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I am submitting herewith a thesis written by Cathy Cay Treer entitled "Voice Onset Time Differences Among Normal Speakers and Speakers with Parkinson's Disease." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Speech Pathology.

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VOICE ONSET TIME DIFFERENCES AMONG NORMAL SPEAKERS AND SPEAKERS WITH PARKINSON'S DISEASE

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Cathy Cay Treer

June 1983

1182851

This thesis is

dedicated to

The Author of Life

"Ascribe to the Lord the

glory due his name"

Psalms 96:8

ACKNOWLEDGEMENTS

Acknowledgements provide the author with the privilege of publicly thanking those who have contributed in an exceptional manner to the completion of this document. Sincere appreciation and gratitude is extended to Neurological Associates and to all the subjects who participated in this study. For a job, the use of a typewriter, and an unlimited supply of paper, the writer is extremely grateful to Mr. James Russell, Jr. Without the cooperation of these people this thesis could not have been completed.

The writer wishes to express her esteem and appreciation to Dr. Carl W. Asp and Dr. Harold L. Luper as they willingly contributed their wisdom and insight to produce a better document. For her thoroughness, perception, patience, wisdom, guidance, and emotional and spiritual encouragement, the writer wishes to attempt to express deep regard and admiration to Dr. Ellen I. Hamby, Committee Chairperson and friend.

The writer is thankful for all of her friends who unknowingly provided encouragement when it was most needed. Special thanks are extended to her "student advisors," Laura Demo, Jan Grissom, Janet Stotts, and Mary Earl Wilder, who edited, advised, encouraged, and listened patiently to her throughout this project.

The author is eternally grateful to her parents, Robert and Glema Treer, who provided constant financial and emotional support throughout this difficult time. Appreciation and love are

also extended to her brother Randy and sister Karen for their concern and encouragement.

Finally, the writer wishes to acknowledge her spiritual family, especially her brothers and sisters in Christ at the UTK Christian Student Fellowship for their love, prayers, and constant care throughout this endeavor. Indeed, it is with humor as well as deepest sincerity that the writer agrees with Hezekiah, who stated,

"Surely it was for my benefit
that I suffered such anguish."

Isaiah 38:17

ABSTRACT

The purpose of this investigation was to examine the differences in voice onset times (VOTs) for the consonants /b/,/p/,/g/, and /k/ among ten speakers with Parkinson's disease and dysarthria (PKN-D), ten speakers with Parkinson's disease and no observable dysarthria (PKN-NOD), and ten normal speakers (NOR). The subjects were asked to repeat the sentence "Say____again" after the examiner who varied the stimuli /bip/,/pip/,/gip/, and /kip/ until five repetitions of each stimulus were obtained. The responses were played into a Voice Identification Unit (Voice Identification, Inc., Series 700) and spectrograms were made. VOTs for the stimuli /b/,/p/,/g/, and /k/ were determined from the spectrograms.

Statistical analyses involved obtaining individual subjects' mean VOTs for all four consonants, group means and ranges for each of the four consonants, a total mean VOT for each group across all four consonants, and mean VOTs for each consonant across all three groups. A two factor mixed design analysis of variance with repeated measures on one factor (Bruning and Kintz, 1977) was used to determine whether statistically significant differences existed among the three groups of subjects and among the VOTs for the four different consonants. The results of the analysis of variance indicated that there were significant differences in VOTs among the

consonants /b/,/p/,/g/, and /k/. The Scheffé test for multiple comparisons (Bruning and Kintz, 1977) was utilized to determine between which groups of speakers significant differences existed across the four consonants. The results of the Scheffé revealed that there were significant differences in VOTs between the speakers with Parkinson's disease and dysarthria and the normal speakers for every consonant. In addition, the Scheffé revealed a significant difference in VOTs between the PKN-NOD speakers and the NOR speakers for /k/, and between the PKN-D and the PKN-NOD speakers for /p/.

The findings of this investigation suggest that dysarthric speakers with Parkinson's disease do have incoordination of their phonatory and articulatory movements. Secondly, the findings partially support the hypothesis that the deterioration of speech in individuals with Parkinson's disease begins with laryngeal changes and progresses forward in the vocal tract affecting the tongue and then the lips. Finally, the results of this investigation indicate that voice onset time might be used to detect an emerging dysarthria in speakers with Parkinson's disease and no observable dysarthria. However, much more research is needed to provide additional information about the onset and progression of dysarthria in individuals with Parkinson's disease.

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CHAPTER I

INTRODUCTION

Parkinson's disease is a slowly progressive disease of the extrapyramidal system. The basal ganglia and the substantia nigra are the specific areas involved (Mueller, 1971; Slotiuk 1976; Duvoisin, 1978). Parkinson's disease is characterized by tremor, rigidity, and slowness of movement (Canter, 1963; Mueller, 1971; Pallis, 1971; Duvoisin, 1978). When these characteristics affect the speech musculature, a hypokinetic dysarthria results (Darley, Aronson, and Brown, 1975). According to most investigators (Canter, 1963, 1965a, 1965b; Darley, Aronson, and Brown, 1969a, 1969b; Mueller, 1971; Kreul, 1972; Logemann, Fisher, Boshes, and Blonsky, 1978), laryngeal involvement is a significant aspect of hypokinetic dysarthria. Yet, the nature of this involvement needs to be more clearly delineated. Therefore, the purpose of this investigation was to obtain more information about the phonatory characteristics of speakers with Parkinson's disease through analysis of voice onset time.

Review of Literature

Many of the studies on the speech associated with Parkinson's disease have examined various aspects of the basic speech processes including phonation, respiration, articulation, resonance, and prosody. The literature reviewed below will include studies on

the speech characteristics and motor speech patterns associated with Parkinson's disease. It will also contain underlying theoretical bases for these speech characteristics and motor speech patterns.

Canter (1963) analyzed the speech characteristics of patients with Parkinson's disease in terms of intensity, pitch, and duration. The subjects for the investigation were 17 males with Parkinson's disease and 17 control subjects matched to the Parkinson's group according to age. A speech sample was obtained for each subject as he read the first paragraph of the "Rainbow Passage" (Fairbanks, 1960, p. 127) in a sound-treated room. The intensity measures were obtained as the recorded speech samples were played into a high-speed graphic level recorder. A sound pressure level for each intensity peak was determined. These sound pressure levels were averaged to obtain a mean peak sound pressure level which represented the intensity of a subject's speech. The range of sound pressure levels was determined as an index of the intensity variability. The author observed that the vocal intensity variabilities were comparable for the group with Parkinson's disease and the control group.

Measures of fundamental frequency were obtained as the recorded speech samples were fed into a direct-writing oscillograph. A median fundamental frequency represented the subject's average pitch level. Pitch variability was determined by analyzing the difference between the highest and lowest frequency the subject had produced. The investigator observed that the subjects with Parkinson's disease spoke at significantly higher pitch levels and used more restricted pitch ranges than the normal subjects.

Regarding duration, the total time required to read the "Rainbow Passage" was determined and the rate of speaking was expressed in words per minute. Other durational measures taken were mean pause length, mean phrase length, and mean syllable duration. No significant differences between the experimental and control groups in terms of rate of speaking, pause length, phrase length, or syllable duration were noted although individual instances of deviations were observed.

Continuing his comparison of the speech characteristics of subjects with Parkinson's disease with those of the control subjects, Canter (1965a) examined the ability of the two groups to produce different levels of vocal intensity, to phonate at very high and very low pitch levels, and to sustain phonation. During the "quiet" phonation, the subjects with Parkinson's disease could not produce syllables as low in intensity as the control subjects. During "loud" and "shouted" phonation, the subjects with Parkinson's disease produced syllables of significantly less intensity than the control subjects.

As an assessment of the ability of a subject to produce very high and very low pitches, the subjects were instructed to sing the syllable "no." Beginning at a comfortable pitch level, the subject sang down the scale until he got as low as he could. Then he sang up the scale as high as he could. This was repeated three times in each direction. Lowest and highest frequencies were obtained from the subject's performance on this task to determine maximum pitch range. There was no significant difference between the two groups

in the production of high pitches. There was a significant difference in the production of low pitches between the two groups. The subjects with Parkinson's disease could not produce pitches as low as those of the control subjects. There was also a significant difference in the total pitch range between the two groups. The subjects with Parkinson's disease had a markedly reduced pitch range.

The third task to measure maximum performance of the speech mechanism was having the subjects sustain the vowel /ɑ/ as long as possible on a single breath. This was repeated three times and the responses were played into a high speed graphic level recorder. The vowel duration was measured to the nearest tenth of a second. The subjects with Parkinson's disease differed significantly from the control group as they sustained the vowel /ɑ/ half as long as the control group.

A third investigation by Canter (1965b) examined the speech characteristics of subjects with Parkinson's disease in terms of articulation characteristics, motor control of the articulators, and over-all speech adequacy. The subjects were the same as those involved in the two previous studies. There were 17 males with Parkinson's disease and 17 age-matched control subjects. Motor control of the articulators was assessed by having the subjects perform several diadochokinetic tasks. For example, rapid repetition of the syllable /ba/ assessed maximum rate of lip movement. Tongue tip movement was observed through rapid repetition of the syllable /da/ and back of the tongue movement was evaluated by having the subjects repeat the syllable /ga/. Also, the ability to

alternate vocal fold adduction and abduction was assessed through rapid repetition of the syllable /hɑ/. The subjects were recorded while repeating each syllable for thirty seconds. Diadochokinetic rates were measured to the nearest half syllable. When possible, the number of syllables repeated during a five second interval of continuous phonation was counted and recorded as movements per second. In attempting to measure diadochokinetic rates in the subjects with Parkinson's disease, however, a phenomenon referred to as "complete freezing" sometimes occurred. This complete freezing referred to occasions when a subject produced a continuous sound throughout the thirty second period rather than a series of distinct syllables. Results revealed an impaired ability in the subjects with Parkinson's disease to produce rapid movements of the tongue-tip, back of the tongue, lips and vocal folds. Tongue-tip involvement was typically greater than lip involvement.

An analysis of articulation characteristics was achieved by having three judges rate the clarity of articulation of the subjects during a reading of the "Rainbow Passage," and by recording the passages and evaluating them on sound spectrograms. Results revealed imprecise production of plosive consonants and evidence of incoordination of phonatory and articulatory activity among the subjects with Parkinson's disease. The author reported a high correlation between motor control of the articulators and clarity of articulation ($r = .87$). The same three judges who rated the clarity of articulation also rated the over-all speech adequacy of the subjects in terms of pitch, loudness, duration, voice quality, and

articulation. Clarity of articulation was more highly correlated with over-all speech adequacy than measures such as vocal pitch and duration. Four measures of physiological support, maximum pitch range, maximum intensity range, maximum duration of sustained phonation, and articulatory diadochokinesis were compared to the subjects' rankings on over-all speech adequacy. Articulatory diadochokinesis had the strongest relationship with over-all speech adequacy ($r = .82$).

Based on his findings of reduced ability to produce variations in intensity, reduced ability to produce low pitches, restricted pitch range, and reduced ability to sustain phonation, Canter (1965a) concluded that these patients had reduced physiological support for speech. He suggested that many of the patients were already using much of their "reserve function" to produce simple connected speech. He also suggested that impaired diadochokinetic rates implied that the oral musculature was involved as a unit, although tongue involvement tended to be greater than lip involvement, and, furthermore, that articulation disorders were either the result of inadequate valving of the articulators during production of plosives or of the incoordination of the laryngeal and oral cavity (canter, 1965b).

More information concerning speech characteristics associated with Parkinson's disease was obtained in a study by Darley, Aronson, and Brown (1969a). The authors conducted an investigation on 212 patients with dysarthria due to seven neurologic disorders, one of which was Parkinson's disease. The investigators studied the motor

speech problems of each of the seven neurologic disorders and described the distinctive speech dimensions that characterized them. Speech samples were recorded for each patient as they read the "My Grandfather" (Van Riper, 1954) passage. Thirty-second samples were dubbed from these recordings to produce listening tapes. Each speech sample was rated by three judges on a series of thirty-eight dimensions, each of which has a descriptive name (e.g., pitch breaks, monoloudness, reduced stress, etc.). Each dimension was rated on a seven point equal appearing interval scale, with one representing normal speech and seven representing very severe deviation from normal. Results of the investigation permitted the authors to present speech deviations that were characteristics of each of the seven neurologic groups, and to present the incidence of the various dimensions across the seven groups.

The dimensions associated with the patients with Parkinson's disease in order or prominence included monopitch, reduced stress, monoloudness, imprecise consonants, inappropriate silences, short rushes, harsh voice, breathy voice, low pitch, and variable rate. Four of the dimensions associated with Parkinson's disease (monopitch, monoloudness, harsh voice, and imprecise consonants) appeared to some degree in all seven groups. Although reduced stress, inappropriate silences, and short rushes of speech occurred in other groups, these dimensions were most prominent in Parkinson's disease. Similarly, breathy voice and variable rate appeared more prominently in only one other neurological group, while only two other groups evidenced the low pitch dimension more severely than the Parkinson's group.

In a further study of the same 212 patients, Darley, Aronson, and Brown (1969b) examined the tendency for certain deviant speech dimensions to occur in clusters. These clusters were determined by arranging the deviant speech dimensions in each neurologic disorder in a correlation matrix to evaluate how the dimensions were related to each other. The correlation matrix for the speech of patients with Parkinson's disease revealed one cluster and four uncorrelated dimensions. The cluster, known as prosodic insufficiency, was named to represent insufficient vocal emphasis patterns with a reduction of stress on normally stressed syllables and words. This cluster was extended to include short rushes of speech, variable rate, and imprecise consonants. The uncorrelated dimensions were inappropriate silences, breathy voice, harsh voice, and low pitch. The authors suggested that this cluster of prosodic insufficiency was due to reduced range of movements of the muscles involved in speech. According to the authors, the extension of the cluster to include short rushes of speech, variable rate, and imprecise consonants appeared to result from very fast repetitive movements of very reduced range, which is seen only in patients with Parkinson's disease.

Another investigation comparing motor speech patterns of subjects with Parkinson's disease to those of normal control subjects was presented by Mueller (1971). This study was designed to obtain physiological measures of sustained vowel phonation and syllable repetitions produced by dysarthric speakers with Parkinson's disease. Subject selection included five males with Parkinson's disease, five

females with Parkinson's disease, and a control group of five males and five females matched as closely as possible in age, height, and weight to the experimental subjects. The tasks were a maximum sustained phonation of the vowel /a/, and repetition of the syllable /sʌ/ for three and for seven seconds. Measures included volume of air expended during syllable productions, oral airflow rates, intra-oral pressures, phonation times, and number of syllables produced. Results indicated that the mean phonation times of the sustained phonation of /a/ for the control subjects were significantly longer than those for the subjects with Parkinson's disease. The control subjects used significantly larger amounts of air during this task than did the subjects with Parkinson's disease. Oral airflow rates were comparable between the two groups. Measures obtained during repeated productions of the syllable /sʌ/ included the total utterance time, number of syllables produced, peak intraoral pressure, oral flow rate, total amount of air expended, and rate of utterance per second. The subjects with Parkinson's disease had significantly less phonation time, significantly fewer total number of syllables produced, and significantly less intraoral pressure during the syllable production task. Regarding rate of syllable production per second, there was no significant difference between the two subject groups.

Mueller's findings (1971) of reduced airflow rates and reduced intraoral pressure during the syllable production task suggested that the neuromuscular involvement in Parkinson's disease inhibited the individual from generating enough aerodynamic energy necessary for

normal articulation. It was suggested that this reduction in aerodynamic energy also might account for the decreased phonation time and reduced number of syllables produced. This suggestion is consistent with Canter's (1965a) report of reduced physiological support for speech.

Kreul (1972) investigated the speech performance of subjects with Parkinson's disease by obtaining measures of sustained phonation, diadochokinesis, and reading rates. These measures were recorded and contrasted among young normal adults, healthy elderly adults, and subjects with Parkinson's disease. The subjects consisted of 45 healthy young normal adults, 22 elderly adults, and 23 subjects with Parkinson's disease. The subjects sustained three vowels: /ɑ/, /o/, and /i/ as long as possible in a single breath. For young adults and the subjects with Parkinson's disease, the vowel /i/ could be sustained significantly longer than the vowel /ɑ/. No significant vowel duration differences were noted for the elderly subjects. The durations for the elderly subjects were much less than those for the subjects from the other two groups. A reduced ability to prolong a vowel was associated with both age and Parkinson's disease.

Five measures of diadochokinesis were recorded: three syllable rates /pʌ/, /tʌ/, and /kʌ/, the vowel /i/ interrupted, and a vowel transition from /u/ to /i/. Results revealed that the rates for the /pʌ/. /tʌ/, and /kʌ/ did not differ significantly among the groups. Measurements of the interrupted vowel /i/ indicated that the subjects with Parkinson's disease had significantly slower rates than

the young and elderly normal adults, but there was no significant difference between the young and elderly normal adults. The same was true in the case of the vowel transition from /u/ to /i/.

As for reading rate, three reading rates were recorded: one for a 300 word passage read at a normal rate, the same passage read at an accelerated rate, and a 61-word passage read at a rapid reading rate. The young subjects demonstrated much faster reading rates than older subjects. All three groups were able to increase their reading rates by about 30%. Both the elderly group and the subjects with Parkinson's disease exhibited slowed reading rates. Kreul indicated that reading rate was least likely to differentiate between elderly normal and elderly Parkinson subjects.

Netsell, Daniel, and Celesia (1975) conducted an investigation to learn more about the neuromuscular basis for dysarthria in subjects with Parkinson's disease. The authors recorded perceptual, acoustic, and kinesiologic data from the subjects in a variety of speaking activities. Twenty-two subjects who had Parkinson's disease performed the speech tasks in a sitting position. Surface electromyographic (EMG) electrodes were bilaterally positioned over the orbicularis oris superior. Air pressure in the nose, in the oral cavity, and audio signals of the speech productions were recorded in addition to the EMG signals. The subjects were asked to produce sentences requiring rapid opening and closing of the lips, and they were asked to produce the syllable /pɑ/ at two, four, and six per second rates.

Half of the subjects demonstrated short rushes of speech in attempting to perform the tasks. Syllable repetition rates exceeded 13 per second. The authors indicated that the 13 per second rate was above the upper limit for voluntary control of repetition rates (fewer than ten per second), suggesting a lack of immediate voluntary control resulting in an acceleration phenomenon. Some control of this acceleration behavior was gained by increasing the loudness level to about twice the loudness of the subject's normal production. Weakness in the neuromuscular control signal was suspected as the subjects with Parkinson's disease had muscle action potential bursts that were shorter in duration and lower in amplitude than those of the control subjects.

The excessive rate of syllable repetition was interpreted as evidence that the subject was in some neuromuscular setting over which he had no voluntary control. The authors suggested that acceleration and tremor may have a common neurogenic basis, but the nature of that basis could not be determined from their data. The weakness appeared to be of neurogenic origin rather than resulting from muscle contractile weakness, muscle fatigue, or difficulties at the myoneural junction. The investigators suggested that weakness in the control signals, rigidity, or the acceleration phenomenon could be the neuromuscular basis for reduced range of movement in patients with Parkinson's disease.

More information on speech and voice symptoms in subjects with Parkinson's disease was provided by Logemann, Fisher, Boshes, and Blonsky (1978). These investigators reported the frequency of

patterns of co-occurrence of various vocal tract dysfunctions among 200 patients with Parkinson's disease. Two trained listeners judged two speech samples for each subject, listening for specific rate, voice, resonance, and articulation disorders. The listeners were informed to note the presence of a particular dysfunction, but not the severity. Disorders included breathiness, roughness, hoarseness, tremulousness, reduced pitch range, inappropriate speaking pitch, repetition of syllables, abnormally prolonged syllables, too-short syllables, too-long pauses, hypernasality, and an articulation disorder. Results indicated that voice disorders were the most frequent abnormalities. Next in frequency were articulation disorders, which were followed by disorders of speech rate. Regarding articulation, every subject with an articulatory disorder misarticulated at least /k/ and /g/. The alveolar fricatives /s/ and /z/ followed the /k/ and /g/ in error frequency. Every subject (except one) who exhibited any articulation problems also demonstrated laryngeal disorders.

Logemann, et al. (1978) suggested that the patterns of coexistence of various vocal-tract dysfunctions may indicate subgroups of patients with Parkinson's disease. Each subgroup would represent a specific pattern of neurologic lesion that would cause that particular cluster of vocal-tract problems. Logemann, et al. (1978) also presented another interpretation of their data as being that the cluster of symptoms represented a progression in dysfunction. The first signs of dysfunction would begin with laryngeal changes and

progress to include other areas of neuromuscular control of the vocal tract, such as the lips and tongue.

Summary

The studies cited have reported varying results concerning the speech of subjects with Parkinson's disease. Concerning the most frequent impairments associated with the speech of Parkinson's patients, Logemann, et al. (1978) indicated that voice disorders were most frequent followed by articulation disorders. Logemann, et al. (1978) further divided the patients in the study into groups on the basis of co-occurrence of vocal tract symptoms from laryngeal dysfunction alone to laryngeal dysfunction and misarticulations of the back tongue, tongue blade, lips and tongue-tip. Canter (1965b) noted that tongue-tip involvement was typically greater than lip involvement.

Regarding sustained phonation, Canter (1965a), Mueller (1971), and Kreul (1972) reported a reduced ability to sustain a vowel when compared with normal subjects. However, Kreul (1972) also associated this reduced ability with age. The younger adults were able to sustain a vowel significantly longer than either the elderly subjects or the subjects with Parkinson's disease.

In terms of pitch, Canter (1965a) reported a restricted pitch range and a typically higher pitch level in the Parkinson's group (1963). However, Darley, et al. (1975) observed a deviation toward a lower than average pitch level.

Another frequently discussed aspect concerning the speech of individuals with Parkinson's disease is rate of speech. Some

investigators have reported an increased rate of speech while others have reported a reduced speaking rate. Canter (1965b) reported an impaired ability to produce rapid repetitive movements although no significant differences were noted in terms of rate of speaking (Canter, 1963). Mueller (1971) reported a reduced number of syllables produced for the Parkinson's group during a repetition task of the syllable /s·/ for three and for seven seconds. Kreul (1972) reported a slowed reading rate in the subjects with Parkinson's disease.

However, Netsell, et al. (1975) noted an accelerated syllable repetition rate among the subjects with Parkinson's disease. Darley, et al. (1975) observed a variable rate in the individuals with Parkinson's disease, and stated that it was part of a cluster of speech characteristics known as prosodic insufficiency. According to Darley, et al. (1975), the basis for the dysarthria in individuals with Parkinson's disease is rapid repetitive movements of reduced range.

Statement of Purpose

Despite the discrepancies noted in the previous section, one striking similarity among the studies is the presence of phonatory involvement in all groups of speakers with Parkinson's disease and dysarthria. With regard to the underlying basis of this involvement, Darley, Aronson, and Brown (1975) attribute the phonatory deviations to rigidity of the laryngeal musculature and to an incoordination between laryngeal and articulatory movements.

They state ". . . just as parkinsonian patients often experience difficulty in initiating walking . . . so in speech they may be unable to initiate phonation or to coordinate its initiation with the initiation of articulatory movements" (p. 187). Canter (1965b) also suggests that there may be an incoordination of the laryngeal and oral cavities in speakers with Parkinson's disease. Concerning the prominence of this phonatory involvement, Logemann, et al. (1978) hypothesize that laryngeal changes might be the first symptoms to appear in parkinsonian dysarthria.

If, as Darley, et al. (1975) and Canter (1965b) assert, these patients are unable to initiate phonation or to coordinate its initiation with the onset of articulatory movements, comparisons of voice onset times (VOTs) for normal and dysarthric speakers should reveal this incoordination. Moreover, if phonatory symptoms are indeed among the first to emerge, it is possible that VOT measures on patients with Parkinson's disease and no perceptible dysarthria might be utilized diagnostically to reveal the presence of an emerging dysarthria.

Therefore, the purpose of the present investigation was to compare the voice onset times among the three groups of speakers: normal speakers, speakers with Parkinson's disease and no observable dysarthria, and speakers with Parkinson's disease and dysarthria. Specifically, answers to the following questions were sought:

1. Are there significant differences in voice onset times among the three groups?

2. Are there significant differences in voice onset times for the consonants /b/,/k/,/p/, and /g/?
3. Are there significant differences in the interaction of voice onset times for the four consonants among the three groups of speakers?

CHAPTER II

PROCEDURES

Subjects

Thirty subjects, ten neurologically normal speakers (NOR), ten speakers with Parkinson's disease and no observable dysarthria (PKN-NOD), and ten speakers with Parkinson's disease and dysarthria (PKN-D) were selected for this investigation. All subjects were native speakers of English, had no structural speech mechanism anomalies, and demonstrated hearing sensitivity not exceeding 30 decibels in the better ear (ANSI, 1969) at 500, 1000, and 2000 Hertz as determined by puretone hearing thresholds. Also, the speakers had no previous medical history of a speech, language, or neurological disorder as determined by reading the medical charts, consulting with the neurologist, or interviewing the subject and his/her spouse.

The twenty patients with Parkinson's disease were diagnosed by a neurologist as having Parkinson's disease and no other neurological disorder. The ten subjects with Parkinson's disease and dysarthria were defined as those who received a score from 1-7 on the rating scale on any of the items on the Evaluation of Connected Speech Adequacy (Darley, Aronson, and Brown, 1975), and who presented no evidence of neuromuscular dysfunction on the oral mechanism examination. The ten subjects with Parkinson's disease and no observable dysarthria were defined as those who did not receive

any score on the rating scale on any of the items and who did not evidence neuromuscular problems on the oral mechanism examination.

The NOR subjects consisted of eight males and two females with a mean age of 61.9 years. The PKN-D subjects consisted of eight males and two females with a mean age of 62.6 years. The PKN-NOD subjects consisted of five males and five females with a mean age of 62.5 years. Descriptive data for the individual subjects are presented in Appendix A.

Stimuli

The stimuli for the speech task consisted of four CVC sequences: /bip/,/pip/,/gip/, and /kip/. Stop consonants were selected since their manner of production provides visible phone boundaries, and, thus, minimizes acoustic segmentation errors. Stop consonants are clearly distinguished from other speech sounds by a "silent gap" or absence of spectral energy as the stop consonant is released (Dew and Jensen, 1977). The consonants /b/,/p/,/g/,/k/ were chosen because they allow measurements from extreme points of articulation, labial and velar, and because they represent both voiced and voiceless consonants. The vowel /i/ was selected for study because it is considered to be longer in duration, and, thus, easier to observe on a spectrogram. Another reason /i/ was selected was because consonants preceding /i/ have longer voice onset times than when they precede other vowels (Klatt, 1975; Dew and Jensen, 1977). The final consonant /p/ was selected to allow three of the four stimuli to be more meaningful utterances ("beep," "keep," "peep") and the fourth

stimuli to be more word-like ("geep"). Each stimulus was embedded in the carrier phrase, "Say____again."

Equipment

A cassette tape recorder (Panasonic, RQ323AS) was used to obtain recordings of each stimulus presentation and each subjects' productions of the experimental sequence. Spectrograms were made of the recorded CVC stimuli using the Voice Identification Unit (Voice Identification, Inc., Series 700).

Experimental Procedures

Each subject was seated in a quiet room facing the examiner. A mouth-to-microphone distance of approximately six inches was maintained for each subject. A training session of three practice items was completed to familiarize the subject with the task. The three practice items were the words "fun," "red," and "night," embedded in the carrier phrase, "Say____again." The subjects were required to repeat the practice items after the examiner until they demonstrated mastery of the task. Their mastery of the task was demonstrated by repeating the entire phrase, "Say____again." After the subjects performed the practice items adequately, the examiner presented the first stimulus item (/bip/) embedded in the sentence, "Say____again." The subject imitated the examiner, and the examiner presented the next stimulus item (/kip/) embedded in the sentence, "Say____again," and the subject repeated the sentence. This method of presentation was repeated for the third (/pip/) and fourth (/gip/)

stimulus items. The above process was continued until each stimulus item had been produced five times for a total of twenty responses per subject. All of the subjects' responses were tape recorded on a Panasonic (RQ323AS) cassette recorder.

Acoustic Analysis

The recorded responses were dubbed from the tape recorder (Panasonic, RQ323AS) into the Voice Identification Unit to obtain wideband (300 Hz broadband pass filter) spectrograms of the CVC stimuli. The middle three productions of each of the five productions of the four stimulus items were selected for analysis. Occasionally, one or two of the middle three productions were judged by the examiner as unacceptable for measurement due to poor fidelity of the recording or difficulty in dubbing the response. If only one of the middle three productions was unacceptable, then the first production was used for analysis. Both the final production and the first production were substituted for acoustic analysis when two of the middle three productions were judged as unacceptable. A total of twelve CVC spectrograms were analyzed for each subject.

Voice onset times (VOTs) were obtained for each of the twelve spectrograms analyzed for each subject. To assist in obtaining these measures, vertical segmentation lines were drawn at the release of the stop consonant and at the onset of the vocalic element. VOT was defined as the time, expressed in milliseconds, between the release of the plosive consonant, as indicated by the onset of frication noise, and the beginning of vertical striations in the

second and higher formants (Klatt, 1975). Figure 1 illustrates the sites of measurement. Line A denotes the release of the consonant and Line B denotes the onset of voicing. The distance between these two points was measured and converted to millisecond values using the following formula:

$$12.5 \text{ mm} = 100 \text{ ms}, \frac{(\text{value in mm}) \times (100 \text{ ms})}{(12.5 \text{ mm})}$$

After the spectrograms were made and the VOTs determined by the above procedure, the VOTs for each subject's three repetitions per consonant then were averaged. Thus, a mean VOT for each of the four consonants was obtained for each subject. These mean VOTs for each subject's productions of each of the four consonants are presented in Appendix B. All statistical analyses are based upon these mean VOTs.

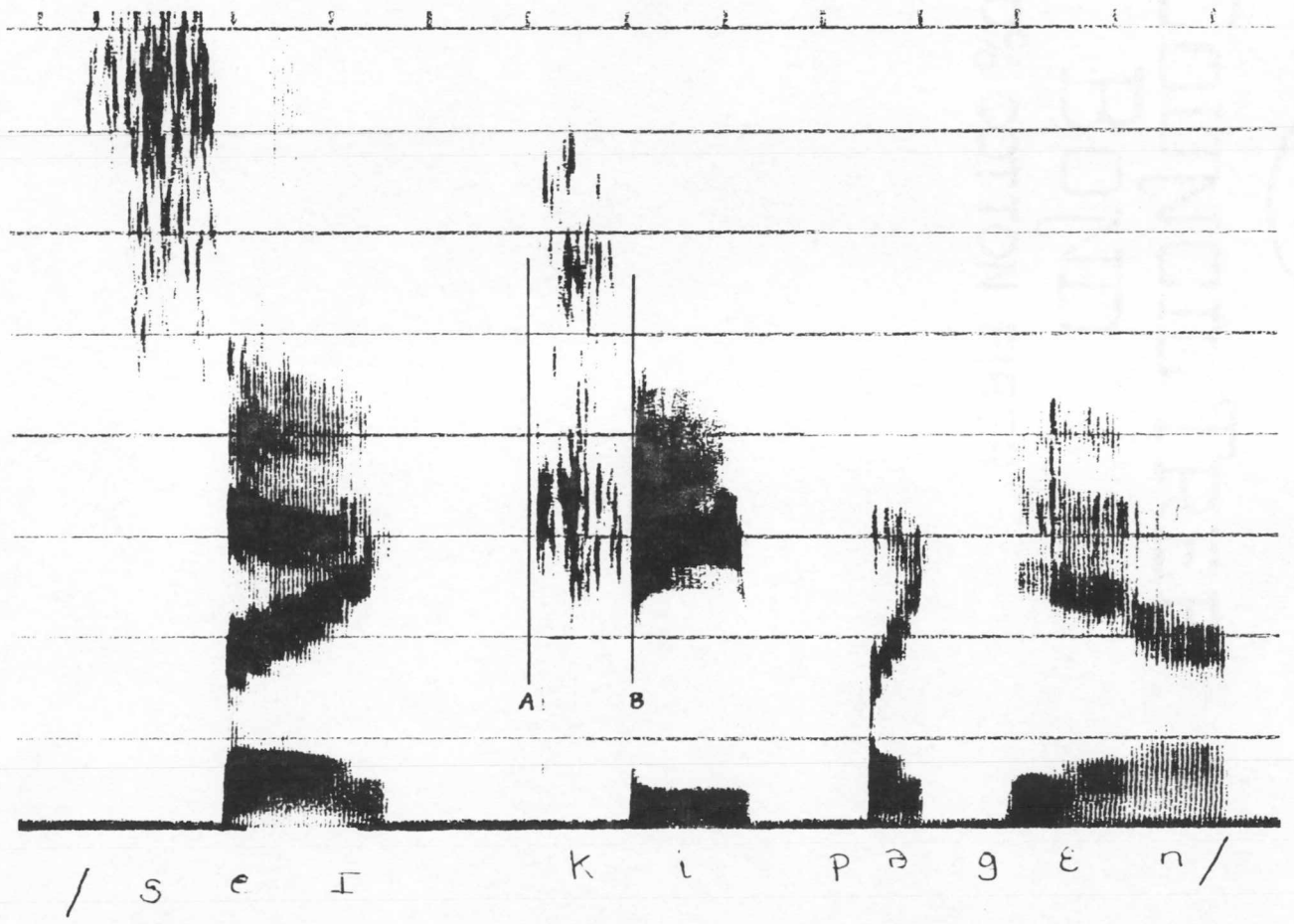


Figure 1. Spectrogram indicating sites of measurement for VOT in the utterance "Say peep again."

CHAPTER III

RESULTS

Reliability

Intra-Examiner Reliability

Intra-examiner reliability was established by remeasuring the VOTs for fifteen randomly selected responses, five from each group. A standard error then was computed for the two sets of measurements using the following formula:

$$S.E. = \sqrt{\frac{\Sigma (X_1 - X_2)^2}{2N}}$$

where X_1 = initial voice onset time measurements

X_2 = repeated voice onset time measurements

N = number of measurements

The standard error of measurement for voice onset time was 1.27 milliseconds (ms). This value is within ranges reported by Klatt (1975) and Gay (1978) for VOT measurements.

Intra-Subject Reliability

Intra-subject reliability was established by readministering the entire experimental testing procedure within three weeks after the first assessment to three randomly selected subjects, one from each group. A standard error was computed for the two sets of measurements for each of the three subjects using the following

formula:

$$S.E. = \sqrt{\frac{\Sigma(X_1-X_2)^2}{2N}}$$

where X_1 = initial voice onset time measurements

X_2 = repeated voice onset time measurements

N = number of measurements

The standard errors of measurement were 17.57, 1.49, and 6.1 ms, respectively, for the PKN-D, PKN-NOD, and NOR subjects. A review of the literature revealed that none of the VOT studies reported values for intra-subject reliability. The fact that the PKN-D subject had the largest standard error of measurement is consistent with Colson's (1979) finding that the speech-disordered group in her study had the largest intra-subject error of measurement. However, it also should be noted that the dysarthric subject had the longest interim period between testing and retesting.

Statistical Analysis

Mean VOTs for each consonant for each group were determined by averaging the individual mean VOTs for the subjects within each group. A range of VOTs for each group also was ascertained for each consonant. These data are summarized in Table I. Thus, Table I presents the mean VOTs and ranges of responses within groups for each consonant, the total mean VOT for each group across all four consonants, and the total mean VOT for each consonant, expressed in milliseconds for the PKN-D, PKN-NOD, and NOR groups.

TABLE I. Summary of mean VOTs and range of responses among groups for each consonant, total means for each group, and total means for each consonant, expressed in milliseconds (ms) for the PKN-D, PKN-NOD, and NOR groups.

	Consonant				
	/b/	/p/	/g/	/k/	Total Mean
PKN-D					
Mean	27.3	66.7	46.5	90.8	57.8
Range	14.7-49.3	28.0-121.3	26.7-72.0	58.7-142.7	
PKN-NOD					
Mean	16.4	49.5	32.8	84.5	45.8
Range	9.3-24.0	30.7-94.7	17.3-42.7	42.7-125.3	
NOR					
Mean	10.3	40.0	23.3	67.7	35.3
Range	6.7-14.7	26.7-70.7	10.7-38.7	52.0-102.7	
Total Mean	18.00	52.05	34.23	81.02	

As can be seen in Table I, the PKN-D subjects had a total (i.e., across all consonants) mean VOT of 57.8 ms, the longest mean VOT of all three groups. The total mean VOT for the PKN-NOD subjects was 45.8 ms, while the NOR subjects had a total mean VOT of 35.3 ms. Thus, the NOR subjects had the shortest mean VOT value and the mean VOT value for the PKN-NOD subjects was between that of the NOR and the PKN-D subjects.

Regarding individual consonants, it may be seen in Table I that the voiceless consonants /k/ and /p/ had the longest mean VOTs with values of 81.02 and 52.05 ms, respectively. The VOTs for the voiced consonants were shorter in duration, with /g/ having a mean VOT of 34.23 ms and the consonant /b/ having a mean of 18.00 ms.

A two factor mixed design analysis of variance with repeated measures on one factor (Bruning and Kintz, 1977) was used to determine whether statistically significant differences existed among the three groups of subjects and among the VOTs for the four different consonants. The results of this analysis of variance are summarized in Table II. These results indicate that:

1. There were significant differences in VOTs among the PKN-D subjects, the PKN-NOD subjects, and the NOR subjects ($F = 7.76$, $df = 2$, $p < .005$).
2. There were significant differences in VOTs among the consonants /b/,/p/,/g/, and /k/ ($F = 144.35$, $df = 3$, $p < .001$).
3. The interaction effects were not significant.

TABLE II. Summary of two-factor mixed design analysis of variance with repeated measures on one factor to compare the performance among dysarthric subjects with Parkinson's disease, non-dysarthric subjects with Parkinson's disease, and normal subjects.

Source	SS	df	ms	F*	p
Total	109351.7	119	--	--	--
Between Subjects	27770.37	29	--	--	--
Groups	10136.83	2	5068.42	7.76	.005
Error	17633.54	27	653.09	--	--
Within Subjects	81581.33	90	--	--	--
Consonants	65552.25	3	21850.75	114.52	.001
Interaction	573.40	6	95.57	.501	NS
Error	15455.68	81	190.81	--	--

* F ratios: ms groups/ ms error between; ms consonants/ ms error within; ms interaction/ ms error within.

Differences Among Groups

As previously shown in Table II, a significant difference among the three groups of speakers ($F = 7.76$, $df = 2$, $p < .005$) was found by means of a two factor mixed design analysis of variance with repeated measures on one factor. The Scheffé test for multiple comparisons (Bruning and Kintz, 1977) was utilized to determine between which groups of speakers significant differences existed across all four consonants. The results of the Scheffé are displayed in Table III. As indicated in Table III, the difference of 22.5 ms between the PKN-D speakers and the NOR speakers was statistically significant ($p < .005$). The difference of 10.5 ms between the PKN-NOD and the NOR speakers was not statistically significant, nor was there a significant difference in mean VOTs between the PKN-NOD speakers and the PKN-D speakers (12.0 ms). Additional analyses were necessary to determine whether statistically significant differences existed between groups for each individual consonant. More information concerning these differences for individual consonants will be presented in subsequent sections.

Differences Among Groups For Each Consonant

Differences Among Groups for the Consonant /b/

As indicated in Table I, the mean VOT for the consonant /b/ was 27.3 ms for the PKN-D subjects, 16.4 ms for the PKN-NOD subjects, and 10.3 ms for the NOR subjects. Not only did the PKN-D subjects have the longest VOT for /b/, but they also exhibited the greatest

TABLE III. Differences in mean VOTs, expressed in milliseconds, among dysarthrics with Parkinson's disease (PKN-D), nondysarthrics with Parkinson's disease (PKN-NOD), and normal subjects (NOR), across all four consonants.

	PKN-D	PKN-NOD	NOR
PKN-D		12.0	22.5*
PKN-NOD			10.5

* Significant (critical difference = 22.2 ms, $p < .005$) difference.

variability of responses as indicated by their range of VOTs. The range of responses for each group is graphically displayed in Figure 2. As can be seen in Figure 2, the PKN-D subjects' responses ranged from 14.7 - 49.3 ms. The NOR subjects demonstrated the least variability of VOT values as their responses ranged from 6.7 - 14.7 ms. The degree of variability for the PKN-NOD subjects, like the mean VOT for these subjects, was greater than that for the NOR subjects and less than that for the PKN-D subjects. The VOTs for the PKN-NOD subjects ranged from 9.3 - 24.0 ms.

Additional information about the three groups becomes apparent upon further examination of Figure 2. This figure shows that there is little overlap between the PKN-D and the NOR groups. A VOT value of 14.7 ms was the shortest duration achieved by any of the PKN-D speakers and the longest duration produced by any of the NOR speakers. Despite the fact that the PKN-D and NOR groups were separable on the basis of ranges of scores, however, the VOTs for the PKN-NOD subjects were completely overlapped by those of the other two groups. Values from 14.7 to 24.0 ms were common to both the PKN-D and the PKN-NOD speakers, while values from 9.3 - 14.7 ms were common to both the NOR and the PKN-NOD subjects. This information suggests that while VOT values for /b/ may distinguish the NOR group from the PKN-D group, those values do not separate the PKN-NOD group from either of the remaining two groups of speakers.

To determine whether these VOT differences among the groups for the consonant /b/ were statistically significant, the Scheffé test for multiple comparisons again was utilized (Bruning and Kintz, 1977).

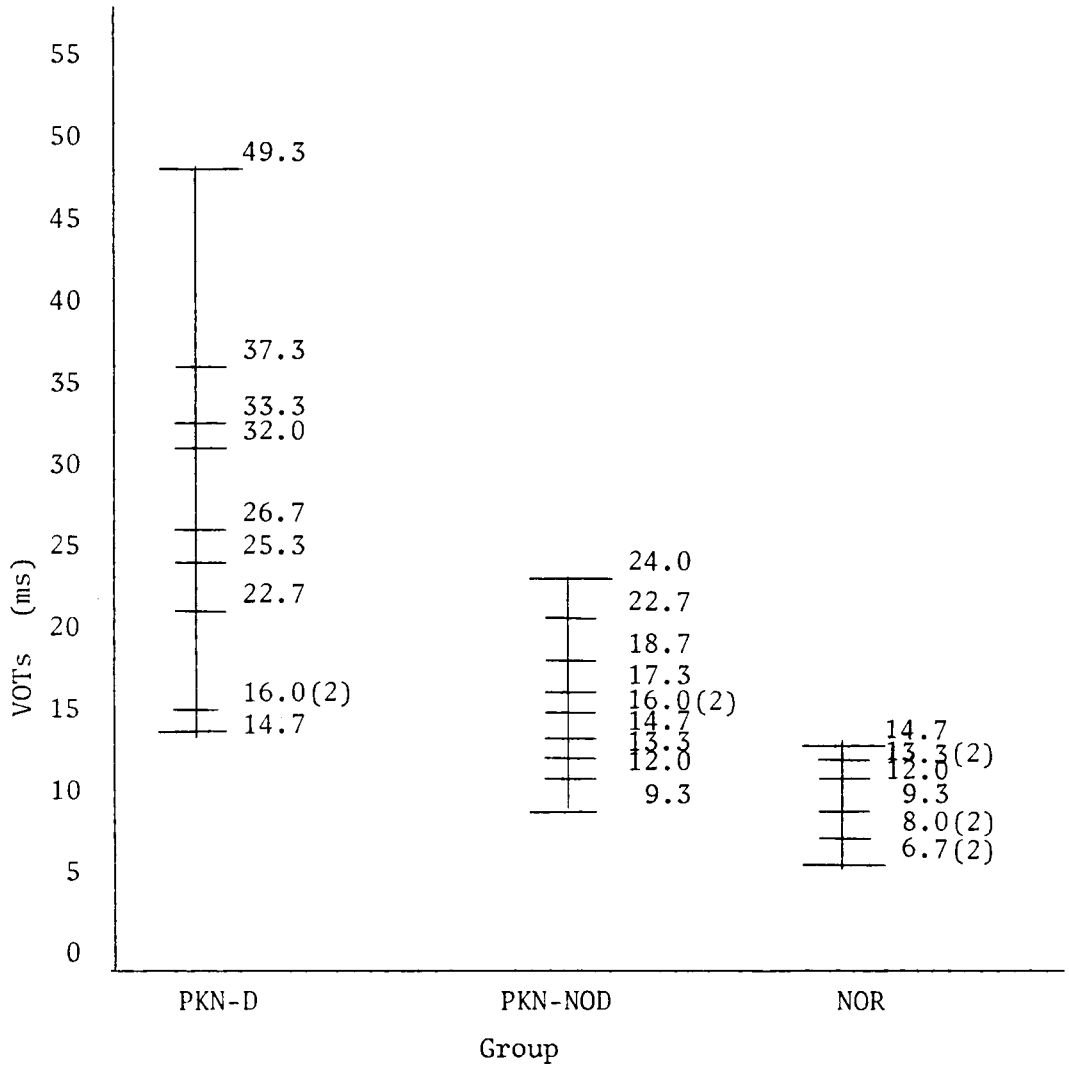


Figure 2. Range of VOTs for /b/ for PKN-D, PKN-NOD, and NOR subjects.

The results of the Scheffé are presented in Table IV. As can be seen in Table IV, the difference of 17.0 ms between the PKN-D and the NOR subjects indeed was significant (critical difference = 16.0 ms, $p<.05$). The difference of 10.9 ms between the PKN-NOD subjects and the PKN-D subjects was not significant. The difference in VOTs for /b/ between the PKN-NOD subjects and the NOR subjects also was not significant (6.1 ms). Thus, the results confirmed the findings discussed above for mean VOTs, range of responses, and degree of overlap among the groups, and suggest that the VOT values for /b/ do differentiate the PKN-D group from the NOR group.

Differences Among Groups for the Consonant /p/

Table I indicated that the mean VOT for /p/ was 66.7 ms for the PKN-D subjects, 49.5 ms for the PKN-NOD subjects, and 40.0 ms for the NOR subjects. The ranges of VOT responses within each group and individual VOTs for /p/ are presented graphically in Figure 3. In addition to having the longest mean VOT for /p/, the PKN-D subjects also evidenced considerable variability in their responses, with scores ranging from 28.0 - 121.3 ms. The PKN-NOD subjects did not have as large a range as that of the PKN-D subjects. The VOTs for the PKN-NOD subjects ranged from 30.7 - 94.7 ms. The NOR subjects had the smallest range of VOTs with values from 26.7 - 70.7 ms.

Closer inspection of Figure 3 revealed extensive overlapping of VOT values among the groups. VOT values from 30.7 - 68.0 ms were common to all three groups of speakers. Twenty-one (21) of the 30 speakers (six PKN-D, nine PKN-NOD, and six NOR speakers) produced

TABLE IV. Differences in mean VOTs, expressed in milliseconds, among PKN-D subjects, PKN-NOD subjects, and NOR subjects for the consonant /b/.

	PKN-D	PKN-NOD	NOR
PKN-D		10.9	17.0*
PKN-NOD			6.1

* Significant (critical difference = 16.0 ms, $p<.05$) difference.

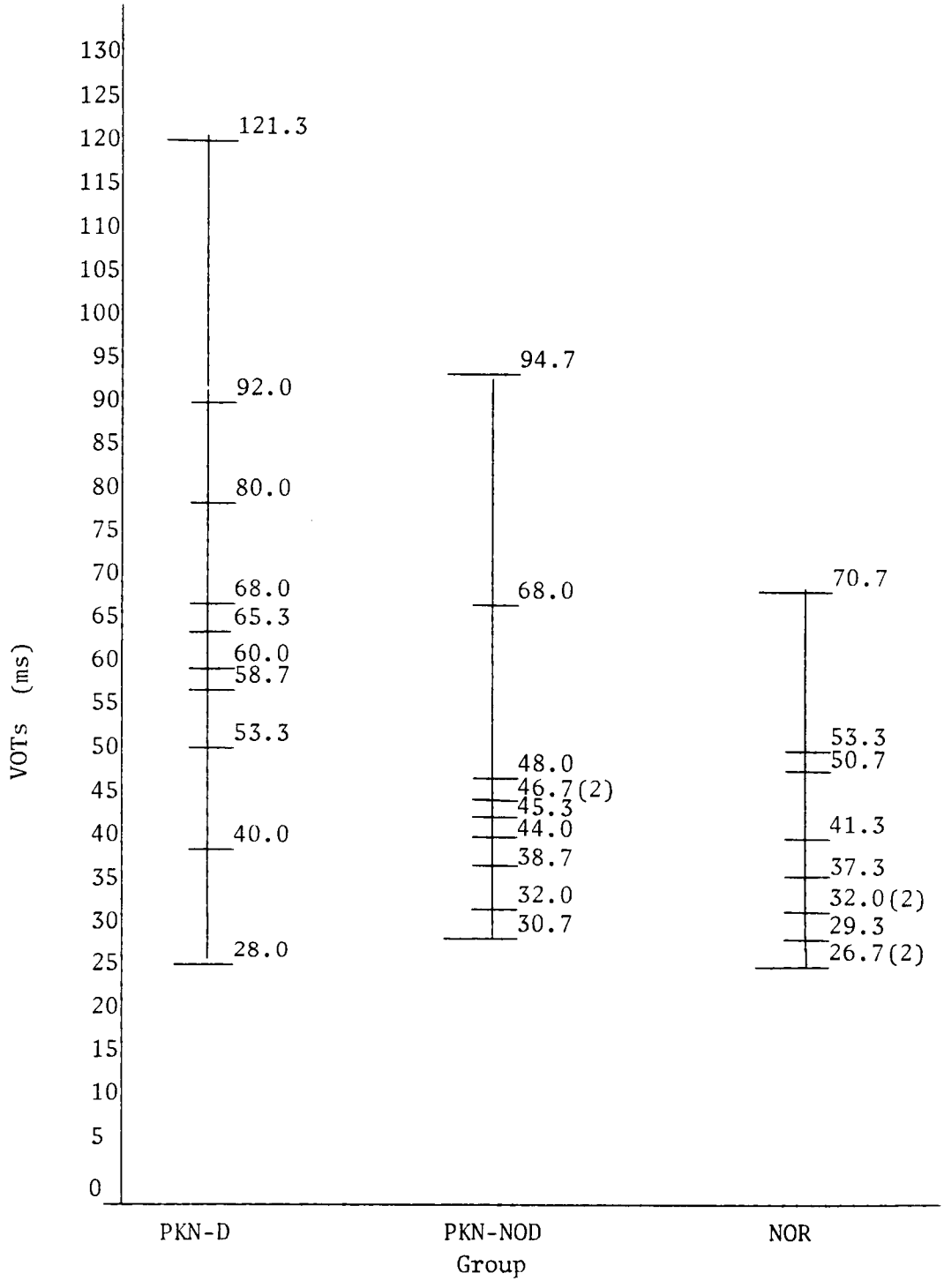


Figure 3. Range of VOTs for /p/ for PKN-D, PKN-NOD, and NOR subjects.

VOT values within this range. Of the remaining speakers, five (three PKN-D, one PKN-NOD, and one NOR) had VOT values greater than 68.0 ms, and four (one PKN-D and three NOR) speakers had values less than 30.7 ms. Thus, while the groups appeared to differ from one another in their mean scores and in the extent of their ranges, an examination of the degree of overlapping of scores among groups suggests that the groups may not be distinctly separable.

To determine whether the differences in VOTs for /p/ were significant among the groups, the Scheffé analysis was performed (Bruning and Kintz, 1977). Results of the Scheffe are presented in Table V. A significant (critical difference = 26.2 ms, $p<.001$) difference existed between the PKN-D and the NOR subjects (26.7 ms). There was also a significant (critical difference = 16.0 ms, $p<.05$) difference of 17.5 ms between the PKN-D and the PKN-NOD subjects. The difference in VOTs between the PKN-NOD subjects and the NOR subjects was not significant (9.5 ms). Thus, despite the overlap discussed above, it appears that the mean VOT values for /p/ did spearate the three groups.

Differences Among Groups for the Consonant /g/

According to Table I, the mean VOT for /g/ for the PKN-D subjects (46.5 ms) was the longest VOT of all three groups. The PKN-NOD subjects, with a mean VOT of 32.8 ms, had a mean VOT shorter than that of the PKN-D subjects yet longer than that of the NOR subjects. The mean VOT for the NOR subjects was 23.3 ms. Figure 4 graphically displays the individual VOTs and the ranges of

TABLE V. Differences in mean VOTs, expressed in milliseconds, among PKN-D subjects, PKN-NOD subjects, and NOR subjects for the consonant /p/.

	PKN-D	PKN-NOD	NOR
PKN-D		17.5*	26.7**
PKN-NOD			9.5

* Significant (critical difference = 16.0 ms, $p<.05$) difference.
** Significant (critical difference = 26.2 ms, $p<.001$) difference.

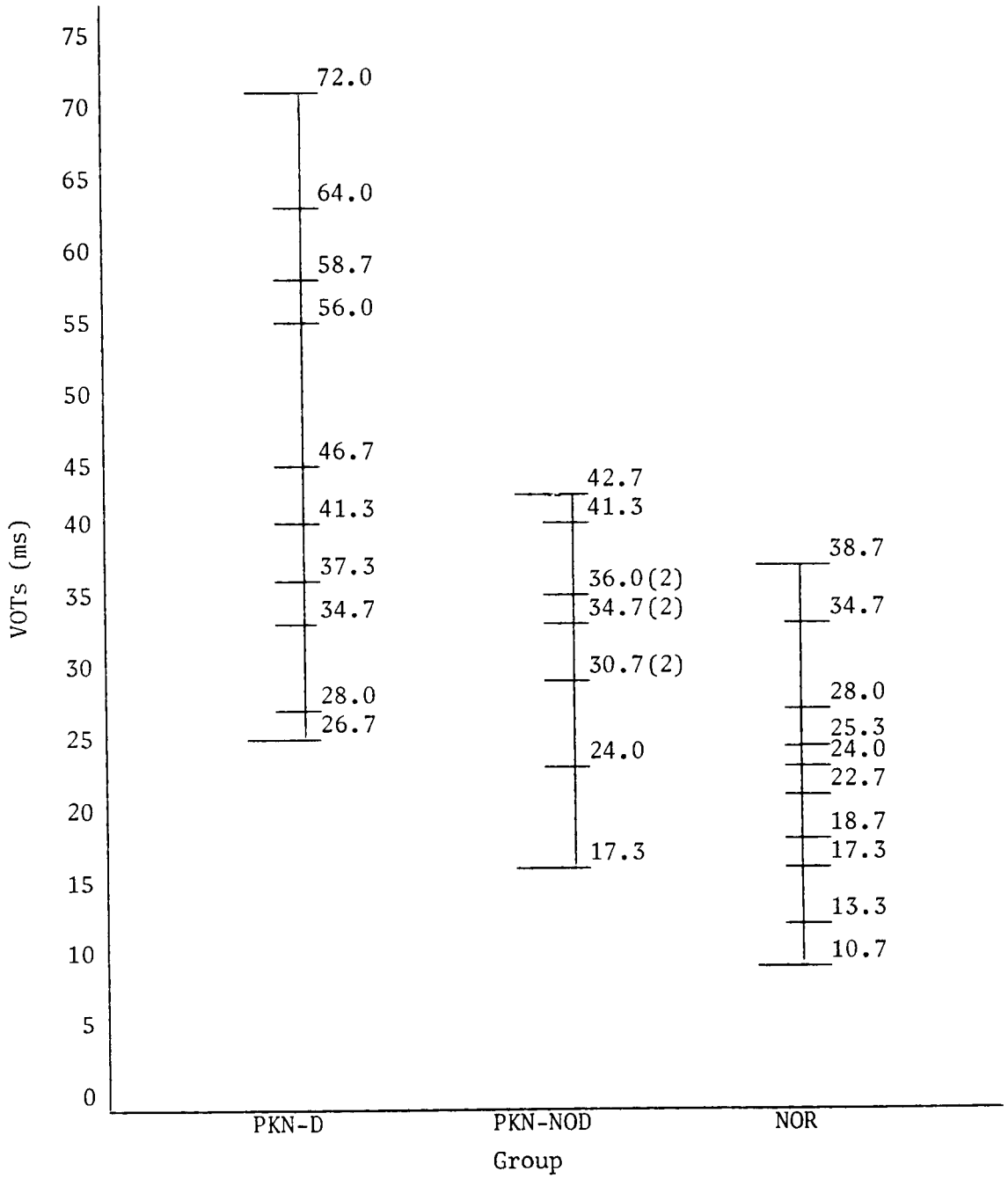


Figure 4. Range of VOTs for /g/ for PKN-D, PKN-NOD, and NOR subjects.

responses for each group. In addition to having the longest mean VOT, the PKN-D subjects also exhibited the most variability as judged from their range. As can be seen in Figure 4, the VOT values for the PKN-D subjects ranged from 26.7 - 72.0 ms, the largest range of the three groups for /g/. The PKN-NOD subjects exhibited the smallest range of responses as their values ranged from 17.3 - 42.7 ms. For the consonant /g/, the NOR subjects had a range of VOTs that was slightly greater than that of the PKN-NOD subjects as the NOR group had values ranging from 10.7 - 38.7 ms. Thus, /g/ was the only consonant in which the NOR group had a greater range of responses than the PKN-NOD group.

Further investigation of the range of VOT values for each group in Figure 4 indicated some degree of overlap across the groups. The PKN-D group was the only group of subjects with VOTs greater than 42.7 ms. The NOR group was the only group of subjects with VOTs less than 17.3 ms. Values from 26.7 - 42.7 ms were common to the PKN-D and the PKN-NOD groups. Similarly, values from 17.3 - 38.7 ms were shared by the PKN-NOD and the NOR groups. In addition to these two examples of overlap, values from 26.7 - 38.7 ms were common to all three groups of speakers. Thirteen (43.3%) speakers (four PKN-D, six PKN-NOD, and three NOR) fell within this range.

To assess the significance of the observed differences in VOTs for /g/ among the groups a Scheffé test for multiple comparisons was utilized (Bruning and Kintz, 1977). The results of the Scheffé are displayed in Table VI. A significant (critical difference = 22.2 ms, $p<.005$) difference of 23.2 ms was obtained between the PKN-D and the

TABLE VI. Differences in mean VOTs, expressed in milliseconds, among PKN-D subjects, PKN-NOD subjects, and NOR subjects for the consonant /g/.

	PKN-D	PKN-NOD	NOR
PKN-D		13.7	23.2*
PKN-NOD			9.5

* Significant (critical difference = 22.2 ms, $p < .005$) difference.

NOR subjects. The difference of 9.5 ms between the PKN-NOD and the NOR subjects was not significant, nor was the difference of 13.7 ms between the PKN-D and the PKN-NOD subjects. These findings reflect the results discussed above for the mean VOTs, ranges of responses, and the extent of overlap of values and indicate that the PKN-D subjects can be distinguished from the NOR subjects for the VOT for /g/.

Differences Among Groups for the Consonant /k/

As can be seen in Table I, the mean VOT for /k/ was longest for the PKN-D subjects. The mean VOT for those subjects was 90.8 ms. The PKN-NOD subjects had a mean VOT of 84.5 ms, and the NOR subjects had a mean VOT of 67.7 ms, the shortest mean VOT for all three groups. The range of responses for each group is graphically presented in Figure 5. The PKN-D subjects again exhibited the greatest variability as well as having the longest mean VOT. The VOTs for the PKN-D subjects ranged from 58.7 - 142.7 ms. The range of responses for the PKN-NOD subjects was slightly less than that of the PKN-D group, as their values ranged from 42.7 - 125.3 ms. The NOR subjects exhibited the least variability as their VOTs ranged from 52.0 - 102.7 ms.

As was true for the previous consonants, a closer inspection of Figure 5 revealed considerable overlap of VOTs among the three groups. However, the pattern of overlap for /k/ was somewhat different than that for the consonants /b/,/p/, and /g/ in that the VOT values for the PKN-NOD group completely overlapped those of the

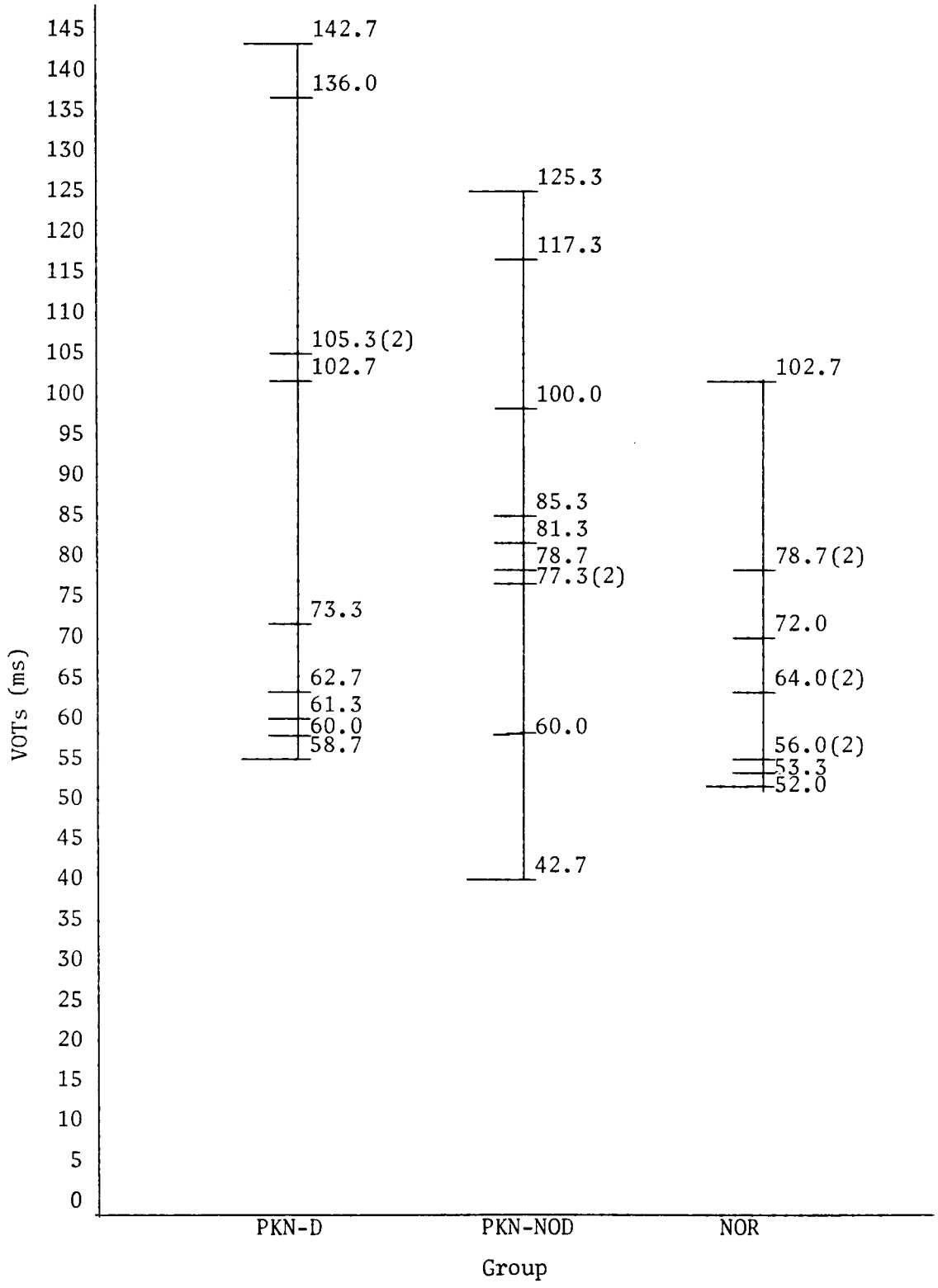


Figure 5. Range of VOTs for /k/ for PKN-D, PKN-NOD, and NOR subjects.

NOR group. Only the PKN-D subjects had VOTs greater than 125.3 ms, while the PKN-NOD group had the only subjects with a VOT less than 52.0 ms. VOTs between 60.0 and 102.7 ms were common to all three groups of speakers. Over half (16 or 53.3%) of the subjects had scores which fell within this range. Those speakers included five PKN-D, seven PKN-NOD, and four NOR individuals.

The Scheffé analysis (Bruning and Kintz, 1977) was performed to determine whether there were significant differences in VOTs between the groups. The results of the Scheffé are presented in Table VII. According to Table VII there was a significant (critical difference = 22.2 ms, $p<.005$) difference of 23.1 ms between the PKN-D and the NOR subjects. There was also a significant (critical difference = 16.0 ms, $p<.05$) difference of 16.8 ms between the PKN-NOD and the NOR subjects. The difference of 6.3 ms between the PKN-NOD and the PKN-D subjects was not significant. The results of the Scheffé are supported by the values reported for mean VOTs and ranges of responses. Hence, although a considerable degree of overlapping values has been discussed above, the differences between the PKN-D and the NOR speakers, and between the PKN-NOD and the NOR speakers still were significant.

Summary

In summary of the differences among groups, Table I indicates that for every consonant the mean VOT was greatest for the PKN-D subjects. On the other hand, the NOR subjects had the smallest mean VOT for each consonant. The mean VOT for each consonant for

TABLE VII. Differences in mean VOTs, expressed in milliseconds, among PKN-D subjects, PKN-NOD subjects, and NOR subjects for the consonant /k/.

	PKN-D	PKN-NOD	NOR
PKN-D		6.3	23.1**
PKN-NOD			16.8*

* Significant (critical difference = 16.0 ms, $p < .05$) difference.
** Significant (critical difference = 22.2 ms, $p < .005$) difference.

the PKN-NOD subjects was greater than that for the NOR subjects yet less than that for the PKN-D subjects. With regard to range of responses for all the consonants, the PKN-D subjects had the greatest range. The NOR subjects had the smallest range for three of the four consonants (/b/,/p/,/k/), while the PKN-NOD subjects had a range of VOT values that were slightly larger than that of the NOR subjects for the consonant /g/. There were significant differences in VOT values between the PKN-D subjects and the NOR subjects for all four consonants. Also, there was a significant difference in VOT values between the PKN-NOD and the NOR subjects for /k/, and between the PKN-D and the PKN-NOD subjects for /p/.

Differences Among Consonants

Although it was not the primary purpose of this investigation, the differences among the four consonants were examined. As stated in Table II, there was a statistically significant difference among the consonants ($F = 114.52$, $df = 3$, $p<.001$). Figure 6 graphically displays the mean VOTs for the four consonants across all three groups. As can be seen in Figure 6, the consonant with the longest mean VOT was /k/ with a mean VOT of 81.02 ms. The mean VOT for /p/,/g/, and /b/ were next in order of duration with mean VOTs of 52.05, 34.23, and 18.00 ms, respectively.

The VOTs for each consonant within each group are graphically displayed in Figure 7. As indicated in Figure 7, each of the three groups followed the overall sequence of VOTs with /k/ being the

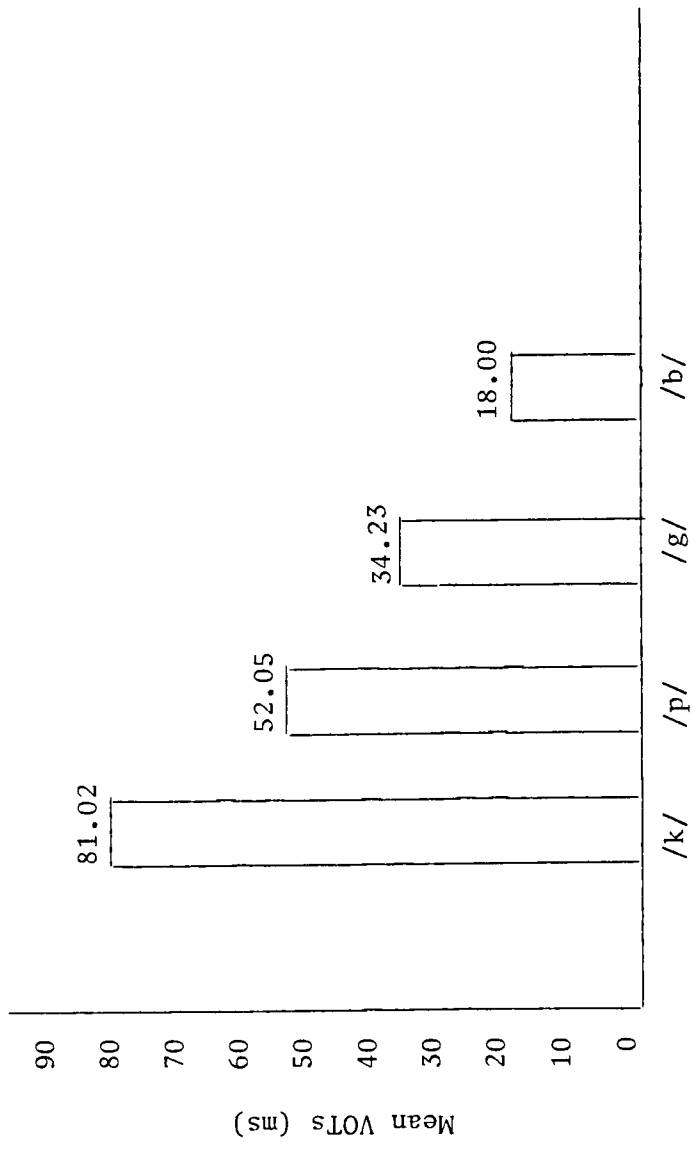


Figure 6. Mean VOTs (ms) for each of the four consonants across all three groups.

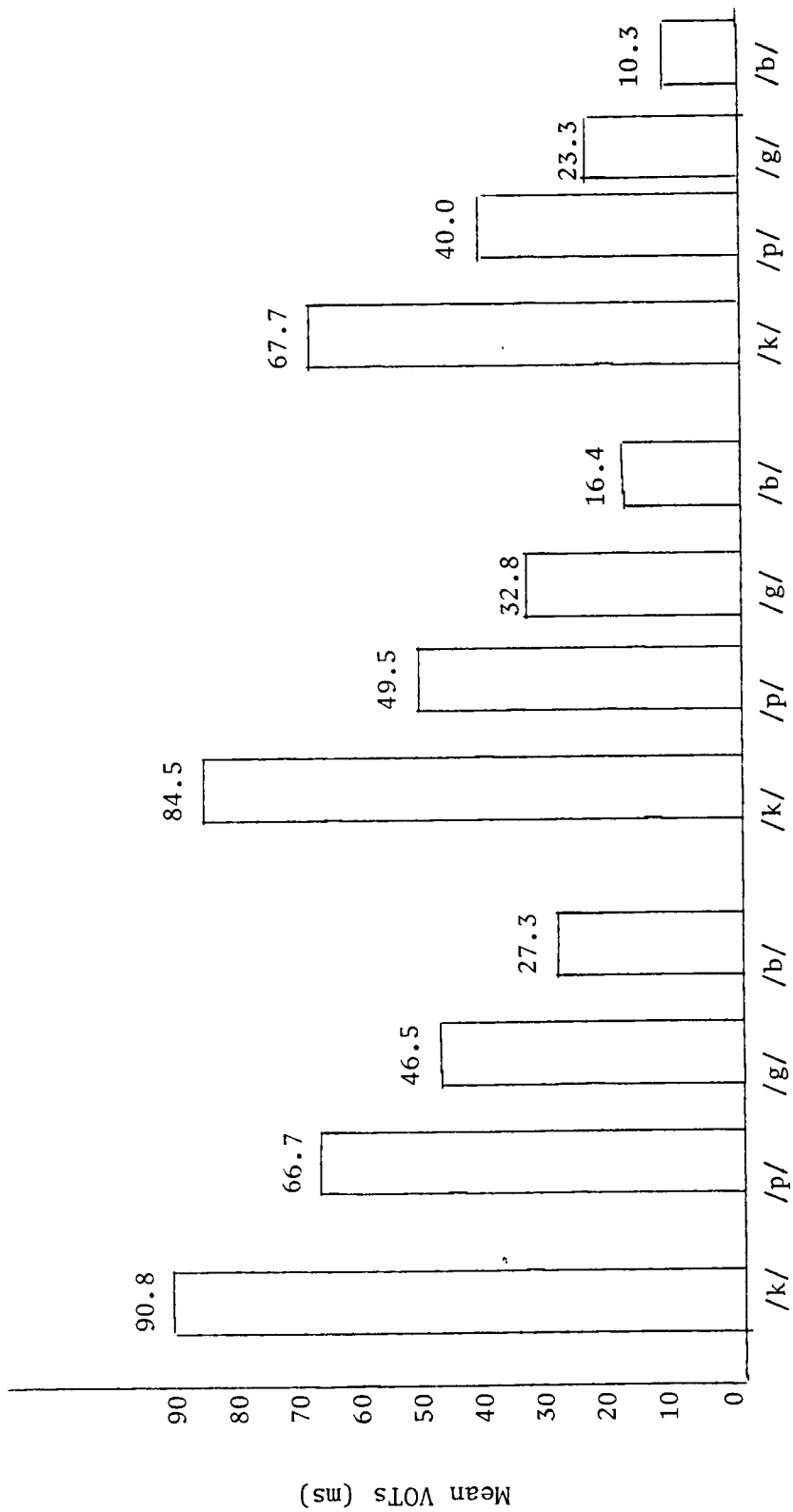


Figure 7. Mean VOTs (ms) for each of the four consonants for the PKN-D subjects, the PKN-NOD subjects, and the NOR subjects.

longest followed by /p/,/g/, and /b/ successively. Individual exceptions to this sequence were observed within the PKN-NOD and the PKN-D groups. Subject 19 of the PKN-NOD subjects had VOTs that followed the order of /k/,/g/,/p/, and /b/ from longest to shortest VOT, respectively. Subjects 4, 6, 9, and 10 of the PKN-D group also had VOTs for consonants that followed a different sequence. Subject 6 had a sequence of /k/,/p/,/b/,/g/; and subjects 9 and 10 had a sequence of VOT values of /k/,/g/,/p/,/b/. These sequences are in order from longest to shortest VOT.

Summary

In summary, the mean VOTs for the four consonants across all three groups, in order from longest to shortest VOT, were /k/,/p/, /g/,/b/. Each of the three groups and all of the NOR subjects followed this sequence of VOTs. Individual exceptions within the PKN-D and PKN-NOD groups were discussed.

CHAPTER IV

DISCUSSION

This investigation compared VOTs among three groups of speakers: normal speakers (NOR), speakers with Parkinson's disease and no observable dysarthria (PKN-NOD), and speakers with Parkinson's disease and dysarthria (PKN-D). Differences in VOTs among the three groups were reported in the previous chapter. In this chapter, the present data will be compared with results from previous investigations. Then, explanations for the findings of this investigation will be presented and discussed.

Comparisons of Present Data with Results from Previous Investigations

Data for NOR Subjects

The VOT findings for the NOR subjects in this investigation compare closely with those reported by Klatt (1975). The VOTs for the NOR subjects in this study were 67.0, 40.0, 23.3, and 10.3 ms for /k/,/p/,/g/, and /b/, respectively. Klatt reported VOTs of 70.0, 47.0, 27.0, and 11.0 ms for /k/,/p/,/g/, and /b/, respectively. Thus, while the values from this investigation were slightly shorter than those in the Klatt study, the VOTs for each consonant in this study were within 7.0 ms of those reported by Klatt.

Data for PKN-D and PKN-NOD Subjects

A comparison of the results of the present investigation with those of previous investigations indicates that the present findings not only support but also extend the findings of those studies. Although there have been no previous VOT studies reported for dysarthric speakers with Parkinson's disease (PKN-D), studies have been done on the phonatory characteristics of these speakers using other experimental methods. Utilizing a variety of techniques, those studies have consistently found indications of phonatory involvement in speakers with Parkinson's disease. Canter (1965a) and Darley, Aronson, and Brown (1975) reported pitch deviations in individuals with Parkinson's disease. Disorders in rate of speech were reported by Canter (1965b), Mueller (1971), Kreul (1972), Darley, et al. (1975), and Netsell, Daniel, and Celesia (1975). Logemann, Fisher, Boshes, and Blonsky (1978) indicated that voice disorders were the most frequent speech disorder in individuals with Parkinson's disease. The finding of some degree of phonatory involvement in the present study is in agreement with the studies discussed above. Thus, although different methods of assessing the phonatory mechanism were used in the various studies, the above mentioned researchers as well as the present investigator all reported some form of phonatory involvement in dysarthric speakers with Parkinson's disease.

In addition to supporting the findings from previous studies, the results of the present investigation provide new information regarding the nature of the phonatory impairment in PKN-D speakers.

Through a method of assessment not yet utilized with individuals with Parkinson's disease, that of analysis of voice onset time, information regarding the ability to coordinate the phonatory and articulatory mechanisms was obtained. This information suggests that in addition to the previously mentioned types of phonatory impairment, PKN-D speakers also manifest a reduced ability to coordinate the initiation of phonatory movements with the initiation of articulatory movements. This incoordination may be a significant aspect of hypokinetic dysarthria. Explanations for this impairment will be discussed in the succeeding section.

With regard to the PKN-NOD speakers, a review of the literature revealed no data which were directly or indirectly comparable. Thus, the data from the PKN-NOD group cannot be interpreted in the context of information from any previous investigations.

Explanations for Results

The purpose of this investigation was to obtain more information about the phonatory characteristics of speakers with Parkinson's disease. More specifically, the purpose of this investigation was to evaluate some hypotheses formulated from suggestions made by Canter (1965b), Darley, et al. (1975), and Logemann, et al. (1978). Canter (1965b) and Darley, et al. (1975) suggested that the phonatory involvement in speakers with Parkinson's disease was due to incoordination between the phonatory and articulatory mechanisms. Logemann, et al. (1978) suggested that

deterioration in the speech of individuals with Parkinson's disease would begin with laryngeal changes and continue forward in the vocal tract affecting the back of the tongue, the tongue-tip, and finally the lips. Canter (1965b) also implied that the progression of deterioration was from back to front although he did not discuss laryngeal changes.

Incoordination Between Articulatory and Phonatory Mechanisms

Voice onset time is a durational measure which provides an assessment of the amount of time which elapses from the release of a plosive to the beginning of voicing. Thus, voice onset time is an acoustic measurement of the ability to coordinate the phonatory and articulatory mechansims. If as Canter (1965b) and Darley, et al. (1975) suggest, individuals with Parkinson's disease have difficulty initiating phonatory movements and coordinating those movements with articulatory movements, then these difficulties should be manifested in a difference in VOTs between speakers with Parkinson's disease and normal speakers. The findings of this investigation were that the VOTs for the PKN-D speakers were significantly longer than those for the NOR speakers. This result confirms the above mentioned hypothesis and supports Canter (1965b) and Darley, et al.'s (1975) suggestion that individuals with Parkinson's disease do in fact exhibit incoordination of the phonatory and articulatory mechanisms.

One obvious explanation for the differences in VOTs between the PKN-D and the NOR subjects is the presence of hypokinetic dysarthria in the PKN-D speakers. The PKN-D and the NOR subjects were matched

with respect to age and sex, and there was no evidence of hearing loss. Therefore, these factors cannot account for the differences in VOTs between the two groups. The only known differences between the NOR and the PKN-D speakers were that the PKN-D individuals had dysarthria and that they were receiving medication to control their Parkinson's disease. Although the precise effects of this medication on these individuals is not known, there did not appear to be a relationship between the amount of medication received and the degree of delay in VOT in the PKN-D speakers. Hence, it would appear that the only plausible explanation for the observed differences between the PKN-D and the NOR subjects is the hypokinetic dysarthria.

The underlying basis for the dysarthria in PKN-D speakers is rigidity. Darley, et al. (1975) postulated that when the parkinsonian characteristics of rigidity affect the speech musculature, hypokinetic dysarthria results. As rigidity affects the laryngeal musculature, an increased resistance to movement results. Thus, rigidity in the laryngeal muscles, which control the movements of the vocal folds, could result in a delayed approximation of the vocal folds. Such a delay would disturb the synchrony of muscle contractions between the phonatory and articulatory mechanisms. Hence, rigidity of the speech musculature, and the resulting hypokinetic dysarthria, might produce an incoordination of phonatory and articulatory movements in PKN-D speakers.

Not only does the presence of dysarthria appear to account for the differences in VOTs between the PKN-D and the NOR speakers, but the degree of delay in VOT appears to be related to the severity of the dysarthria. The longest VOT for each consonant for the PKN-D group was a VOT from a severely dysarthric subject. Likewise, the shortest VOT for each consonant for the PKN-D group was either a mildly or mildly-moderately dysarthric subject. Consequently, the severity of the dysarthria appeared to be related to the degree of delay in VOT for the PKN-D subjects.

Progression of Speech Dysfunction

A second hypothesis was formulated from suggestions made by Canter (1965b) and Logemann, et al. (1978) regarding the progression of dysfunction of speech in individuals with Parkinson's disease. Logemann, et al. (1978) suggested that deterioration in the speech and voice of individuals with Parkinson's disease would begin with laryngeal changes and continue to spread throughout the vocal tract affecting the back of the tongue, the tongue-tip, and finally the lips. Canter (1965b) also suggested a progression of involvement from back to front as he reported greater impairment of the tongue-tip than the lips in speakers with Parkinson's disease. If laryngeal changes are one of the first symptoms in parkinsonian dysarthria, then VOT might be a sensitive indicator of an emerging dysarthria. Furthermore, if the progression of dysfunction spreads from back to front, VOTs for consonants involving the back of the tongue should be more delayed than VOTs for consonants involving the lips.

With regard to Logemann, et al.'s (1978) hypothesis that laryngeal changes are one of the first symptoms of parkinsonian dysarthria, the findings of this investigation revealed that the PKN-NOD speakers had longer VOTs than the NOR speakers for all four consonants. Although these differences in VOTs were not significant and cannot confirm Logemann, et al.'s (1978) hypothesis, the fact that the VOTs for the PKN-NOD subjects were longer than those for the NOR subjects suggests the possibility of the presence of an emerging dysarthria although none was perceived. It is possible that the PKN-NOD group contained subjects in all stages of the progression of Parkinson's disease. Perhaps those with longer VOTs might be on the verge of developing dysarthria while others may not have progressed to that stage. The findings of this study cannot provide this information. However, a longitudinal study of this group of PKN-NOD speakers would determine if those who developed dysarthria first were those who had longer VOTs in this investigation.

With respect to Canter (1965b) and Logemann, et al.'s (1978) suggestion that the progression of dysfunction would continue to spread throughout the vocal tract to the tongue and then to the lips, it would be expected that the VOTs for the velar consonants /g/ and /k/ would be affected prior to the VOTs for the labial consonants /b/ and /p/. The finding that the VOTs for all the consonants for the PKN-D speakers were significantly delayed did not provide much information regarding the progression of dysfunction.

However, the VOTs for the PKN-NOD group partially substantiated Canter (1965b) and Logemann, et al.'s (1978) suggestion of progressive dysfunction. The PKN-NOD subjects had significantly longer VOTs for the velar consonant /k/ than the NOR subjects, suggesting that the back of the tongue has been affected in these subjects. Similarly, there was a significant difference between the PKN-D and the PKN-NOD subjects in the VOT for the labial consonant /p/, suggesting that the progression of dysfunction had not yet affected the lips in the PKN-NOD subjects. However, the results of this study only partially supported the progression of deterioration as the VOTs for the voiced consonants /g/ and /b/ for the PKN-NOD subjects were not significantly different from either of the other two groups.

One possible reason why the VOTs for the voiceless consonants reflected the progression of dysfunction of the vocal tract while the VOTs for the voiced consonants did not is the amount of coordination necessary for completion of the task. It is possible that a greater degree of coordination between the phonatory and articulatory mechanisms was required as the subjects alternated from a voiced vowel in /se:/ to a voiceless consonant followed by a voiced vowel in /pip/ or /kip/. The increased difficulty of the task placed greater demands on all three groups, but the differences were more apparent in the disordered groups. Thus, it is possible that the apparent progression of dysfunction from the back of the vocal tract, as evidenced in the voiceless consonants in the PKN-NOD group,

was in reality only an indication of the greater demands of coordination for this group of sounds.

Summary

In summary, the results of this investigation for the PKN-D subjects are in agreement with the results of previous investigations for dysarthric speakers. The results for the PKN-D speakers also provide new information through a different method of assessing the speech of individuals with Parkinson's disease, that of voice onset time. The significant differences in VOTs reported for the PKN-D subjects are consistent with the observed dysarthria in that group. Regarding the PKN-NOD subjects, no previous studies have been reported involving PKN-NOD subjects. The observed differences in the VOTs for /k/ and /p/ for the PKN-NOD subjects are to be noted as they reflect Canter (1965b) and Logemann, et al.'s (1978) hypothesis on the progression of dysfunction. These differences were observed in acoustical analysis although no speech disorder was perceived in the PKN-NOD subjects. More research is needed to obtain more information and to provide more comparisons between the PKN-D and the PKN-NOD individuals.

Limitations of the Study and Suggestions For Future Research

One limitation of this study was the manner in which the stimulus items were presented. Each stimulus was repeated in the carrier phrase, "Say___again." The VOTs obtained from this

experimental task were taken from isolated sentences. Conversational speech is more continuous as it consists of one sentence after another. It is possible that the VOTs obtained from this experimental task may be different and less representative than those obtained from conversational speech.

Another limitation was the order of presentation of the stimuli. The order of presentation was not randomized; therefore, the subjects could have anticipated what their responses should be. This anticipation factor possibly could have affected the VOT measures.

A third limitation of this study was that these subjects with Parkinson's disease were on medication to control their symptoms. It is not known how much the medication affected the results of this investigation. There did not seem to be a relationship between the amount of medication a subject was taking and the degree of delay of VOT. All of the subjects were on various types and varying amounts of medication. To have taken the subjects off of the medication they were receiving possibly could have jeopardized their medical stability and increased their parkinsonian symptoms.

A final limitation of this study was the wide range of severity of involvement within the PKN-D and the PKN-NOD groups. No measures were taken to control or limit the degree of involvement of the dysarthria or the Parkinson's disease in the PKN-D speakers. The PKN-NOD speakers also varied widely in terms of severity of involvement. This wide range of severity could have accounted for the large range of VOTs for the groups with Parkinson's disease.

These limitations lead to suggestions for future research. One suggestion is to obtain more comparative information between the PKN-D and the PKN-NOD subjects. None of the previous studies examined the speech characteristics of PKN-NOD speakers. As Parkinson's disease is progressive in nature, much could be learned from comparative studies between PKN-D and PKN-NOD subjects.

Another suggestion for future research is to assess the VOTs of dysarthric speakers who had less variety in terms of severity of dysarthria. For instance, the dysarthric speakers in this investigation ranged from mildly to severely dysarthric. The range of VOTs obtained in this study reflect this range of severity of dysarthria. Comparative information could be obtained if VOTs were assessed in a group of severely dysarthric speakers, a group of moderately dysarthric speakers, and a group of mildly dysarthric speakers.

A third suggestion for future research is to do a longitudinal study on the PKN-NOD subjects. It might be that the PKN-NOD group included subjects at various stages of the progression of Parkinson's disease. Those subjects with longer VOTs may be on the verge of developing dysarthria. A longitudinal study would reveal if those in whom an observable dysarthria emerged first were in fact those PKN-NOD subjects with the longer VOTs.

A fourth suggestion for future research is to assess the effects of medication on individuals with Parkinson's disease. An assessment of the speech of subjects prior to being placed on

medication could be compared with an assessment of the speech of those subjects after they have been receiving medication. This information would be very helpful in determining the effects of medication on the speech of individuals with Parkinson's disease.

A final suggestion is to measure VOTs from connected speech. Measuring VOTs from a connected speech sample could provide more information about typical speech than those from isolated tasks.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to examine the differences in voice onset times (VOTs) for the consonants /b/,/p/,/g/, and /k/ among ten speakers with Parkinson's disease and dysarthria (PKN-D), ten speakers with Parkinson's disease and no observable dysarthria (PKN-NOD), and ten normal speakers (NOR). The subjects were asked to repeat the sentence "Say____again" after the examiner who varied the stimuli /bip/,/pip/,/gip/, and /kip/ until five repetitions of each stimulus were obtained. The responses were played into a Voice Identification Unit (Voice Identification, Inc., Series 700) and spectrograms were made. VOTs for the stimuli /b/,/p/,/g/, and /k/ were determined from the spectrograms.

Statistical analyses involved obtaining individual subjects' mean VOTs for all four consonants, group means and ranges for each of the four consonants, a total mean VOT for each group across all four consonants, and mean VOTs for each consonant across all three groups. A two factor mixed design analysis of variance with repeated measures on one factor (Bruning and Kintz, 1977) was used to determine whether statistically significant differences existed among the three groups of subjects and among the VOTs for the four different consonants. The results of the analysis of variance indicated that there were significant differences in VOTs among the

consonants /b/,/p/,/g/, and /k/. The Scheffé test for multiple comparisons (Bruning and Kintz, 1977) was utilized to determine between which groups of speakers significant differences existed across the four consonants. The results of the Scheffé revealed that there were significant differences in VOTs between the speakers with Parkinson's disease and dysarthria and the normal speakers for every consonant. In addition, the Scheffé revealed a significant difference in VOTs between the PKN-NOD speakers and the NOR speakers for /k/, and between the PKN-D and the PKN-NOD speakers for /p/.

The findings of this investigation suggest that dysarthric speakers with Parkinson's disease do have incoordination of their phonatory and articulatory movements. Secondly, the findings partially support the hypothesis that the deterioration of speech in individuals with Parkinson's disease begins with laryngeal changes and progresses forward in the vocal tract affecting the tongue and then the lips. Finally, the results of this investigation indicate that voice onset time might be used to detect an emerging dysarthria in speakers with Parkinson's disease and no observable dysarthria. However, much more research is needed to provide additional information about the onset and progression of dysarthria in individuals with Parkinson's disease.

REFERENCES

REFERENCES

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

Bruning, J.L., and Kintz, B.L., Computational Handbook of Statistics (2nd Ed.). Glenview, Illinois: Scott, Foresman, and Company (1977).

Canter, G.J., Speech Characteristics of Patients with Parkinson's Disease: I. Intensity, Pitch, and Duration. Journal of Speech and Hearing Disorders, 28, 221-229 (1963).

Canter, G.J., Speech Characteristics of Patients with Parkinson's Disease: II. Physiological Support for Speech. Journal of Speech and Hearing Disorders, 30, 44-49 (1965a).

Canter, G.J., Speech Characteristics of Patients with Parkinson's Disease: III. Articulation, Diadochokinesis, and Overall Speech Adequacy. Journal of Speech and Hearing Disorders, 30, 217-224 (1965b).

Colson, K., Acoustical Analyses of Duration Differences in the Production of Nonsense Syllables by Normal and Apraxic Speakers. M.A. Thesis, University of Tennessee (1979).

Darley, F.L., Aronson, A.E., and Brown, J.R., Differential Diagnostic Patterns of Dysarthria. Journal of Speech and Hearing Research, 12, 246-269 (1969a).

Darley, F.L., Aronson, A.E., and Brown, J.R., Clusters of Deviant Speech Dimensions in the Dysarthrias. Journal of Speech and Hearing Research, 12, 462-496 (1969b).

Darley, F.L., Aronson, A.E., and Brown, J.R., Motor Speech Disorders. Philadelphia: W.B. Saunders (1975).

Dew, D., and Jensen, P.J., Phonetic Processing: The Dynamics of Speech. Columbus, Ohio: Charles E. Merrill (1977).

Duvoisin, R.C., Parkinson's Disease. A guide for patient and family. New York: Rave Press (1978).

Fairbanks, G., Voice and Articulation Drillbook (2nd Ed.). New York: Harper (1960).

Gay, T., Effect of Speaking Rate on Vowel Formant Movements. Journal of the Acoustical Society of America, 63, 223-230 (1978).

Klatt, D.H., Voice Onset Time, Frication, and Aspiration in Word-Initial Consonant Clusters. Journal of Speech and Hearing Research, 18, 686-706 (1975).

Kreul, E.J., Neuromuscular Control Examination (NMC) for Parkinsonism: Vowel Prolongations and Diadochokinetic and Reading Rates. Journal of Speech and Hearing Research, 15, 72-83 (1972).

Logemann, J.A., Fisher, H.B., Boshes, B., and Blonsky, E.R., Frequency and Co-Occurrence of Vocal Tract Dysfunctions in the Speech of a Large Sample of Parkinson Patients. Journal of Speech and Hearing Disorders, 43, 47-57 (1978).

Mueller, P.B., Parkinson's Disease: Motor-Speech Behavior in a Selected Group of Patients. Folia Phoniatrica, 23, 333-346 (1971).

Netsell, R., Daniel, B., and Celesia, G.G., Acceleration and Weakness in Parkinsonian Dysarthria. Journal of Speech and Hearing Disorders, 40, 170-178 (1975).

Pallis, C.A., Parkinsonism: Natural History and Clinical Features. British Medical Journal, 3, 683-690 (1971).

Slotiuk, M. Dysarthria in Parkinsonism. Human Communication, 1, 65-71 (1976).

Van Riper, Charles. "My Grandfather." Speech Correction: Principles and Methods. Englewood Cliffs, New Jersey: Prentice-Hall, Inc. (1954).

APPENDICES

APPENDIX A

TABLE VIII. Age, sex, speech dimensions, severity rating, severity of dysarthria, severity of Parkinson's disease, and mean age of PKN-D subjects.

Subject	Age	Sex	Speech Dimensions	Severity (1-7)	Severity of Dysarthria	Severity of Parkinson's Disease
1	61	M	Decreased Rate	4	Mild-Moderate	Moderate
			Variable Rate	4		
			Inappropriate Silences	4		
			Imprecise Consonants	4		
			Repeated Phonemes	2		
			Monoloudness	2		
			Intelligibility	2		
2	65	M	Hoarse	4	Mild-Moderate	Moderate
			Breathy (continuous)	6		
			Rapid Rate	3		
			Variable Rate	3		
3	60	M	Monopitch	4	Severe	Severe
			Decreased Loudness	7		
			Monoloudness	4		
			Loudness Decay	5		
			Breathy (continuous)	7		
			Rate (slow)	4		
			Short Phrases	6		
			Reduced Stress	6		
			Inappropriate Silences	3		
			Excess and Equal Stress	3		
			Imprecise Consonants	5		
			Reduced Intelligibility	5		
4	47	M	Reduced Loudness Level	3	Mild-Moderate	Mild
			Monoloudness	3		
			Rapid Rate	3		
			Short Phrases	2		
			Increase of Rate in Segments	3		
			Increase of Rate Overall	3		
			Reduced Stress	1		
			Variable Rate	1		
			Inappropriate Silences	1		
			Short Rushes of Speech	2		

TABLE VIII (Continued)

Subject	Age	Sex	Speech Dimensions	Severity (1-7)	Severity of Dysarthria	Severity of Parkinson's Disease
5	68	M	Rate	5		
			Short Phrases	7		
			Inappropriate Silences	5		
			Short Rushes of Speech	6	Severe	Severe
			Imprecise Consonants	5		
			Prolonged Phonemes	5		
			Repeated Phonemes	6		
			Reduced Intelligibility	3		
6	61	F	Pitch Breaks	4	Mild-Moderate	Mild
			Hoarse	4		
7	70	F	Voice Tremor	4		
			Harsh Voice	2	Mild-Moderate	Moderate
			Hypernasality	2		
			Inappropriate Silences	2		
8	55	M	Breathy (continuous)	5		
			Rapid Rate	3		
			Increase of Rate in Segments	5	Moderate	Moderate
			Increase of Rate Overall	5		
			Short Rushes	3		
			Imprecise Consonants	4		
			Intelligibility	3		
9	72	M	Monopitch	4		
			Voice Tremor	3		
			Monoloudness	4		
			Strained-Strangled Voice	4		
			Increased Rate	4	Severe	Severe
			Reduced Stress	3		
			Inappropriate Silences	2		
			Imprecise Consonants	7		
			Distorted Vowels	5		
			Reduced Intelligibility	7		
10	67	M	Monopitch	3		
			Monoloudness	3	Mild	Moderate
			Increased Rate	1		
			Increase in Rate Overall	1		
			Imprecise Consonants	1		
Mean Age	62.6					

TABLE IX. Age, sex, severity of Parkinson's Disease, and mean age of PKN-NOD subjects.

Subject	Age	Sex	Severity of Parkinson's Disease
11	65	F	Mild
12	73	F	Mild-Moderate
13	60	M	Mild
14	47	M	Moderate
15	60	M	Mild
16	67	M	Mild-Moderate
17	72	M	Mild
18	55	F	Mild-Moderate
19	55	F	Mild-Moderate
20	71	F	Moderate-Severe
Mean Age	62.5		

TABLE X. Age, sex, and mean age of NOR subjects.

Subject	Age	Sex
21	59	M
22	62	M
23	58	M
24	47	M
25	68	M
26	62	F
27	71	F
28	55	M
29	70	M
30	67	M
Mean Age	61.9	

APPENDIX B

TABLE XI. Summary of mean VOTs, group means, and ranges for dysarthric speakers with Parkinson's disease (PKN-D), nondysarthric speakers with Parkinson's disease (PKN-NOD), and normal speakers (NOR), expressed in milliseconds.

	Subjects	/b/	/p/	/g/	/k/
PKN-D					
	1	25.3	40.0	34.7	58.7
	2	16.0	65.3	58.7	102.7
	3	49.3	92.0	72.0	105.3
	4	33.3	80.0	41.3	62.7
	5	32.0	121.3	46.7	136.0
	6	37.3	58.7	28.0	61.3
	7	16.0	53.3	26.7	73.3
	8	22.7	68.0	37.3	105.3
	9	26.7	60.0	64.0	142.7
	10	14.7	28.0	56.0	60.0
Mean		27.3	66.7	46.5	90.8
Range		14.7-49.3	28.0-121.3	26.7-72.0	58.7-142.7
PKN-NOD					
	11	12.0	68.0	36.0	81.3
	12	16.0	46.7	24.0	78.7
	13	9.3	38.7	17.3	42.7
	14	14.7	94.7	42.7	117.3
	15	22.7	48.0	41.3	125.3
	16	13.3	46.7	34.7	100.0
	17	16.0	32.0	30.7	60.0
	18	18.7	45.3	30.7	85.3
	19	24.0	30.7	34.7	77.3
	20	17.3	44.0	36.0	77.3
Mean		16.4	49.5	32.8	84.5
Range		9.3-24.0	30.7-94.7	17.3-42.7	42.7-125.3
NOR					
	21	6.7	32.0	22.7	64.0
	22	8.0	29.3	17.3	64.0
	23	6.7	32.0	24.0	72.0
	24	8.0	41.3	10.7	56.0
	25	13.3	26.7	25.3	52.0
	26	12.0	50.7	28.0	78.7
	27	10.7	53.3	38.7	78.7
	28	9.3	37.3	13.3	53.3
	29	14.7	26.7	18.7	56.0
	30	13.3	70.7	34.7	102.7
Mean		10.3	40.0	23.3	67.7
Range		6.7-14.7	26.7-70.7	10.7-38.7	52.7-102.7

VITA

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