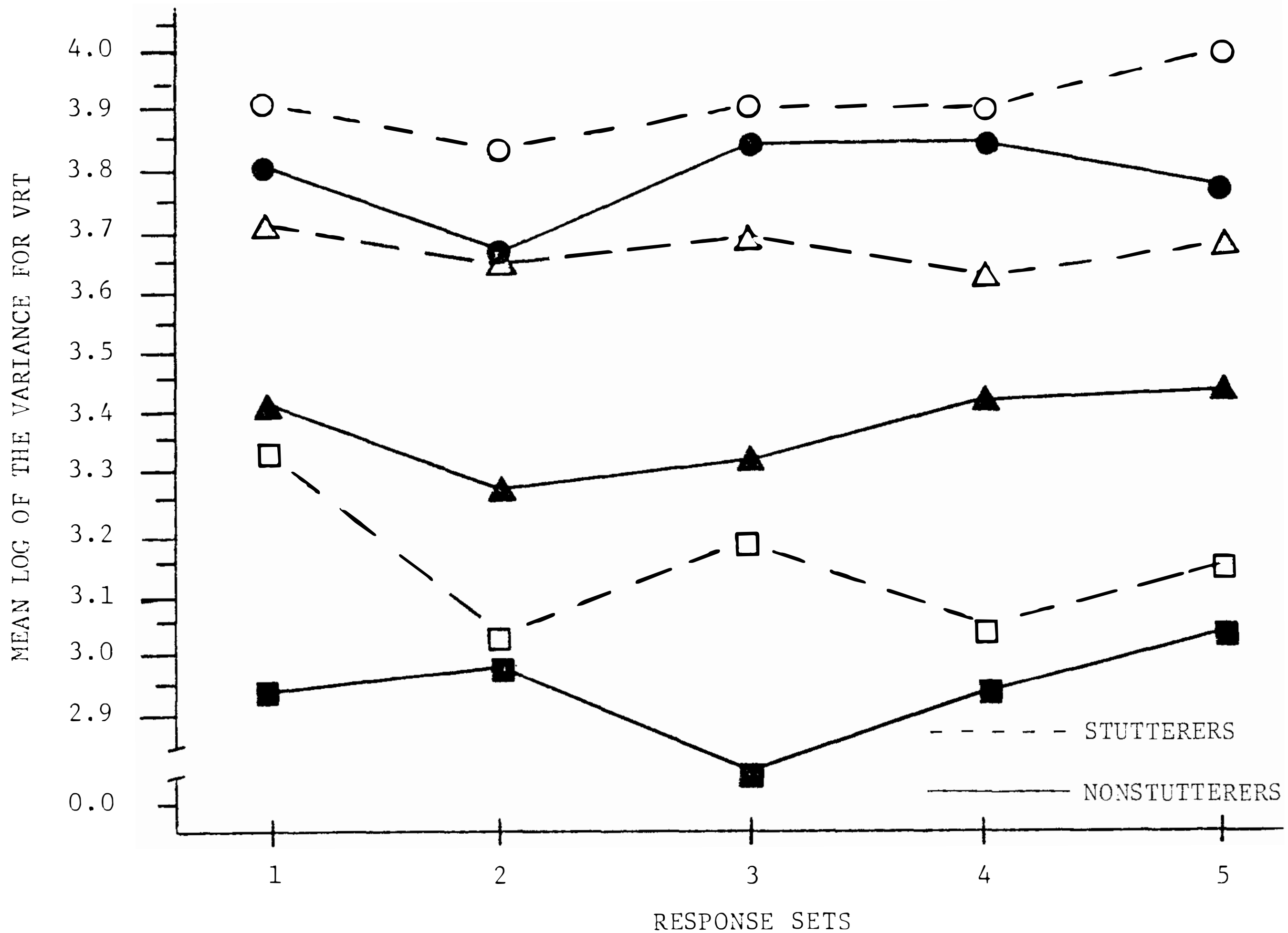

Figure 9. Mean log of the variance of voice reaction times for the five year old (○ ●), nine year old (△ ▲), and adult (□ ■) stutterers and nonstutterers for response sets one through five.

TABLE 8

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE FACTORS AGE, GROUP, AND SET, WITH REPEATED MEASURES ON SET WITH RESPECT TO THE LOG OF THE VARIANCE OF VOICE REACTION TIME.

SOURCE	SS	df	MS	F	P
BETWEEN SUBJECTS	39.7339	53			
AGE	28.9846	2	14.4923	90.75	0.0001
GROUP	2.6470	1	2.6470	16.58	0.0002
AGE x GROUP	0.4358	2	.2179	1.36	0.27
SUBJECT (AGE x GROUP)	7.6665	48	.1597		
WITHIN SUBJECTS	14.4179	216			
SET	0.6740	4	.1685	2.66	0.034
AGE x SET	0.3589	8	.0449	0.71	0.68
GROUP x SET	0.3301	4	.0825	1.30	0.27
AGE x GROUP x SET	0.8967	8	.1121	1.77	0.09
SUBJECT x SET (AGE x GROUP)	12.1582	192			

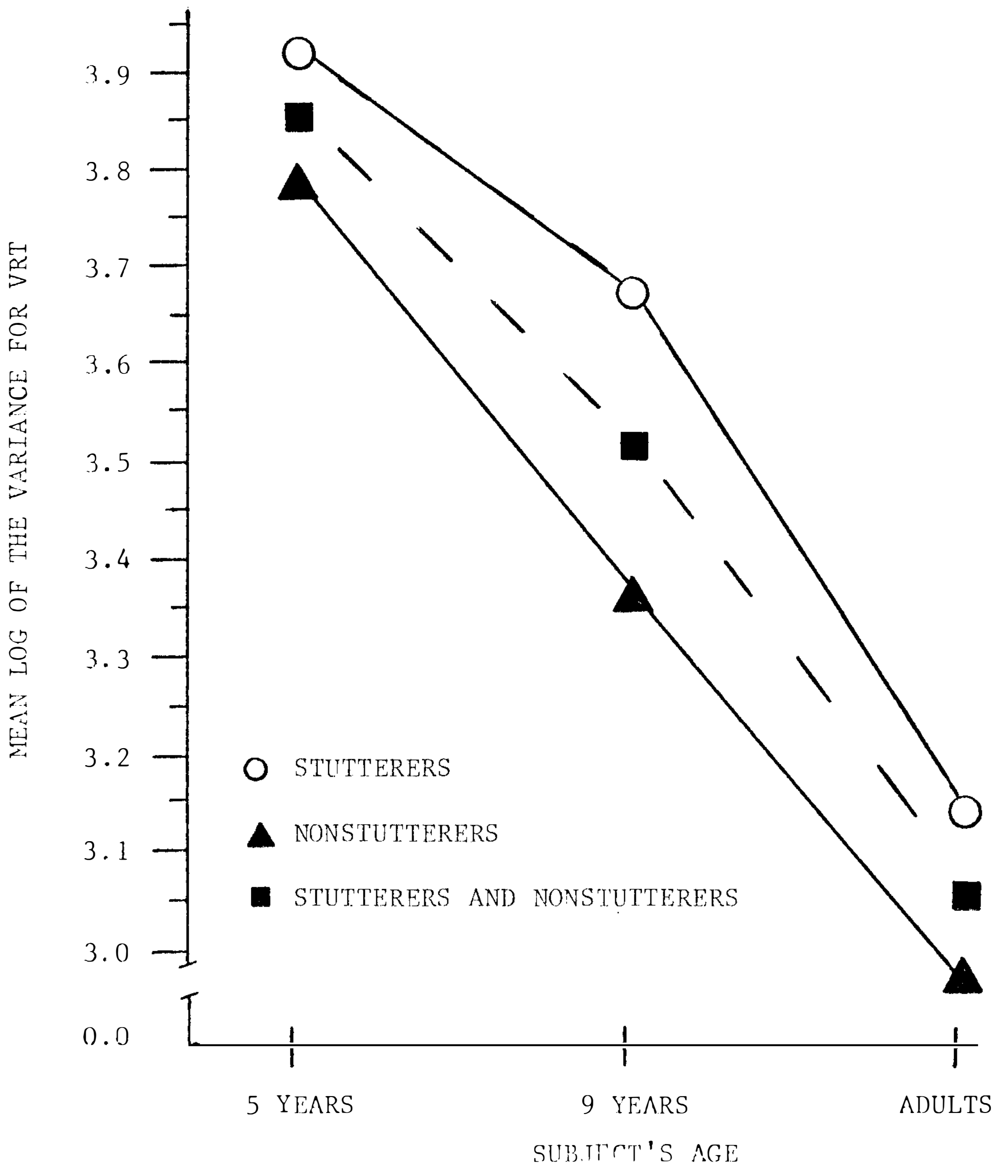

Figure 10. Mean log of the variance for the five year old, nine year old, and adults stutterers and nonstutterers collapsed across sets, as well as the mean log of the variance for each age level collapsed across groups and sets.

Table 9 summarizes the post hoc comparisons between the MLV for the five year old (mean = 3.8554), nine year old (mean = 3.5205), and adult (mean = 3.0560) subjects. Significant differences were found between each of the three age means indicating that although the mean VRT for the nine year old children approximated that of the adults, intrasubject response variability continued to show a marked decrease beyond this age. The proportional reduction in response variability between five and nine years of age was 42 percent of the total reduction across all age groups while the decrease between the nine year olds and adults was 58 percent.

Set effect on intrasubject VRT variability. As noted in the preceding section, the Age x Set interaction was nonsignificant indicating that the pattern of change in response variability from one set to another did not differ significantly as a function of the age of the subjects. Figure 11 displays the MLV for the stutterers and the nonstutterers collapsed across Age for response sets one through five as well as the MLV for each set collapsed across Age and Group. Both the stutterers and the nonstutterers appeared to demonstrate similar patterns of variability across the response sets. This observation was supported by a nonsignificant Group x Set interaction ($F = 1.30$, $df = 4$, $p = .27$). The test for the main effect for Set was significant ($F = 2.66$, $df = 4$, $p = .03$), however, suggesting that the overall subject variability differed between sets. Results of the post hoc comparisons between set MLVs are shown in Table 10. Nonsignificant differences were found between all possible combinations of sets indicating that the Bonferroni test for multiple comparisons was not able to discern which of the response sets would be

TABLE 9

ANALYSIS OF THE DIFFERENCE BETWEEN THE MEAN LOG OF THE VARIANCE (MLV) FOR EACH OF THE THREE AGES (COLLAPSED ACROSS GROUPS) UTILIZING THE BONFERRONI METHOD FOR MULTIPLE COMPARISONS.

AGE	MEAN	df	t-STATISTIC
5 YEAR OLDS	3.855		
vs.		48	2.52*
9 YEAR OLDS	3.521		
5 YEAR OLDS	3.855		
vs.		48	6.04**
ADULTS	3.056		
9 YEAR OLDS	3.521		
vs.		48	3.52**
ADULTS	3.056		

* Significant at the .05 level
** Significant at the .001 level

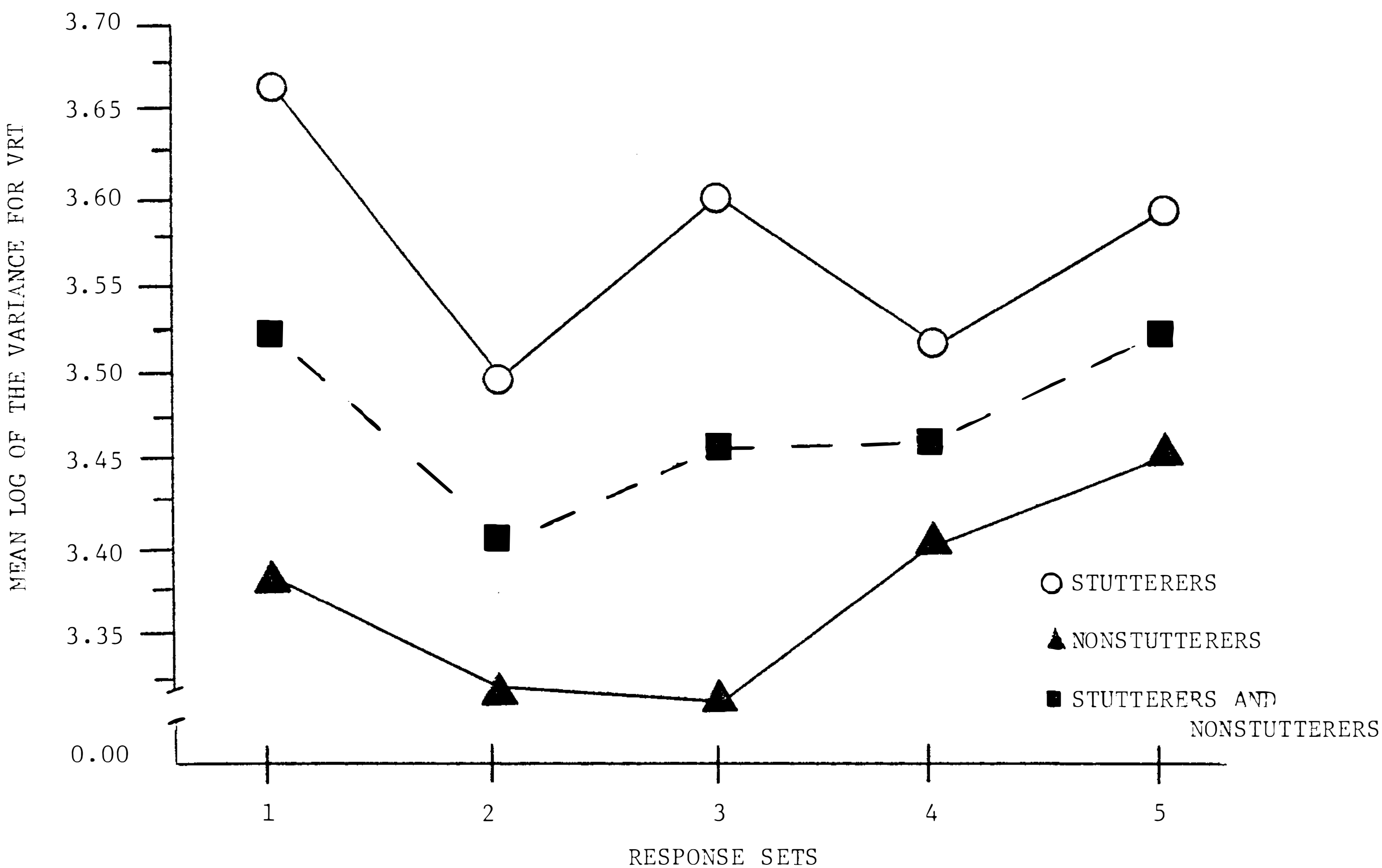

Figure 11. Mean log of the variance for the stutterers and nonstutterers (collapsed across ages) for sets one through five, as well as the mean log of the variance for each set collapsed across groups and ages.

TABLE 10

ANALYSIS OF THE DIFFERENCES BETWEEN THE MEAN LOG OF THE VARIANCE (MLV) FOR EACH OF THE FIVE RESPONSE SETS (COLLAPSED ACROSS AGE AND GROUP) UTILIZING THE BONFERRONI METHOD OF MULTIPLE COMPARISONS.

SET	MEAN	BONFERRONI MULTIPLE COMPARISON TEST*
1	3.5189	+
2	3.4053	|
3	3.4554	|
4	3.4608	|
5	3.5466	+

* A vertical line connecting any two means indicates no significant difference between those means (p = 05).

consistently lower. Although these comparisons were nonsignificant, inspection of Figure 11 suggests a pattern in the data characterized by an initial reduction in response variability from set one (mean - 3.5189) to set two (mean = 3.4053) followed by an increase in variability between each of the additional sets attaining a maximum value on set five (mean = 3.5466).

Group effect on intrasubject VRT variability. Inspection of Table 7 (p. 74) reveals that the stutterers demonstrated a greater intrasubject variability in VRT performance than the nonstutterers. The overall MLV collapsed across Age and Set was 3.5762 for the stutterers and 3.3784 for the nonstutterers. This difference in intrasubject variability was supported by a significant main effect for Group ($F = 16.57$, $df = 1$, $p = .0002$) as shown in Table 8 (p. 76). As previously noted, the Group and Age interaction was nonsignificant (p. 72) with both groups exhibiting a significant decrease in response variability with an increase in age. Both groups also demonstrated similar patterns of MLV across the response sets characterized by an initial decrease from set one to set two followed by a subsequent increase with each additional set of responses. Thus, while both groups of subjects exhibited similar patterns of intrasubject variability across ages as well as across response sets, the stutterers consistently demonstrated a significantly greater degree of intrasubject inconsistency in their voice reaction time performance than the nonstutterers.

CHAPTER IV

DISCUSSION

Interpretation of the results obtained in this study are presented with respect to: (1) the effect of age on the voice reaction time performance of stutterers and nonstutterers, (2) group differences in voice reaction time performances, and (3) the effect of practice (Set effect) on voice reaction time performance. Each of these factors will be discussed with respect to their effects on both voice reaction time and intrasubject response variability.

Age and Voice Reaction Time Performance

The mean voice reaction time as well as intrasubject response variability decreased significantly with an increase in age for both the stutterers and the nonstutterers. A significant reduction in mean voice reaction time occurred between five and nine years of age. The difference in VRT between the nine year olds and adults was nonsignificant, although the nine year olds exhibited mean VRTs which were consistently longer than the adults. The within-subject variability showed a continued reduction for both groups across all age levels. It was also noted that although significant differences were observed between the groups with respect to both the mean and variability of VRT, the stutterers paralleled the nonstutterers with respect to both the rate and and degree of voice reaction performance change with age. The overall percent decrease in mean VRT from five years of age to adulthood was 47 percent and 45 percent for the stutterers and nonstutterers, respectively. In addition, reduction in intrasubject response variability was 20 percent for the stutterers and 22 percent for the nonstutterers.

The observed decrease in the mean voice reaction times as well as response variability with increased age is consistent with previous investigations on the developmental pattern of simple motor reaction time in normal subjects (Goodenough, 1935; Jones, 1937; Czudner and Rourke, 1972; Rourke and Czudner, 1972; Elliott, 1970). Goodenough (1935) and Jones (1937), for example, each tested a large sample of normal children (N = 250) ranging in age from two-and-a-half to eleven-and-a-half years of age on a finger tap response task to auditory stimuli. A regular, progressive decrease in both mean RT as well as intrasubject response variability was observed through nine years of age decreasing more gradually until approximating adultlike performance by about twelve years. Figure 12 displays the mean VRT for the stutterers and the non-stutterers utilized in this study as well as the mean finger tap response times reported by Goodenough (1935) at the same ages. It is clear that although the overall voice reaction times are longer than the finger reaction times the similarity between results obtained in this and Goodenough's study with respect to the developmental pattern across ages is dramatic. The greater decrease in RT for all subjects occurred between the ages of five and nine years with significantly less change between nine years and adulthood.

The faster VRTs as well as the increase in response stability with age observed in this study appear to reflect the course in development of the neuro-physiological integrity of the individual. More specifically, evidence has shown that the increase in both the speed and stability in executing motor reaction tasks may be attributable primarily to maturation

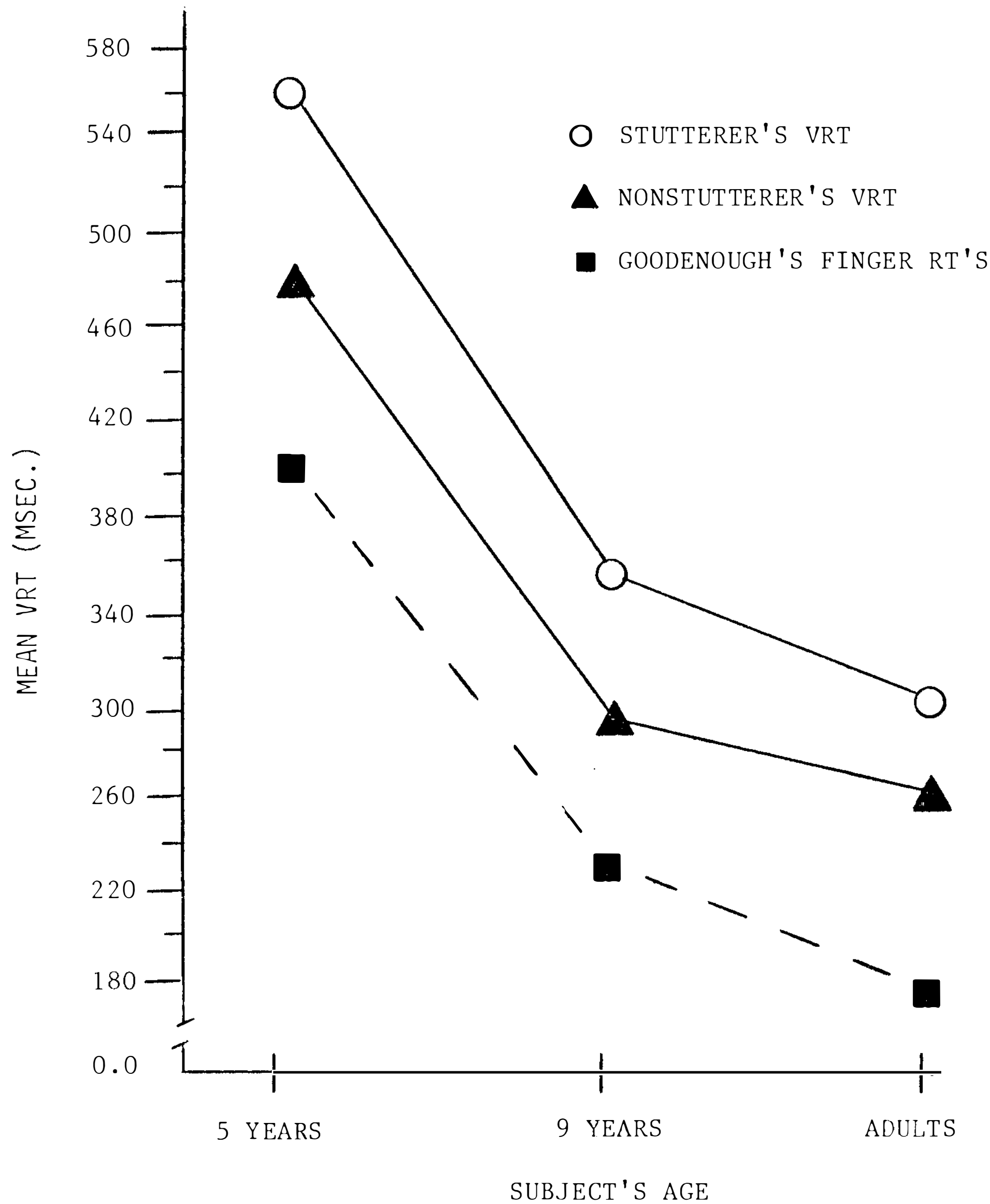

Figure 12. Overall mean voice reaction times for the five year old, nine year old, and adult stutterers and nonstutterers, as well as the mean finger tap reaction times reported by Goodenough (1935) for subjects of the same age.

of central processing capabilities. Weiss (1965) and Botwinick and Thompson (1966) for example, reported that the mechanical response time for motor reaction tasks is unaffected by the age of the subject, indicating that variation in reaction time performance for normal subjects is associated with premotor rather than mechanical factors. Dustman and Beck (1965) investigated the latency of sensory transmission as a function of age and reported that the latency of the initial wave of the evoked potential for both visual and auditory stimuli was the same for both six year old and sixteen year old subjects. Further, Magladery (1959) investigated the motor nerve conduction factors in young and old subjects and reported that the motor nerve pathways in the child were shorter than those of adults and exhibited similar conduction velocities. Development of central processing therefore appears to demonstrate the most marked effect on both the speed and stability of motor reaction capability. It is difficult to specifically identify which factors account for variation in reaction time with age. Luria (1932), however, suggested that

> The slow, more variable RT for younger children reflects a state of diffused nervous excitation during which the child is unable to make the simple integrated movement necessary to respond, even though his attention is apparently centered on doing so.

The instability in the perceptual-motor integration process in the young child has been described behaviorally as excessive and diffuse muscle tension in the general body as well as in the specific muscles involved in the overt response (Elliott, 1970). The subsequent increase in the neuro-physiological capabilities of the individual with age have been observed in the development of electroencephalographic patterns characterized by increased stability and less diffuse brain wave rhythms. As

the child matures, therefore, he appears to develop the capability of not only focusing more attention specifically on the reaction task at hand but also of executing more precise neuromuscular control over the motoric activity involved in the response. This increase in neuro-motor control is reflected not only in faster reaction time but by marked reduction in response variability as well.

The reported development of reaction time performance with age also appears to parallel the pattern of increased precision in executing speech motor control and timing. A primary characteristic associated with speech motor development has been reported as the progressive decrease in within-subject variability in executing the motoric patterns required during speech production. The most marked decrease in intrasubject variability for speech production is observed between the ages of three and eleven years when it assumes adultlike stability (Kent, 1976). This greater stability of speech motor control has been observed for processes involving laryngeal adjustment (fundamental frequency), precision of vocal tract configuration (formant patterns), and the timing relationship between voicing onset and supraglottal articulatory movement (voice onset time) (Eguchi and Hirsh, 1969; Preston, Jeni-komishian, and Stark, 1967; Preston and Port, 1968, 1969; Malott and Schneiderman, 1976; Kent, 1976; Zlatin and Koenigstnecht, 1976). Tingley and Allen (1975) further reported that the temporal aspects of speech production also come under increasingly precise control as the child grows older, attaining relative decreased variance of timing like that for adults by approximately eleven years of age.

The results of this study, then, lend support to the findings of previous research that an increase in neuromuscular control for both speech and nonspeech tasks with age may reflect development in the neurophysiological integrity of the individual. This development is characterized by an increase in speed and stability in executing motoric control. In addition, these results demonstrate that with regard to voice reaction ability, both the stutterers and the nonstutterers exhibit commensurable patterns of development demonstrated by a reduction in both the mean VRT as well as intrasubject response variability.

Set Effect on Voice Reaction Time Performance

The nonstutterers, as a group, exhibited little or no improvement in mean voice reaction time from one set to the next. These results suggest that the control subjects began the task at or near the lower limit at which they were able to initiate voicing and maintained this response capability throughout the experiment. The pattern for intrasubject response variability was somewhat different, however. A decrease in response variability was observed from set one through set three followed by a subsequent increase with the addition of sets four and five. The observed increase in response stability at the onset of the experiment most likely reflects a practice effect resulting from the repetitive initiation of the vocal response. Factors such as subject fatigue, loss of attentiveness, and decreased motivation may account for the increase in response variability observed for the final two sets. This explanation appears consistent with previous investigations, indicating that the greatest source of variation for simple motor reaction tasks reflects central factors associated with the subject's

state of attentiveness or readiness to respond (Gibson, 1941; Lansing, Schwartz, and Lindsley, 1959; Botwinick and Thompson, 1966; Alegria and Delhaye-Rembaux, 1975).

Although both groups demonstrated essentially the same pattern with respect to changes in intrasubject response variability across sets, the stutterers exhibited a more marked practice effect for mean voice reaction time performance. As a group, the stutterers showed an improvement in VRT of 19 msec. between sets one and two as compared to an improvement of only 1 msec. for the nonstutterers. This original reduction in VRT for the stutterers was followed by a gradual increase in VRT with sets three, four, and five. The stutterers, as compared to the nonstutterers, appeared to require more response practice in order to reach the lower limits of their voice reaction time observed in this study. This additional practice may have been necessary to compensate for an inherent difficulty in initiating voicing. The increase in the mean response times with the additional sets, then, might reflect factors such as fatigue, loss of attentiveness, and motivation characteristic of the nonstutterers. Since the nonstutterers began the experiment at reaction speeds which approximated the lower limits of their performance, the decreased motivational factors would have little effect on overall voice reaction performance other than to increase response variability. The stutterers, however, appeared to require more practice and greater vigilance in order to compensate for the original deficit in voice initiation ability. Fatigue, decreased motivation, and attentiveness, then, appear to have a more marked effect on the voice reaction capabilities of the stutterers than nonstutterers.

Differences Between Stutterers and Nonstutterers

Between group comparisons revealed that both the mean voice reaction times and the intrasubject response variability were significantly greater for the stutterers than the matched controls at each of the three age levels. These results are consistent with previous research in this area indicating that the voice reaction ability of adult stutterers is significantly slower than that of adult nonstutterers (Hayden, 1975; Adams and Hayden, 1976; Starkweather, 1976; Cross and Shadden, 1977). Whether the slower, less stable voice reaction ability for stutterers results from learning factors associated with the development of the individual's stuttering problem or is characteristic of an inherent disfunction which may originally contribute as a disruptive factor in the fluent speech production process has not been determined. The results of this investigation, however, bear meaningfully on this inquiry. If the stutterer's inappropriate voice reaction times result from the increased muscular tension, struggle, and associated anticipatory avoidance behavior characteristic of stuttering development (Bloodstein, 1960; Van Riper, 1963; Andrew and Harris, 1964; Luper and Mulder, 1964) then both VRT and response variability would be expected to increase with age. The results of this study are not consistent with this assumption, however. In fact, the largest mean difference between the stutterers and the nonstutterers with respect to both voice reaction time and response variability was exhibited by the five year old subjects. Although both groups demonstrated a commensurate decrease in VRT and response variability with an increase in age, the stutterers were significantly slower and more

variable than the nonstutterers. In addition, the relative difference between the two groups decreased, rather than increased, with age. Thus, the stutterers appeared not to exhibit a deterioration in voice reaction performance with age but actually improved voice reaction ability, although as a group never attaining the same speed or stability as the normal speakers.

Before abandoning the effects of learning on VRT performance, however, care must be taken in the interpretation of these findings. The youngest age level investigated in this study was five years. Although as previously stated, anticipatory fear and struggle behavior are usually thought to increase with age, Bloodstein (1960) noted that some stutterers may exhibit anticipatory fears by as early as five years. Thus, the slower VRT for the five year old subjects in this study may have resulted from learning factors associated with their stuttering development which occurred before this age. The data presented in this study does not allow for more than intuitive speculation in this regard. The trends in the data suggest, however, that the relative voice reaction performance for the stutterers improves gradually from five years of age to adulthood. If the slower VRT for the five year old stutterers resulted from learning factors associated with stuttering development, then longer and less stable voicing difficulty would be suggested beyond this age as the individual develops more substantial overt struggle and anticipatory avoidance reaction associated with his stuttering problem. Since in actuality the opposite trend was observed in the data, it is suggested that the slower, less stable voice reaction times may result from an

inherent disfunction characterized by difficulty in promptly executing behaviors associated with vocalization. This disruption in voicing onset is apparently irrespective of associated stuttering behavior. Also, since the response utilized was simple vocalization of the neutral vowel /ʌ/ the slower voice initiation occurred in the absence of the more complex physiological adjustments involved in speech production. Since the voicing onset difficulty was exhibited at an early period in the child's development of motor speech control, the slower, less stable voice initiation ability may be a contributing factor in the original disruption in the coordination between the respiratory, phonatory, and articulatory processes required for fluent speech.

The indication that the stutterers demonstrated significantly more intrasubject response variability than the nonstutterers is an important finding and merits independent consideration. Not only were the voice reaction times slower but the stutterers also appeared to exhibit difficulty in consistently executing the precise adjustment required in initiating phonation. This inconsistency in voice initiation ability may be a significant factor in the attempts of the individual to develop coordination in the motoric processes involved in fluent speech production. If the stutterer exhibits slower, yet relatively stable voice initiation capability, then compensatory motor patterns might be learned during early stages of speech development which would allow for the delay in voicing onset. The extreme variability with respect to the latency of voicing onset from one moment to the next, however, would appear to indicate that this is a difficult task for the subject. Inconsistency

in vocal onset would appear to inhibit to some degree the learning of the necessary compensatory motoric patterns. Thus, the extreme variability in executing control over the voice initiation process may in itself be a significant contributing factor in the disruption of fluent speech production.

A definitive explanation as to the loci of disruption in voice onset capability of the stutterer is tentative, at best; however, results from previous investigations may lend to speculative hypotheses. Starkweather, et al. (1976) for example, investigated the assumptions proposed by Webster (1974) that slow vocal onset in stutterers is related to a deviation in auditory functioning resulting from disfunction in the middle ear musculature. This explanation was discounted by Starkweather, et al., however, when they found that stutterers demonstrated significantly slower VRTs for visual as well as auditory stimuli. Since similar disruption in voice reaction times have been found utilizing both visual and auditory stimulus cues, the effect of inappropriate sensory transmission may be tentatively disregarded as a significant contributing factor. Further investigation utilizing other stimulus modalities may lend more supportive information in this regard.

Adams (1972) suggested that inappropriate vocal functioning for stutterers results from disruption in the aerodynamic patterning resulting from an imprecise timing relationship between the respiratory, phonatory, and articulatory processes. Schwartz (1974) has gone even further to suggest that the disruption in the vocal activity for stutterers results from a lack of medullary inhibition of the airway dialation reflex resulting in inappropriate abduction of the vocal folds in response to increases in

subglottic pressures during normal speech production. Although these explanations appear tenable, they suggest that the slow VRT for stutterers results from inappropriate activity associated directly with the speech production processes. McFarland (1976), however, investigated the neural response times (onset of stimulus to onset of muscle action potential for overt response) for adult stutterers and nonstutterers on both speech and non-speech related tasks. Subjects were asked to respond as quickly as possible to auditory stimuli by initiating the syllables /bæ/ and /pæ/ (speech) and merely closing the lips (non-speech). The neural response times for both the speech and non-speech tasks were significantly longer for the stutterers than for the nonstutterers. These results suggest that the delayed response times for stutterers may result primarily from factors involved in the neural processes rather than the overt mechanical responses. Moreover, the slow neural response time was exhibited for non-speech as well as speech related tasks. Further evidence in this area has resulted from pilot data comparing the reaction times between stutterers and nonstutterers on a finger tap response task (Cross and Luper, 1978). The same subjects utilized in the present study were also asked to respond as quickly as possible to the onset of twenty 1 kHz tones by depressing a telegraph key with the index finger of the preferred hand. Significantly slower reaction times were observed for the stutterers than the nonstutterers at each of the three age levels investigated. It appears, therefore, that both adult and very young child stutterers demonstrate significantly slower and more variable reaction capability for tasks involving both speech and nonspeech related motoric activity.

Van Riper (1971) has surveyed an extensive body of literature investigating the role of organistic factors in stuttering. It is beyond the scope of this investigation to pursue each of these factors in detail. However, considerable evidence is presented indicating that at least some stutterers when compared to nonstutterers demonstrate disruption in neural control of motoric activity characterized by greater perserverative motor activity (Eisenson, 1958; King, 1961), less coordination of fine motor control for nonspeech tasks (Seth, 1934; Schilling, 1959; Baldan, 1965; Bruno, Camarda, and Curi, 1965), and less coordination of musculature involved in speech production (West and Nusbaum, 1929; Rickenberg, 1956; Zaleski, 1965). Further, substantial evidence has also been presented indicating that a large number of stutterers exhibit atypical electroencephalograms (EEGs) and that younger stutterers (5-12 years) are more likely to show them than older ones (Freestone, 1942; Moravek and Langova, 1962; Schonharl and Bente, 1960; Fritzell, Peterson, and Sellden, 1965). Results from these and other studies on EEG suggest that the atypical brain wave patterns may imply some form of neurological damage or malfunctioning characterized by interference in the bilateral gating of the efferent and afferent nervous impulses required for smooth motoric speech. These findings are of particular interest in view of the results presented in this study indicating that stutterers, as a group, appear to demonstrate slower, less stable reaction times involving initiation of both speech and non-speech motor activity and that the younger stutterers appear to exhibit more difficulty than the adults.

Starkweather, et al. (1976) proposed that central factors contributing to vocal onset for stutterers may be characteristic of less well

established hemispheric dominance for vocalization. Orton (1927) and Travis (1931) originally suggested that a lack of cerebral dominance creates mistiming of the motor impulses to the bilateral speech muscles producing stuttering. Recent evidence has been reported that a large number of adult stutterers exhibit a mixed or reversed dominance for auditory perception utilizing dichotic listening tasks (Curry and Gregory, 1969; Perrin and Eisenson, 1970; Perrin, 1970; Starkweather, Bergman, and Hoffman, 1975). Generally, these studies have found that stutterers, as a group, demonstrate significantly less right ear preference for competing speech stimuli typically exhibited by most nonstutterers. Recently, Sommers, Brady, and Moore (1975) investigated the left and right ear preference on dichotic tasks involving words and digits for stuttering and nonstuttering children and adults at three age levels (4-10 years, 11-16 years, and 17-48 years). The stutterers at each of the three ages showed significantly less of the typical right ear preference for both the words and digits than the nonstutterers. These results supported the findings of previous studies that some stutterers appear to demonstrate a lack of hemispheric dominance for auditory perception. Of particular interest in this study, however, was the finding that although the nonstuttering children and adults performed alike on the dichotic task, the right ear scores of the stuttering children were significantly smaller than those of the adult stutterers, progressively approximating the adult scores with an increase in age. In interpreting these results the authors suggested that:

> The speech perceptual function and/or hemispheric lateralization of speech may continue to develop in some stutterers at a slower rate than nonstutterers. Perhaps the spontaneous remission of stuttering in older children is related to the development of a greater degree of speech perceptual ability and/or hemispheric dominance.

These results may bear meaningfully on the findings that, although stutterers demonstrate significantly slower and more variable reaction times for speech and nonspeech tasks, their performance relative to that of the nonstutterers improves with age. The greater difficulty with respect to motor initiation ability observed for the five year old stutterers in this study may in part reflect a less well developed hemispheric dominance which gradually improves for some individuals with age. The prolonged development in motor reaction ability for the stutterers, then, may be attributable to the slower, more gradual development in central processes associated with precision in programming and executing the motoric commands involved in the reaction task. The delayed development in hemispheric dominance may account not only for the slower speed in initiating the response but also for the greater intrasubject response variability.

Although a large number of both children and adults who stutter demonstrate a less well established hemispheric dominance for auditory perception, the specific relationship between dominance for auditory perception and motor output is uncertain. As noted by Starkweather, et al. (1976):

> It is uncertain just what "dominance" means for a bilaterally represented function such as vocalization. To explain these results it is not necessary to assume anything more elaborate than the lack of dominance involves a slower reaction time. It may have no relationship or only a partial relationship to "dominance" as expressed in handedness, eye preference, or ear advantage.

Little evidence was found in the literature determining whether stutterers exhibit a lack of hemispheric dominance for motor performance as well as auditory perception. Research has indicated, however, that reaction time

for normal subjects is dependent upon the nature and hemispheric presentation of the stimulue cue (Filbey and Glassaniga, 1969; Geffin, Bradshaw, and Wallace, 1971; Levy and Bowers, 1974). Levy and Bowers (1974), for example, found finger tap reaction times to a verbal stimulus buried in a dichotic listening task were 132 msec. slower when presented to the left ear than the right ear of normal subjects. Cross and Shadden (1978) reported there was little or no difference in voice reaction times to pure tone stimuli when presented to either the left or right ears of adult stutterers and nonstutterers. The authors suggested, however, that the lack of ear effect was not surprising since, as noted by Geffin, et al. (1971) and others, simple detection of a uniform stimulus cue does not result in interhemispheric differences in simple motor reaction time. Both the detection of the pure tone stimuli and the initiation of the undifferentiated vocal response may be represented equally well in either hemisphere. Starkweather (personal communication) is presently investigating both the voice and articulatory reaction time for adult stutterers and nonstutterers in response to linguistic stimuli presented visually to the left and right hemispheres separately. Results from this and future investigations may provide more meaningful information regarding the nature of the delay and variation in motor reaction ability of stutterers.

Finally, the question arises as to whether the slow, more variable voice reaction times are typical of all stutterers as a group or are representative of only a portion of atypical speakers. An analysis of the data presented in this study found that twelve of the twenty-seven stutterers exhibited mean VRTs which were more than one standard deviation above the mean VRT for the nonstutterers at comparable ages. Twenty-two

of the twenty-seven stutterers' VRTs were greater than the mean VRT for the nonstutterers. Thus, although a large majority of the stutterers exhibited mean VRTs which were slower than the typical nonstutterer, 44 percent of these subjects exhibited scores which were more than one standard deviation above the mean for the controls. Similarly, Sommers, et al. (1975) reported that 53 percent of the stutterers tested in their dichotic listening study exhibited the reported lack of right ear preference for dichotic words. Results from this and previous studies, then, lend support to the inference that stutterers, as a group, may represent a heterogeneous population demonstrating varying degrees of voice reaction ability. Although the severity of the individual's stuttering problem may account for some of the between subject variation in VRT, the procedures utilized in this study for measuring stuttering severity were too insensitive to allow for any meaningful inference. Specific factors contributing to the differentiation of individuals who stutter into sub-clinical groups is open to further investigation.

Generally, the results of this study lend support to the hypothesis that the original disruption in the speech production process for at least some stutterers may be associated with an inability to consistently initiate prompt motor activity involved in the onset of voicing. This disruption appears to occur at early stages in the development and stabalization of speech production. Further, evidence from this and other investigations suggests that the slower, more variable motor reaction ability of young children and adults who stutter may in part result from damage or disruption in the development of neural control mechanisms involved in motor activity. Little evidence was reported in this investigation supporting

the hypothesis that the disruption in voicing onset results from learning factors associated with the development of stuttering. Although further research is needed to either verify or refute these assumptions, there are strong indications that disruption in motor control exhibited by some stutterers may result from neurological factors involving central motor processing, such as a lack of hemispheric dominance.

CHAPTER V

SUMMARY AND CONCLUSIONS

The mean and intrasubject response variability of voice reaction time to auditory stimuli was investigated for five year old, nine year old, and adult stutterers and nonstutterers. The subjects who participated in this study were twenty-seven stutterers and twenty-seven nonstutterers matched for age and sex. There were nine stutterers and nine nonstutterers at each of the three age levels. All of the stutterers had been reported to have exhibited the onset of stuttering behavior by no later than five years of age.

Each of the subjects was presented with a total of fifty-five pre-recorded 1000 Hz tones bilaterally through stereo earphones at 80 dB SPL. The stimuli were divided into five equal sets of eleven tones each. Data analysis was based on responses two through eleven for each set for a total of fifty responses per subject. The duration of each tone was one second and the silent interval between each of the tones varied randomly among three, four, five, and six seconds. A one minute rest period was provided between each set. The subjects were instructed to respond to the onset of each tone as quickly as possible by initiating the neutral vowel sound /ʌ/ with what they considered to be their natural conversational loudness and effort and to hold it until the tone ended. A training period was provided for the five year old and the nine year old subjects until the investigator determined that they understood and could consistently perform the task. Each of the subjects was then given ten practice trials in order to become familiar with the test procedures.

Voice reaction time (VRT) was measured with an electronic digital counter triggered by the onset of the pure tones. Vocal onset from the subject was transduced by a condenser microphone two inches from the subject's lips. When the voltage level of the acoustic signal exceeded 460 mVolts (approximately 80 dB SPL vocal intensity level) the circuit to the counter was broken and stopped the clock.

Two three-factor analyses of variance with repeated measures on one factor (Set) were utilized to investigate the effects of the three experimental variables of Age (five, nine, and adult), Group (stutterers and nonstutterers), and Set (one through five) on both the mean and intrasubject response variability (calculated from the log of the variance) of voice reaction time. Conclusions drawn from these analyses may be summarized as follows:

1. Both the stutterers and the nonstutterers exhibited a significant decrease in mean voice reaction time with an increase in age. The five year old subjects for both groups exhibited significantly longer VRTs than the nine year olds and the adults. However, while the VRTs for the nine year olds were longer than those of the adults, the differences were not significant.
2. Similarly, the intrasubject response variability decreased significantly with an increase in age for both the stutterers and the nonstutterers with significant differences found between each of the age groups. Thus, while the mean VRT approximated that of the adults by nine years of age, the intrasubject variability continued to decrease through adulthood.
3. Between group comparisons revealed that the mean VRTs for the stutterers were significantly longer than those of the matched

nonstutterers at each of the three age levels. The largest difference between the means for the two groups of subjects was found for the five year olds (60 msec.), decreasing to 50 msec. for the nine year olds and 30 msec. for the adults. The Group x Age interaction, however, was nonsignificant.

4. The intrasubject response variability for the stutterers was also significantly greater than that for the nonstutterers at each of the three age levels. As with the mean VRT, the greatest difference in response variability between the two groups occurred for the five year olds, progressively decreasing as age increased.

5. The Age x Set interaction for the mean voice reaction time was nonsignificant indicating that age had little or no effect on the rate or degree of adaptation for the mean VRT across response sets. The stutterers as a group, however, demonstrated a pattern of adaptation for mean VRT which was dissimilar to that of the nonstutterers. The stutterers exhibited a decrease in mean VRT from set one to set two of 19 msec. This decrease was followed by a progressive increase in VRT with each additional set, attaining a maximum value for set five which was 6 msec. longer than set one. The nonstutterers showed little or no change in mean VRT across sets, attaining a minimum value on set one.

6. The Age x Set interaction for intrasubject response variability was nonsignificant indicating that age had little effect on the rate or degree of adaptation with respect to response variability.

7. Similarly, the Group x Set interaction for intrasubject response variability was also nonsignificant. This indicated that the stutterers and the nonstutterers exhibited similar patterns of change in variability across sets.

8. The combined intrasubject response variability for both the stutterers and the nonstutterers decreased from set one to set two. This was subsequently followed by an overall increase in subject variability with sets three, four, and five.

The results of this study suggest that the slower, more variable voice initiation ability for stutterers may not result from factors associated with the development of the stuttering disorder with age. Difficulty in promptly initiating voicing, on the other hand, may contribute to early disruption in the timing relationship between respiratory, phonatory, and articulatory processes needed for fluent speech production. The results of this study as well as those reported from previous investigations might be interpreted to suggest that the slow voice initiation ability, at least in some individuals, may result from disruption in the development of motor programming involved in early stages of speech production. This disruption also appears to be exhibited in nonspeech as well as speech related motor tasks and may reflect factors involved in central processing such as a lack of hemispheric dominance.

Implications for Further Research

1. Investigation of voice reaction performance of children who stutter and those who do not utilizing a more diffuse range of ages might provide more specific information regarding the development of voice

initiation difficulty. Particular attention should be focused on the performance abilities of children younger than five years of age. This may include subjects not necessarily categorized as exhibiting a "stuttering" problem per se but may include a continuum of "highly fluent" and "highly disfluent" children.

2. Research has indicated that stutterers demonstrate slower, more variable reaction times for nonspeech as well as speech tasks, such as a finger tap response. Investigation of the neural response time and the mechanical response time of stutterers and nonstutterers utilizing electromyographic recordings of antagonistic muscle groups for a finger lift response may provide valuable information regarding the loci of disruption.

3. Similarly, investigation of the neural response time and the mechanical response time for voicing onset utilizing EMG recordings of antagonistic adductory and abductory intrinsic laryngeal musculature may provide information regarding the specific nature of voice onset disruption for stutterers.

4. Advanced experimental procedures have been utilized to differentiate between the relative contribution of three basic components of neural response time in motor reaction tasks (Netsell and Daniel, 1974). Investigation of the sensory time, the central processing time, and the motor time of stutterers and nonstutterers on a simple motor reaction task (such as a finger lift response) might provide valuable quantitative evidence regarding the loci of possible disruption in the neural processes of stutterers.

5. There is some evidence that slow vocal onset for stutterers may result from a lack of hemispheric dominance for motor tasks. "Splitting

the hemispheres" for voice reaction tasks utilizing stimuli with varying degrees of linguistic complexity appear warranted. As noted by Starkweather (personal communication) use of the visual stimulus modality may be the best way of accomplishing this task of presenting competing stimuli to each hemisphere independently without confounding the results with auditory perceptual factors.

6. Respiratory processes play a significant role in voice initiation. Delay in onset of respiratory forces involved in vocal fold vibration may contribute to the observed slower voice reaction times for stutterers. It would appear advantageous to compare the reaction times of various respiratory musculature involved in speech production, such as the internal and external intercostals.

7. Both frequency and severity of stuttering varies under different conditions of physical and psychological stress. The effect of stress-varying situations on voice reaction performance may be investigated by experimentally manipulating stress related conditions, such as negative performance feedback, increasing audience size, etc.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adams, M., Some motor determinants of fluency and stuttering. Paper presented at the Annual Convention of the American Speech and Hearing Association, San Francisco (1972).

Adams, M., A physiologic and aerodynamic interpretation of fluent and stuttered speech. J. Fluency Dis., 1, 35-47 (1974).

Adams, M., and Hayden, P., The ability of stutterers and nonstutterers to initiate and terminate phonation during production of an isolated vowel. J. Speech Hearing Res., 19, 290-296 (1976).

Adams, M., and Reis, R., The influence of the onset of phonation on the frequency of stuttering. J. Speech Hearing Res., 14, 639-644 (1971).

Adams, M., and Reis, R., The influence of the onset of phonation on the frequency of stuttering: A replication and reevaluation. J. Speech Hearing Res., 17, 752-754 (1974).

Adams, M., Reimenschneider, S., Metz, D., and Conture, E., Voice onset and articulatory constriction requirements in a speech segment and their relation to the amount of stuttering adaptation. J. Fluency Dis., 1, 24-31 (1975).

Agnello, J., Apparatus for simultaneously recording speech spectra and physiological data. U.S. Patent Office, 3, 743, 783 (1973).

Agnello, J., Laryngeal and articulatory dynamics of dysfluency interpreted within a vocal tract model. In Vocal Tract Dynamics and Dysfluency: Proceedings of the First Annual Hays Martin Conference on Vocal Tract Dynamics. New York, New York: Speech and Hearing Institute (1975).

Agnello, J., Wingate, M., and Wendall, M., Voice onset and voice termination times of children and adult stutterers. Paper presented at the Annual Convention of the Acoustical Society of America, St. Louis (1974).

Algeria, J., and Delhaye-Rembaux, M., Sequential effects of foreperiod duration and conditional probability of the signal in a choice reaction time task. Acta Psychologica, 31, 321-328 (1975).

Andrew G., and Harris, M., The Syndrome of Stuttering. London: Heinemann (1964).

Baldan, G., Study of the vestibular function in a group of stutterers: Electronystagmographic researches. De Therapia Vocis et Loguellae, I, 349-351 (1965).

Becquerel (1847), cited by Charles Van Riper, The Nature of Stuttering. Engelwood Cliffs, New Jersey: Prentice-Hall, p. 337 (1971).

Bell., C, Philosophical transaction, 2, Archives of General Medicine (1832).

Bellis, C., Reaction time and Chronological age. Proc. Soc. Exper. Biol. and Med., 30, 801-803 (1933).

Besozzi, T., and Adams, B., The influence of prosody on stuttering adaptation. J. Speech Hearing Res., 12, 818-824 (1969).

Bloodstein, O., The development of stuttering: Changes in nine basic features. J. Speech and Hearing Dis., 25, 219-237 (1960).

Bluemel, C., Primary and secondary stammering. Quarterly J. of Speech, 18, 187-200 (1932).

Botwinick, J., and Thompson, L., Premotor and motor components of reaction time. J. Exper. Psychol., 71, 9-15 (1966).

Brenner, M., Perkins, W., and Soderberg, G., The effect of rehersal on frequency of stuttering. J. Speech Hearing Res., 15, 483-486 (1972).

Bruno, G., Camarda, V., and Curi, L., Contribution to the study of organic causal factors in the pathogenesis of stuttering. Bolletino delle Malattie dell'Orecchio, della Gola, del Naso, LXXXIII, 753-758 (1965).

Chevrie-Muller, C., A study of laryngeal function in stutterers by the glotto-graphic method. In Proceedings VII Conr'es de la Socie't'e Francais de Medecine de la Voix et de la Parols, Paris (1963).

Chocholle, R., Variation de temps du reaction auditif en fonction de l'intensite diverses frequinces. Anne Psychol., 41-42, 65-124 (1945).

Coen (1895), cited by Charles Van Riper, The Nature of Stuttering. Englewood Cliffs, New Jersey: Prentice-Hall, p. 337 (1971).

Conture, E., and Colton, G., Laryngeal and respiratory timing in fluent and disfluent production of stutterers and nonstutterers. Paper presented to the Annual Convention of the American Speech and Hearing Association, Houston (1976).

Conture, E., McCall, G., and Brewer, D., Laryngeal activity during the moment of stuttering: Some preliminary observations. Paper presented at the Annual Convention of the American Speech and Hearing Association, Las Vegas (1974).

Cross, D., and Luper, H., Finger tap reaction time for five year old, nine year old, and adult stutterers and nonstutterers. Paper in preparation for submission for publication (1978).

Cross D., and Shadden, B., Stimulus ear presentation and voice initiation time for stutterers and nonstutterers. Submitted for presentation at the Annual Convention of the American Speech and Hearing Association, Chicago (1977).

Curry, T., The pitch characteristics of the adolescent male voice. Speech Monogr., 7, 48-62 (1940).

Curry, F., and Gregory, H., The performance of stutterers on dichotic listening tasks thought to reflect central dominance. J. Speech Hearing Res., 12, 73-82 (1969)

Czudner, G., and Rourke, B., Age differences in visual reaction times of "brain damaged" and normal children under regular and irregular preparatory interval conditions. J. Exper. Child. Psychol., 13, 516-526 (1972).

Davis, R., and Green, F., Intersensory differences in the effect of warning signals on reaction time. Acta Psychologica., 30, 155-167 (1969).

Dustman, R., and Beck, E., Visually evoked potentials: Amplitude changes with age. Science, 151, 1013-1014 (1966).

Eguchi, S., and Hirsh, I., Development of speech sounds in children. Acta Otolaryng. Suppl., 257 (1960).

Eisenson, J., A perseverative theory of stuttering. In J. Eisenson (Ed.), Stuttering: A Symposium. New York: Harper (1958).

Elliott, R., Simple reaction time: Effects associated with age, preparatory interval, incentive-shift, and mode of presentation. J. Exper. Child Psychol., 9, 86-107 (1970).

Fairbanks, G., Herbert, E., and Hammond, J., An acoustical study of vocal pitch in seven and eight year-old girls. Child Dev., 20, 71-80 (1949a).

Fairbanks, G., Wiley, J., and Lassman, F., An acoustical study of vocal pitch in seven and eight year-old boys. Child Dev., 20, 63-69 (1949b).

Farnsworth, P., Seashore, R., and Tinkers, M., Speed in simple and serial action as related to performance in certain intelligence tests. Ped. Sem., 34, 537-551 (1927).

Fibiger, S., Stuttering explained as a physiological tremor. STL-QPSR 2-3/1971.

Filbey, R., and Glassaniga, M., Splitting the normal brain with reaction time. Psychomonic Science, 17, 335-336 (1969).

Ford, G., Temporal relationships among intraoral and subglotic air pressure, labial electromyographic activity, and phonation during production of stuttered and fluent words. Doctor dissertation, The University of Tennessee, Knoxville (1975).

Freeman, F., and Ushijima, T., The stuttering larynx: An EMG, fiberoptic study of laryngeal activity accompanying the moment of stuttering. Paper presented at the Annual Convention of the American Speech and Hearing Association, Las Vegas (1974a).

Freeman, F., and Ushijima, T., Laryngeal activity accompanying the moment of stuttering: A preliminary report of EMG investigations. Haskins Laboratories: Status Report on Speech Res. SR-37/38 (1974b).

Freestone, N., A brainwave interpretation of stuttering. Quarterly Journal of Speech, XXVIII, 466-470 (1942).

Fritzell, B., Peterson, I., and Sellden, V., An EEG study of stuttering and nonstuttering school children. De Therapia Vocis et Loguellae, I, 343-346 (1965).

Geffin, G., Bradshaw, J., and Wallace, G., Interhemispheric effects on reaction time to verbal and nonverbal visual stimuli. J. Exper. Psychol., 87, 415-422 (1971).

Gibson, J., A critical review of the concept of set in contemporary experimental psychology. Psychological Bulletin, 38, 781-817 (1941).

Goodenough, F., The development of the reactive process from early childhood to maturity. J. Exper. Psychol., 18, 431-450 (1935).

Grice, G., and Hunter, J., Stimulus intensity effects dependence upon the type of experimental design. Psychological Review, 71, 247-256 (1964).

Hayden, P., The effects of masking and pacing on stutterers and nonstutterers voice and speech initiation times. Doctoral dissertation. Purdue University (1975).

Henriksen, K., and Holmes, J. Ready signal effects as a function of experimental design in simple reaction time. Memory and Cognition, 1, 141-142 (1973).

Hirose, H., and Gay, T., The activity of the intrinsic laryngeal muscles in voice control. Phonetica, 25, 150-164 (1972).

Hollien, H., and Malcik, E., Evaluation of cross-sectional status of adolescent voice changes in males. Speech Monogr., 45, 80-84 (1967).

Hollien, H., and Paul, P., A second evaluation of the speaking fundamental frequency characteristics of post-adolescent girls. Lang. Speech, 12, 119-124 (1969).

Hutchinson, J., and Ringel, R., Aerodynamic patterns of stuttered speech. Paper presented at the Annual Convention of the American Speech and Hearing Association, Detroit (1973).

Jones, H., Reaction times and motor development. J. Educational Psychol., 15, 181-194 (1931).

Kaplan, H., Anatomy and Physiology of Speech. New York: McGraw-Hill (1960).

Kent, R., Anatomical and neuromuscular maturation of the speech mechanism: Evidence from acoustic studies. J. Speech Hearing Res., 19, 421-445 (1976).

Kim, C., A theory of aspiration. Phonetica, 21, 107-116 (1970).

King, P., Perseveration in stutterers and nonstutterers. J. Speech Hearing Res., IV, 346-357 (1961).

Kofeld, D., Effects of the intensity of auditory and visual ready signals on simple reaction time. J. Exper. Psychol., 82, 89-95 (1969).

Lansing, R., Schwartz, E., and Lindsley, D., Reaction time and EEG activation under alerted and nonalerted condition. J. Exper. Psychol., 58, 1-7 (1959).

Lastovka, M., The monosynaptic spinal cord reflex activity changes in stuttering. Folia Phoniat., 22, 129-138 (1970).

Levy, C., and Bowers, D., Hemispheric asymmetry of reaction time in a dichotic discrimination task. Cortex, 10, 18-25 (1974).

Lindsley, D., Psychological phenomena and the electroencephalogram. J. Electroenceph. Clin. Neuropshysiol., 4, 443-456 (1952).

Lisker, L., and Abramson, A., A cross language study of voicing in initial stops: Accoustical measurements. Word, 20, 384-422 (1964).

Lisker, L., and Abramson, A., Some effects of context on voice onset times in English stops. Language and Speech, 10, 1-28 (1967).

Lisker, L., Sawashima, M., and Abramson, A., Cinegraphic observations of the larynx during voiced and voiceless stops. Haskins Laboratories: Status Report on Speech Res. SR-21/22, 201-210 (1970).

Luper, H.L., and Mulder, R.L., Stuttering Therapy for Children. Englewood Cliffs, New Jersey: Prentice Hall (1964).

Luria, A., The Nature of Human Conflicts or Emotion, Conflict and Will: An Objective Study of the Disorganization and Control of Human Behavior, Horsley Gantt (Ed.). New York: Liveright (1932).

Magladery, J., Neurophysiology of aging. In J. E. Birren (Ed.), Handbook of Aging and the Individual. Chicago: University of Chicago Press (1959).

Malott, P., and Schneiderman, C., Formant variability as a function of age. Paper presented at the Annual Convention of the American Speech and Hearing Association, Houston (1976).

McFarland, S., Neural response time of stutterers and nonstutterers for certain oral motor tasks as a function of auditory stimulation. Paper presented at the Annual Convention of the American Speech and Hearing Association (1976).

McGlone, R., Vocal pitch characteristics of children aged one and two years. Speech Monogr., 33, 178-181 (1966).

McGlone R., and McGlone, J., Speaking fundamental frequency of eight-year-old girls. Folia Phoniat., 24, 313-317 (1972).

Mood, A., On the asymptotic efficiency of certain nonparametric two-sample tests. The Annals of Mathematical Statistics, 25, 514-522 (1954).

Moravek, M., and Langova, J., Some electrophysiological findings among stutterers and clutterers. Folia Phoniat., XIV, 305-316 (1962).

Moravek, M., and Langova, J., Problems of the development of the initial tonus in stuttering. Folia Phoniat., 19, 109-116 (1967).

Morley, M., The Development and Disorders of Speech in Children. Edinburgh: Livingstone (1957).

Neter, J., and Wasserman, W., Applied Linear Statistical Models. Homewood, Illinois: Richard D. Irwin, Inc. (1977).

Novika, L., Age features in the electrical activity of the brain in children and juveniles. Pavlov. J. Higher Nerv. Activ., 11, 61-71 (1961).

Orton, S., Studies in stuttering. Archives of Neurology and Psychiatry, XXI, 61-68 (1927).

Perkins, W., Rudas, J., Johnson, L., and Bell, J., Stuttering:disco-ordinations of phonation with articulation and respiration. J. Speech Hearing Res., 19, 509-522 (1976).

Perrin, K., An examination of ear preference for speech and nonspeech stimuli in a stuttering population. Diss. Abst., 30, 1213 (1970).

Perrin, K., and Eisenson, J., An examination of ear preference for speech and nonspeech stimuli in a stuttering population. Paper presented at the Annual Convention of the American Speech and Hearing Association, New York (1970).

Port, D., and Preston, M., Early apical stop production: A voice onset time analysis. Hasking Laboratories: Status Report on Speech Research SR-29/30, 125-149 (1972).

Possamai, C., Granjou, M., Reynard, G., and Requin, J., High order sequential effects and the negative gradient of the relationship between simple reaction time and foreperiod duration. Acta Psychologica, 39, 263-270 (1975).

Prescott, R., Infant cry sound: Developmental features. J. Acoustical Society of America, 57, 1186-1191 (1975).

Preston, M., and Port, D., A report on a study of voicing in initial stop consonants produced during the second year of life. Johns Hopkins School of Medicine, Annual Report of Neurocommunications Laboratory, No. 3, 211-222 (1968).

Preston, M., and Port, D., Further results of voicing in stop consonants in young children. Hasking Laboratories: Status Report on Speech Research SR-13/14, 181-184 (1969).

Preston, M., and Yeni-Komshian, G., Studies on the development of stop consonants in children. Haskins Laboratories: Status on Speech Research SR-11, 49-53 (1967).

Preston, M., Yeni-Kimshian, G., and Stark, R., Voicing in initial stop consonants produced by children in the prelinguistic period from different language communities. Johns Hopkins Univ. School of Medicine, Annual Report of Neurocommunications Laboratory, No. 2, 305-323 (1967).

Rickenberg, H., Diodochokinesis in stutterers and nonstutterers. Journal of the Medical Society of New Jersey, LIII, 324-326 (1956).

Rourke, B., and Czudner, G., Age differences in auditory reaction time of "brain damaged" and normal children under regular and irregular preparatory interval conditions. J. Exper. Child Psychol., 14, 372-378 (1972).

Schilling, A., Electronystagmographic findings as indication of central coordination defect in stutterers. Archive fur Ohren-Nasen-und Kehlkopfheilkunde Verinigt mit Zeitschrift, CLXXV, 457-461 (1959).

Schonharl, E., and Bente, D., Veranderungen im EEG bei stottern. Kongress, Gemeinrhaftstg. allg. Angew. Phonetik., Hamburg-Altona (1960).

Schwartz, M., The core of the stuttering block. J. Speech Hearing Dis., 39, 169-177 (1974).

Serre d'Alais (1874), cited by Charles Van Riper, The Nature of Stuttering. Englewood Cliffs, New Jersey: Prentice Hall, p. 336 (1971).

Seth, G., Psychomotor control in stammering and normal subjects: An experimental study. British Journal of Psychology, XLIX, 139-143 (1958).

Sommers, R., Brady, W., and Moore, W., Dichotic ear preferences of stuttering children and adults. Perceptual and Motor Skills, 41, 931-938 (1975).

Starkweather, W., Bergman, M., and Hoffman, I., The performance of stutterers on dichotically presented CV syllables. Paper presented at the Convention of the New York State Speech and Hearing Association, Grossinger, New York (1975).

Starkweather, W., Hirshman, P., and Tannenbaum, R., Latency of vocalization onset: Stutterers versus nonstutterers. J. Speech Hearing Res., 19, 481-492 (1976).

Teichner, A., Interaction of behavioral and physiological stress reactions. Psychol. Rev., 75, 271-291 (1968).

Tingley, B., and Allen, G., Development of speech timing control in children. Child Dev., 46, 186-194 (1975).

Travis, L., Speech Pathology. New York: Appleton-Century (1931).

Van Riper, C., Speech Correction: Principles and Methods. Fourth Ed., Englewood Cliffs, New Jersey: Prentice Hall (1963).

Van Riper, C., The Nature of Stuttering. Englewood Cliffs, New Jersey: Prentice Hall (1971).

Van Oordt, H., and Drost, H., Development of the frequency range in children. Folia Phoniat., 15, 289-298 (1963).

Vickers, G., The concept of stress in relation to the disorganization of human behavior. In W. Budsler (Ed.,), Modern Systems Research for the Behavioral Scientist. Chicago: Aldine (1968).

Webster, R., A behavioral analysis of stuttering: Treatment and theory. In K.S. Calhoon, H.E. Adams, and K.M. Mitchell (Eds.), Innovative Treatment Methods in Psychopathology. New York: Wiley (1974).

Weiss, A. The locus of reaction time change with set, motivation, and age. J. Gerontol., 20, 60-64 (1965).

West, R., and Nusbaum, E., A motor test for dysphemia. Quarterly Journal of Speech Education, XV, 469-479 (1929).

Winer, B., Statistical Principles in Experimental Design. New York: Appleton-Century-Crofts (1931).

Wingate, M., Prosody in stuttering adaptation. J. Speech Hearing Res., 9, 550-556 (1966).

Wingate, M., Stuttering as a phonetic transition defect. J. Speech Hearing Res., 34, 107-108 (1969).

Wingate, M., Effect on stuttering of changes in audition. J. Speech Hearing Res., 13, 861-873 (1970).

Woodrow, J., The measurement of attention. Psychol. Monogr., 17 (1914).

Woodworth, R., and Schlosberg, H., Experimental Psychology (Revised Ed.). New York: Holt (1954).

Wyke, B., Deus ex machina vocis: An analysis of the laryngeal reflex mechanisms of speech. Br. J. Dis. of Comm., 4, 3-24 (1969).

Wyke, G., The Neurology of stammering. J. Psychosomatic Res., 15, 423-432 (1971).

Zaleski, T., Rhythmic skills in stuttering children. De Therapia Vocis et Loguellae, I, 371-372 (1965).

Zlatin, M., and Koenigstnect, R., Development of the voicing contrast: A comparison of voice onset time in stop perception and production. J. Speech Hearing Res., 19, 93-1-1 (1976).

APPENDICES

APPENDIX A

VOICE REACTION TIMES (MSEC.) FOR THE TEN STIMULUS-RESPONSE CALIBRATION PAIRS

1. 369
2. 492
3. 403
4. 403
5. 275
6. 369
7. 293
8. 271
9. 357
10. 424

APPENDIX B

BASIC INSTRUCTIONS TO THE FIVE AND NINE YEAR OLD SUBJECTS

Have you ever been in a race before? I'll bet you are real fast. Well, today you are going to be in a kind of race. But this time instead of running I would like to find out how fast you can begin to make a sound for me. The sound you will make is /ʌ/. Let me hear you make the /ʌ/ sound just like I did. . . . Good! The signal to begin to make the sound will be tones that sound just like this: (present 1000 Hz tone of one second duration through loudspeaker). As soon as you hear one of these tones you should begin to say /ʌ/ as soon as you can and hold it until you hear the tone stop. Let's try a few for practice. (Present two or three tones through the speaker.) Good! Remember, sometimes the tones will be real close together, and sometimes they will be further apart, so as soon as you hear the tone, begin to say /ʌ/ as quickly as you can and hold it until the tone stops. Then get ready for the next tone. Now let's practice a few more times with these earphones on. Instead of the tones coming from this speaker, they will come out of these earphones so that you can hear them better.

Now that you have had some practice, let's do the rest for real. You will hear eleven tones and then you can take a rest before beginning again.

Are you ready?

APPENDIX C

BASIC INSTRUCTIONS TO THE ADULT SUBJECTS

The purpose of this experiment is to measure how quickly you can react to the onset of a tone by producing the sound /ʌ/. You will be presented with a series of tones through these earphones at a comfortable loudless level. The tones which signal you to begin producing the /ʌ/ sound will all sound like this (Present one of the stimulus tones through the loudspeaker.). As soon as you hear the onset of each of these tones, react as quickly as you can by producing the /ʌ/ sound with what you consider to be your natural conversational loudness and effort, and hold it until the tone ends. Each tone will be one second long. However, the time between each of the tones will vary randomly between three, four, five, and six seconds. After completing the sound, listen carefully for the next tone. You will be presented with a total of fifty-five tones divided into five sets of eleven tones each. There will be a short rest period between each of the sets. Remember, the object is to start producing the /ʌ/ sound as quickly as you can when you hear the onset of each tone. Do you have any questions?

Before we begin the experiment, let's try ten practice trials.

TABLE 11

SUMMARY OF RAW DATA FOR MEAN VOICE REACTION TIMES (MSEC.) FOR ALL SUBJECTS AS A FUNCTION OF GROUP (STUTTERERS AND NONSTUTTERERS), AGE (5 YEARS, 9 YEARS, AND ADULTS), AND SET (ONE THROUGH FIVE).

			SET				
GROUP	AGE	SUBJECT	1	2	3	4	5
Stutterer	5 Years	1	588	563	628	648	683
Stutterer	5 Years	2	468	421	465	432	469
Stutterer	5 Years	3	486	466	489	486	483
Stutterer	5 Years	4	592	532	573	599	541
Stutterer	5 Years	5	814	811	712	770	781
Stutterer	5 Years	6	509	472	480	487	521
Stutterer	5 Years	7	598	543	548	547	582
Stutterer	5 Years	8	549	536	527	593	620
Stutterer	5 Years	9	527	476	543	557	548
		Mean	570	536	552	569	581
Stutterer	9 Years	10	381	365	364	420	452
Stutterer	9 Years	11	370	381	381	381	399
Stutterer	9 Years	12	327	322	338	349	360
Stutterer	9 Years	13	282	275	285	263	268
Stutterer	9 Years	14	395	385	393	380	405
Stutterer	9 Years	15	415	479	337	405	426
Stutterer	9 Years	16	365	378	378	355	377
Stutterer	9 Years	17	357	330	307	328	309
Stutterer	9 Years	18	259	259	315	260	302
		Mean	350	342	345	350	367

TABLE 11 (Continued)

GROUP	AGE	SUBJECT	SET 1	2	3	4	5
Stutterer	Adult	19	394	352	356	386	448
Stutterer	Adult	20	359	298	320	266	274
Stutterer	Adult	21	322	299	255	238	269
Stutterer	Adult	22	326	304	308	306	312
Stutterer	Adult	23	265	286	326	275	272
Stutterer	Adult	24	325	330	311	294	337
Stutterer	Adult	25	307	307	288	294	284
Stutterer	Adult	26	237	224	258	265	260
Stutterer	Adult	27	277	277	275	253	276
		Mean	312	298	300	287	304
Nonstutterer	5 Years	28	483	439	515	559	585
Nonstutterer	5 Years	29	481	466	474	510	491
Nonstutterer	5 Years	30	472	440	421	405	436
Nonstutterer	5 Years	31	350	373	400	364	307
Nonstutterer	5 Years	32	474	536	535	523	521
Nonstutterer	5 Years	33	611	547	767	672	626
Nonstutterer	5 Years	34	510	495	450	458	446
Nonstutterer	5 Years	35	446	391	398	377	389
Nonstutterer	5 Years	36	486	496	460	516	506
		Mean	480	476	492	488	479

TABLE 11 (Continued)

GROUP	AGE	SUBJECT	SET				
			1	2	3	4	5
Nonstutterer	9 Years	37	285	290	277	278	259
Nonstutterer	9 Years	38	304	310	345	339	285
Nonstutterer	9 Years	39	322	336	306	292	332
Nonstutterer	9 Years	40	266	225	227	268	243
Nonstutterer	9 Years	41	304	316	310	313	336
Nonstutterer	9 Years	42	273	262	315	281	280
Nonstutterer	9 Years	43	314	285	285	291	324
Nonstutterer	9 Years	44	286	271	282	266	246
Nonstutterer	9 Years	45	301	296	301	306	279
		Mean	295	288	295	293	287
Nonstutterer	Adult	46	312	310	291	302	304
Nonstutterer	Adult	47	250	272	236	253	278
Nonstutterer	Adult	48	250	263	283	260	303
Nonstutterer	Adult	49	258	275	282	269	270
Nonstutterer	Adult	50	203	226	227	191	208
Nonstutterer	Adult	51	261	249	245	242	278
Nonstutterer	Adult	52	287	292	288	300	286
Nonstutterer	Adult	53	259	250	244	253	269
Nonstutterer	Adult	54	291	308	283	272	285
		Mean	264	272	265	261	276

TABLE 12

SUMMARY OF THE LOG OF THE VARIANCES OF REACTION TIMES IN MSEC. FOR ALL SUBJECTS AS A FUNCTION OF GROUP (STUTTERERS AND NONSTUTTERERS), AGE (5 YEARS, 9 YEARS, AND ADULTS), AND SET (ONE THROUGH FIVE).

			SET				
GROUP	AGE	SUBJECT	1	2	3	4	5
Stutterer	5 Years	1	3.6756	3.7786	3.7513	3.7911	4.0694
Stutterer	5 Years	2	3.2471	3.5667	3.5823	3.2428	3.8893
Stutterer	5 Years	3	3.9775	3.7754	3.8132	4.0517	3.8818
Stutterer	5 Years	4	4.4515	3.8897	4.5036	4.4028	4.2617
Stutterer	5 Years	5	4.0814	3.9771	3.8552	4.0901	4.0896
Stutterer	5 Years	6	3.8551	3.8289	3.6649	3.9334	3.7125
Stutterer	5 Years	7	4.0252	4.2053	3.7145	3.9118	3.9670
Stutterer	5 Years	8	3.0503	3.7140	4.2751	3.7784	4.3165
Stutterer	5 Years	9	3.9594	3.8127	4.0211	3.8842	3.9837
		Mean	3.9248	3.8386	3.9090	3.8985	4.0191
Stutterer	9 Years	10	3.5616	3.5773	3.5465	3.7374	3.9480
Stutterer	9 Years	11	3.6331	3.9126	4.1520	3.5919	3.8855
Stutterer	9 Years	12	3.9362	3.6668	3.6546	3.5186	3.8079
Stutterer	9 Years	13	3.1784	3.1021	3.3013	2.9187	3.2323
Stutterer	9 Years	14	3.4099	3.7605	3.3444	3.8316	3.4673
Stutterer	9 Years	15	3.9594	3.9729	3.8649	3.7926	4.0241
Stutterer	9 Years	16	3.8581	3.6618	3.5075	3.7823	3.3965
Stutterer	9 Years	17	3.9776	3.5718	3.9046	3.6957	3.4894
Stutterer	9 Years	18	3.86571	3.68174	4.0044	3.8439	3.86580
		Mean	3.7089	3.6564	3.6978	3.6347	3.6797

TABLE 12 (Continued)

GROUP	AGE	SUBJECT	SET 1	2	3	4	5
Stutterer	Adult	19	3.3449	3.0481	3.3948	3.1288	3.8693
Stutterer	Adult	20	3.8993	2.9766	3.0199	3.0862	3.2718
Stutterer	Adult	21	3.5026	3.3164	3.0594	2.9687	3.3533
Stutterer	Adult	22	3.6773	2.9546	2.5945	2.9197	2.4991
Stutterer	Adult	23	3.1960	3.7298	3.8512	2.9991	2.5531
Stutterer	Adult	24	3.1983	2.7205	3.3884	2.8363	3.4188
Stutterer	Adult	25	3.2050	2.4219	3.4223	2.8543	3.4087
Stutterer	Adult	26	3.0718	2.6018	3.3774	3.3331	2.6349
Stutterer	Adult	27	2.9177	3.2016	2.5547	3.0759	3.2526
		Mean	3.3348	2.9967	3.1847	3.0225	3.1402
Nonstutterer	5 Years	28	3.8301	2.9296	4.0994	3.8823	4.1991
Nonstutterer	5 Years	29	3.7501	3.9045	4.0967	4.2725	3.6205
Nonstutterer	5 Years	30	3.8824	3.7553	4.0539	3.7352	3.9665
Nonstutterer	5 Years	31	4.4128	4.1094	3.8613	4.1255	3.6186
Nonstutterer	5 Years	32	3.5045	3.4425	3.68021	3.6455	3.9214
Nonstutterer	5 Years	33	3.7173	3.2546	3.6407	3.8275	3.4783
Nonstutterer	5 Years	34	3.7787	3.7318	3.9103	3.8226	3.7551
Nonstutterer	5 Years	35	3.6259	3.7434	3.5427	3.4165	3.7548
Nonstutterer	5 Years	36	3.8025	4.0997	3.7599	3.5754	3.7398
		Mean	3.8116	3.6634	3.8493	3.8559	3.7838

TABLE 12 (Continued)

GROUP	AGE	SUBJECT	SET 1	SET 2	SET 3	SET 4	SET 5
Nonstutterer	9 Years	37	3.3578	3.1400	3.3125	3.0953	3.0085
Nonstutterer	9 Years	38	3.7656	3.4067	3.3236	3.4502	3.5045
Nonstutterer	9 Years	39	3.2804	3.4041	3.3541	3.3312	3.4078
Nonstutterer	9 Years	40	3.4908	3.1737	3.1884	3.6979	3.5188
Nonstutterer	9 Years	41	3.1634	3.3859	3.1540	3.5667	3.5125
Nonstutterer	9 Years	42	3.1904	3.1956	3.6372	3.4957	3.6695
Nonstutterer	9 Years	43	3.1793	2.9894	3.3277	3.0257	3.6648
Nonstutterer	9 Years	44	3.7849	3.1826	3.1928	3.3696	3.3879
Nonstutterer	9 Years	45	3.4192	3.4555	3.3571	3.7465	3.1835
		Mean	3.4035	3.2593	3.3163	3.4199	3.4286
Nonstutterer	Adult	46	2.8885	3.2096	2.6165	3.4828	3.1821
Nonstutterer	Adult	47	2.5668	3.0813	2.6550	3.1853	3.1736
Nonstutterer	Adult	48	3.0136	2.9494	2.9843	2.8859	2.9857
Nonstutterer	Adult	49	3.2012	3.0711	2.8861	3.0193	3.5716
Nonstutterer	Adult	50	3.0649	3.2651	3.2228	3.1788	3.5999
Nonstutterer	Adult	51	3.3135	2.7589	2.1924	2.2484	3.0909
Nonstutterer	Adult	52	2.6893	3.0093	2.3526	2.9455	2.8364
Nonstutterer	Adult	53	2.9746	2.9503	3.3203	2.7683	3.7548
Nonstutterer	Adult	54	2.6628	2.8609	2.7425	2.6892	2.85907
		Mean	2.9305	3.0173	2.7746	2.9337	3.2282

VITA

Douglas Edward Cross was born in Washington, D.C., on March 18, 1950. He received his elementary and secondary education in Bethesda, Maryland. In 1972 he graduated from The University of Alabama with a Bachelor of Science degree in Education with a major in English. In 1974 he graduated from the University of Alabama with a Master of Arts degree in Speech Pathology. He entered the Graduate School of the University of Tennessee in August, 1974, and received the Doctor of Philosophy degree with a major in Speech and Hearing Science in June, 1978.