An Investigation of Pitch Perturbation and Vocal Intensity Characteristics of Stutterers and Nonstutterers

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An Investigation of Pitch Perturbation and Vocal Intensity Characteristics of Stutterers and Nonstutterers

by

Carmen M. Bamberg

A Thesis
Submitted to the
Faculty of the Graduate College
in partial fulfillment of the
requirements for the
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Western Michigan University
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AN INVESTIGATION OF PITCH PERTURBATION
AND VOCAL INTENSITY CHARACTERISTICS
OF STUTTERERS AND NONSTUTTERERS

Carmen M. Bamberg, M.A.
Western Michigan University, 1989

Pitch and amplitude perturbation values were compared for nine adult stutterers and nine adult nonstutterers. Each subject produced ten sustained phonations of the vowels /æ/ and /i/. An automatic pitch-synchronous autocorrelation fundamental frequency tracker was used to extract period and amplitude measures.

Findings revealed that: (a) stutterers had significantly more vocal shimmer than nonstutterers (p = .01), (b) F-ratios for percent jitter between groups approached (p = .07) but did not reach significance, and (c) the vowel /æ/ was produced with higher levels of jitter and shimmer than the vowel /i/. Results support the notion that instability of the vocalization process is present in stutterers during fluent utterances. The potential usefulness of acoustic perturbation measures in understanding, diagnosing, and treating the disorder of stuttering is discussed.
ACKNOWLEDGEMENTS

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Carmen M. Bamberg
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CHAPTER I

REVIEW OF RELATED LITERATURE

History of Stuttering Research

The disorder of stuttering has been subjected to numerous systematic investigations since the 1930s. Research efforts in the field during the 1930s and the early part of the 1940s were based primarily on the premise that stutterers were physiologically inferior to normal-speaking people. Because of that predominant notion, most investigators tried to define physiologic deviations by studying various loci thought to be important for speech production. Laryngeal activity, speech breathing, and articulatory movement received the most attention. The results of those early studies did not conclusively support the existence of any significant deviation in these selected aspects of speech production in the stuttering population. Therefore, by 1944, investigators began to abandon the speech physiology line of inquiry. Relatively few studies of stutterers' speech production abilities were published in the two decades that followed (Adams, 1981).

In 1969, Wingate renewed a research trend in the field of stuttering by reviewing and summarizing
available literature pertaining to techniques of stuttering therapy related to rhythm, singing, and choral speaking, that generated an "artificial" fluency (so called since the fluency is highly dependent upon the condition producing it). He noted that a common feature among techniques that produced a reduction in stuttering was some change in the manner of vocalization. Wingate concluded that vocalization is a crucial element in stuttering, and he asserted that future research endeavors should explore that process more fully.

Wingate (1970) presented a subsequent review that explored another category of fluency-enhancing conditions related primarily to auditory reception. Auditory masking and delayed auditory feedback were the two major conditions discussed. Wingate concluded from his analysis that the reduction in stuttering associated with imposed alterations in auditory feedback was a result of certain changes in vocalization induced by the modification of auditory function. Given that both of Wingate's (1969, 1970) analyses indicated that certain changes in vocal expression were ultimately responsible for improved fluency, he called for additional investigation of the vocalization process that could lead to a more fundamental understanding of the nature of stuttering.
Although parameters related to aspects of speech production other than laryngeal activity have been pursued since the 1930s, a preoccupation with the larynx and laryngeal function continues to predominate in current stuttering research (Adams, 1981). Concurrent with and subsequent to Wingate's (1969, 1970) work, other investigators have focused upon two general areas: (1) analysis of speech patterns, specifically related to the variables of voice onset time, laryngeal reaction time, and coarticulation characteristics; and (2) observation of laryngeal muscle function during speech production by means of electroymyographic recordings and fiberoptic viewings.

Investigations Involving Speech Pattern Analysis

Studies of Voice Onset Time

Voice onset time is the latency between the onset of the quasi-periodic voice signal and some other movement or acoustic event (e.g., onset of mandibular movement, plosive noise burst). Various investigations have shown that voice onset time (VOT) during fluent speech is both longer and more variable in stutterers than in normal talkers (Adams, 1987; Agnello, 1975; Agnello, Wingate, & Wendell, 1974; Hillman & Gilbert, 1977).
Agnello (1975) conducted a study in which adult stutterers and nonstutterers read the syllables /ptz/,
/ba/, /ap/, and /atf/ in a fluent manner. Values of VOT were obtained through simultaneous measurements of
formant patterns and intraoral air pressure tracings. Analysis of mean VOT revealed that stutterers were slower
than nonstutterers in initiating voicing.

Hillman and Gilbert (1977) also compared VOT values between fluent and disfluent speakers. Speech samples
for that study were collected by asking subjects to read a passage. In order to analyze VOT, intervocalic
segments for the voiceless stop consonants /p/, /t/, and /k/ were displayed on wide-band spectrograms. With very
few exceptions, results indicated that VOT values were longer in the fluent speech of the stutterers than in the
fluent speech of the nonstutterers.

Agnello, Wingate, and Wendell (1974) investigated VOT of children who stuttered. Results of that study
revealed that stuttering children, like disfluent adults, have slower voice onset times than their normal-speaking
peers.

Adams (1987) attempted to extend the VOT findings of young stutterers into conversational speech. Ten
preschoolers served as subjects. Five subjects exhibited disfluencies which were considered normal, and five
exhibited incipient stuttering which had recently become a source of parental concern. The children were questioned about line drawings depicting common objects, animals, and actions. Inquiries about the children's own experiences with the objects also were included in order to draw the subjects into a conversation in which the target words might be used. All fluent target words were matched for type and position (relative to adjacent phonemes and words) among the subjects and evaluated using sound spectrography. A total of sixty-five matched word pairs were counted, including seven from the conversational responses. Comparisons between the two groups of subjects yielded significantly longer VOTs in the incipient stutterers than in their normal-speaking peers. The stutterers' values also revealed a larger standard deviation, suggesting a greater variability in the VOT measures.

Findings from other investigations have suggested that stutterers' VOT values may not differ from those of normal talkers. Metz, Conture, and Caruso (1979) compared word-initial stop consonants and stop-consonant clusters produced by five adult stutterers and five normally fluent adult speakers. Each subject read monosyllabic words embedded in the phrase "Say X again." at a comfortable rate, loudness, and pitch level.
Results from broad-band spectrogram analyses indicated that the stutterers' VOTs differed from those of the normally fluent speakers on only 33% of the fluently produced sounds and sound clusters. Therefore, the differences in VOT were not sufficiently consistent or prevalent to support earlier findings that stutterers, at least as a group, are slower than normally fluent speakers in their ability to initiate voicing during fluent speech production.

Watson and Alfonso (1982) also investigated the voicing parameter in adult stutterers and nonstutterers and, like Metz et al. (1979), obtained data contradicting previous VOT findings. In that investigation, subjects initiated voicing under three conditions (whispered vowel, voiced vowel, phrase) in response to both auditory and visual stimulus signals. VOT values were obtained from the spectrographic analysis of nonsense CVC-segments representing all permutations of the phonemes /p/, /t/, /k/, /i/, /u/, and /æ/. No significant group VOT differences were evident between stutterers and nonstutterers.

**Studies of Laryngeal Reaction Time**

The ability of stutterers to quickly initiate and terminate movement of both speech and nonspeech
musculature has been the focus of recent investigation (Adams & Hayden, 1976; McKnight & Cullinan, 1987; Reich, Till, & Goldsmith, 1981; Starkweather, Hirschman, & Tannenbaum, 1976). These investigations, like studies of VOT, have yielded equivocal findings.

Reich et al. (1981) investigated both speech and nonspeech muscle reaction times in a group of thirteen adult male stutterers and thirteen matched controls. The onset of a binaurally presented 1000-Hz pure tone served as the subject's cue to get ready. The tone's duration ranged from 0.5 to 4.0 seconds. Each subject was asked to respond immediately at the offset of the tone. A digital counter was used to measure the time interval between stimulus offset and each of the subject's responses.

Twelve responses were elicited in each of the following modes: (a) unilateral button pressing with the left and right forefingers to measure reaction times of nonspeech musculature, (b) production of an inspiratory phonation and an expiratory throat-clearing gesture to assess nonspeech vibrations of the vocal folds, and (c) production of the isolated vowel /ʌ/ and the meaningful utterance /ʌpə/ to measure speech reaction time. Only fluent responses were counted in the analysis. Moreover, the fastest and slowest responses in
each mode were eliminated so that the mean reaction times were based upon ten responses.

Results revealed that laryngeal tasks yielded longer reaction times than manual tasks for both the stutterers and the nonstutterers. Manual reaction times of stutterers were within normal limits. Although the trend was not significant, there was a tendency for the stutterers' reaction times to increase as the tasks became more speech-like and more linguistically complex. Stutterers and nonstutterers differed significantly only on those tasks requiring speech phonation. Stutterers' reaction times were slower than normal speakers' on the speech-mode laryngeal responses.

Starkweather et al. (1976) focused solely on speech phonation reaction times in a comparison of eleven adult stutterers and eleven normal-speaking adults. The twenty-six test syllables represented a broad range of place and manner of articulation, syllable type, and voicing. The V-, CV-, VC-, and VCV-syllable combinations contained both nonsense and familiar words (e.g., /ihi/ and /it/, respectively). Each target syllable or word was projected onto a screen and served as a ready signal. A green light was then flashed onto the screen, and subjects were instructed to produce the target syllable
immediately upon seeing the light. Each syllable was produced three times.

Only fluent responses were counted in the final analysis. The fastest response of the three trials was subjected to computer analysis for determination of latency of vocalization. Measurement of reaction time was made by determining the time that elapsed between the presentation of the triggering stimulus and the detection of the voltage produced by the onset of voicing.

The analysis showed that while both stutterers and nonstutterers decreased their reaction times with repeated presentation of the same test syllables, stutterers were significantly slower in initiating vocalization across all syllables. Starkweather et al. (1976) also noted significant differences between syllable type categories. Stutterers and nonstutterers did not differ significantly in reaction times for syllables containing an unvoiced consonant, while stutterers were significantly slower when the initial consonant was voiced. Starkweather et al. concluded from this observation that when the demand for rapid onset of vocalization is relaxed, even to a small degree (e.g., for voiceless consonants), stutterers appear to be able to initiate voicing with speed comparable to that of nonstutterers.
Adams and Hayden (1976) measured voice initiation time (VIT) and voice termination time (VTT) in a group of ten adult stutterers and matched controls. A 1000-Hz pure tone was presented to each subject following the alerting phrase "Get ready." This tone was the first of three which Adams and Hayden described collectively as a "train." Subjects were asked to start and stop the phonation of the vowel /ɛ/ with the appearance and disappearance of each tone in the train.

Oscillographic recordings provided permanent graphic readouts of onset, duration, and offset of each tone and each subject's voicing in reaction to the presence of every tone. The three tone scores for each train were averaged to give one VIT value and one VTT value per train for each subject. Although there was considerable variability in the performances of both groups, stutterers had significantly slower VITs and significantly longer VTTs than nonstutterers. Adams and Hayden (1976) concluded that stutterers are less able to promptly start and stop voicing than normal talkers.

Cross and Luper (1979) compared voice reaction times of adult and child stutterers with those of their normally fluent peers. Twenty-seven stutterers and twenty-seven nonstutterers matched for age and sex participated in that study. The experimental group
consisted of 5 year olds, 9 year olds, and those 15 years of age or older.

Test cues consisted of a series of binaurally presented 1000-Hz pure tone pulses one second in duration. Six sets of fifteen tones were presented to each subject. The first tone in each set was preceded by the investigator's instruction to "Get ready." The durations of silent intervals between the offset of each tone and the onset of the following tone ranged from 3 to 6 seconds. Subjects were instructed to initiate /Λ/ as quickly as possible after hearing the onset of the tone and to hold it until that particular tone ended. A comparator gate circuit and electronic digital counter were used for measuring voice reaction time.

Analysis revealed that voice reaction times for both stutterers and nonstutterers significantly decreased as the subjects increased in age. The most substantial reduction in mean reaction time occurred between the 5 year olds and the 9 year olds. Cross and Luper (1979) attributed this finding to an alteration of the developmental aspects of neuro-physiological integrity that is a part of the growth process. Although stutterers' performance was parallel to nonstutterers' for voice reaction relative to both the rate and degree of change with age, significant differences were observed.
between the two groups with respect to mean voice reaction times. Specifically, mean voice reaction times were significantly greater for the stutterers than for the matched controls at each of the three age levels.

McKnight and Cullinan (1987) conducted an investigation which focused solely on young stutterers' ability to initiate phonation. Subjects of that study were seventeen boys ranging in age from 6.2 to 12.1 years. Seven were stutterers receiving special educational services for problems in addition to their stuttering (the SP group). The other ten stutterers had no other speech, language, or learning problems (the SO group). The control group consisted of twenty nonstuttering boys who also exhibited no additional problems (the NS group).

Subjects were given a "ready" signal before a 1000-Hz tone was sounded. Each subject was instructed to begin saying /a/ as quickly as possible when they heard the tone. In a related task, subjects were asked to produce a digit sequence as quickly as possible upon hearing the tone. Responses were tape-recorded and analyzed using an oscillographic strip-chart recorder. Results revealed that voice reaction times were longest for the SP subjects. Moreover, while the SP group's response times were significantly greater than those for
the SO and NS groups, the times for the SO and NS groups were not significantly different.

McKnight and Cullinan (1987) hypothesized that the SPs' longer reaction times might have been related to their other speech, language, and/or learning problems or to some interaction between the other problems and the stuttering behavior.

The investigation of voice onset time by Watson and Alfonso (1982) reviewed previously also included measurements of laryngeal reaction time. Results were similar to those obtained for VOT. No significant differences in reaction times were observed between adult stutterers and nonstutterers. The experimental procedures for that portion of the study were as follows. Either the onset of a 1000-Hz pure tone presented binaurally or a visual signal presented by an incadescent lamp located directly in front of the subject served as a cue to get ready. Stimulus signal durations ranged from one to three seconds. Subjects were instructed to respond immediately at the offset of the auditory or visual signal. Three response conditions were utilized: (1) a whispered /ɑ/, (2) a voiced /ɑ/, and (3) a nonsense-syllable phrase beginning with the voiced schwa (/ə/). Simultaneous tape recordings were made of the signal
tones and of the subjects' responses to them. Recordings were subsequently analyzed on visicorder instruments.

Both stutterers and nonstutterers demonstrated greater reaction times in response to the visual signals than in response to the auditory cues. Moreover, both groups displayed similar reaction times within and across the whispered and voiced isolated vowel conditions and demonstrated significantly greater reaction time values in the phrase condition than in the isolated vowel conditions. Thus, the investigation failed to replicate the frequently demonstrated laryngeal reaction time effect. No significant group differences were found between stutterers and nonstutterers for any of the three response conditions. Watson and Alfonso (1982) believed that the results did not contradict other findings. They hypothesized instead that the long duration foreperiods used in the testing situation allowed the stutterers to posture their speech mechanism for a more rapid initiation of phonation.

A Study of Coarticulation Characteristics

Stromsta (1986) described an investigation of the functions of coarticulation and phonation in the speech disruptions of young children. In that study, speech samples containing disfluent segments were collected from
various children. Their parents listened to the tape-recorded samples and judged which speech disruptions they felt reflected stuttering behavior. The chosen samples were then spectrographically analyzed and categorized as having either normal or abnormal formant transitions and terminations of phonation. According to Stromsta, the spectrograms labeled as "abnormal" showed intraphonemic disruptions, indicating that the speaker had terminated his phonation before transitions into the following sounds could be produced. Those children with spectrograms that lacked smooth formant transitions also failed to evidence air flow between their part-sound and part-syllable repetitions.

All of the subjects were contacted approximately ten years following the initial recording and analysis. Using personal interviews, telephone conversations, and recent tape-recorded samples of conversational speech, Stromsta (1986) again categorized the speakers. If an individual's speech contained repetitions characterized by abnormal formant transitions and abnormal terminations of phonation, he was categorized as "still stuttering." If an individual's spectrogram instead showed formant transitions like those characteristic of normal coarticulation, the person was said to no longer be stuttering.
Results of that investigation showed that a significant relationship existed between the initial spectrographic categorizations and the disfluent behaviors displayed ten years later. Specifically, those who initially had repetitions characterized by abnormal formant transitions and abnormal phonation continued to stutter. Those individuals also had avoidance and struggle behaviors ten years later, while the other subjects did not. Stromsta (1986) concluded that the lack of coarticulation coupled with abnormal terminations of phonation comprise the core behavior of stuttering.

Investigations of Laryngeal Muscle Function

Fiberoptic Investigation

Conture, McCall, and Brewer (1977) conducted an investigation of laryngeal muscle action during stuttering moments in ten adult stutterers. A fiberscope allowed investigators to view the glottis. Subjects were asked to respond in the following ways for different trials: (a) to sustain selected vowels and continuant consonants; (b) to repeat vowels and CV-syllables at normal and fast rates; (c) to converse with an investigator; and (d) to read prose aloud, first alone and then concurrently with an investigator. Because the
first two conditions yielded very few moments of stuttering, only the last two were used for the analysis and description of laryngeal behavior.

Stuttering was defined as any part-word repetition, sound prolongation, or within-word pause. Moments of stuttering were judged by the experimenter. Fiberoptic views of the larynx during moments of stuttering consistently revealed either the presence or absence of glottal opening. In 94 of the 101 stutterings, laryngeal behavior was judged to be abductory (i.e., significant separation of the posterior aspects of the vocal folds) or adductory (i.e., lack of significant separation of the posterior aspects of the vocal folds). The seven exceptions were categorized as "combination" because the distance between the posterior aspects of the folds alternated between approximation and wide separation throughout the course of those disfluencies.

Results of the fiberoptic analysis revealed that 60% of the part-word repetitions were accompanied by abductory laryngeal behavior which appeared to begin simultaneously with the onset of and continued throughout the perceptual correlates of disfluency. During fluent productions of the same speech segments, the folds were not separated. Similar to laryngeal action during fluent speech, 72% of the total sound prolongations were
accompanied by adductory laryngeal behavior. All of the instances of broken words were accompanied by abductory laryngeal behavior. Conture et al. (1977) hypothesized that each type of stuttering may be associated with a different pattern of laryngeal muscle forces. Moreover, they suggested that the observed laryngeal behavior accompanying moments of stuttering may be related to the simultaneous contraction of antagonistic laryngeal muscles.

**Electromyographic Investigation**

Findings similar to those of Conture et al. (1977) have been reported from electromyographic studies of laryngeal behavior in stutterers (Freeman & Ushijima, 1975, 1978). Freeman and Ushijima (1975) reported electromyographic data for one adult stuttering subject and one normal speaking subject. Simultaneous recordings were obtained from four intrinsic laryngeal muscles, three lingual muscles, and one labial muscle. Fluent and stuttered ("faked" disfluencies in the normal speaking individual) productions of the same words were compared for both subjects.

Results indicated that fluent utterances were characterized by the precise balance and timing of laryngeal adductor and abductor forces, while this
adductor-abductor reciprocity was disrupted in the stuttered utterances. During moments of stuttering, simultaneous abductory-adductory activity occurred. Freeman and Ushijima (1975) also noted high levels of lateral cricoarytenoid muscle activity during the stuttered utterances and concluded that the degree of lateral cricoarytenoid activity, in particular, was correlated with the degree of disfluency. These findings are consistent with other work completed by Schwartz (1974) who suggested that inappropriate activity of the posterior cricoarytenoid is a critical phenomenon underlying stuttering.

Freeman and Ushijima (1978) drew similar conclusions from a second, more comprehensive electromyographic investigation of the patterns of speech muscle activity that accompany stuttering. Simultaneous recordings from intrinsic laryngeal muscles and upper airway articulatory muscles were collected from four adult male stutterers. Percutaneous insertions of bipolar, indwelling hook-wire electrodes were made in the posterior cricoarytenoid, interarytenoid, lateral cricoarytenoid, genioglossus, and sternohyoid. Insertions were made perorally into the cricothyroid and thyroarytenoid muscles.

Three of the four subjects read a selected prose passage for the first portion of the experiment. Fluent
utterances were obtained by having subjects read the same passage again under selected fluency-evoking conditions, including choral speaking, rhythmic speaking, delayed auditory feedback, and masking. Data were collected from the fourth subject by having him engage in conversation containing many words that were frequently difficult to produce. Those sentences marked by disfluencies were then used as stimulus material for the fluency-enhancing condition.

Results of the investigation showed that the laryngeal muscles maintained higher levels of activity during the initial recording than during the sample collected under fluency-enhancing conditions. Freeman and Ushijima (1978) noted that levels of laryngeal muscle activity recorded during moments of stuttering were significantly higher than levels necessary to produce the desired phonatory adjustments and vocal tract shape changes for the content of the experimental passage. Glottal closure during stuttering equaled the level characteristic of protective laryngeal closure (e.g., for coughing and swallowing). As such it was considered excessive for normal phonation. Freeman and Ushijima also reported, in support of the hypothesis offered by Conture et al. (1977), that fewer instances of abductory-adductory cocontraction occurred during the fluency-
enhancing conditions. Moments of stuttering were often
marked by disrupted abductory and adductory muscle
reciprocity.

Investigations of Vocal Perturbation

Pitch perturbation, also called vocal jitter, is the
cycle-to-cycle variation in voice fundamental frequency
(Lieberman, 1961). Amplitude perturbation, or vocal
shimmer, is the cycle-to-cycle variation in voice
amplitude (Koike, 1969). Cycle-to-cycle differences in
both frequency and amplitude of the acoustic signal have
been measured in normal talkers (Horii, 1979, 1980, 1982;
Lieberman, 1961). Likewise, aberrant vibration patterns,
those differing from normal speakers', have been
implicated in voice disorders (Doyle, Martin, Bryant, &
Ewert, 1989; Iwata, 1972; Kitajima & Gould, 1976;
Lieberman, 1963). Measures of vocal jitter and shimmer
recently have been applied to a group of stutterers as a
means of evaluating laryngeal function in that population
(Newman, Harris, & Hilton, 1988).

Early methods of jitter analysis were completed
through oscillographic measurements and laryngoscopic
high-speed photography. The process was tedious and
time-consuming. Moreover, values obtained from these
hand measurements were not very accurate (Heiberger &
Horii, 1982). Computer-based analysis methods of the 1970s and 1980s have significantly improved the efficiency and accuracy of perturbation analysis (Heiberger & Horii, 1982).

One early analysis method utilized correlograms to derive perturbation values (Iwata, 1972). In that study, measurements of pitch perturbation were taken from twenty normal speakers and twenty-seven persons with laryngeal pathologies, including chronic laryngitis, laryngeal neoplasm and unilateral vocal cord paralysis. Subjects sustained the vowel /a/ for several seconds at comfortable pitch and loudness levels. Signals were recorded by means of a contact microphone placed over the trachea and were analyzed by a visicorder instrument. Results indicated that only minute differences existed between pitch cycles in the normal talkers. Their pitch periods were highly correlated. In contrast, random, irregular variations of pitch periodicities were noted for the speakers with voice disorders. Pitch periods of the disordered speakers were not highly correlated. Iwata noted that the degree of aperiodicity varied according to the type of laryngeal pathology, with unilateral cord paralysis producing the greatest aperiodicity. He concluded that pitch perturbation values may reliably serve to differentiate speakers with
laryngeal pathologies from individuals without vocal disturbances.

**Perturbation in Speakers With Vocal Pathologies**

Lieberman (1963) hypothesized that pitch perturbations, because of their seemingly universal occurrence across languages, may have their source in the physical processes of speech production, namely at the level of the vocal folds. He further asserted that minute variations of vocal cord vibration produced by physically intact larynges might be different from those produced by pathologic larynges. The specific purposes of Lieberman's (1963) study were to determine the source of pitch perturbations (i.e., Are they due to irregularities in fold vibration?) and to assess the feasibility of detecting pathologic larynges through acoustic measurements of perturbation.

Six speakers without laryngeal pathologies and twenty-three speakers with some form of laryngeal pathology (e.g., tumors, polyps) were subjects of that investigation. Each participant read a 3-minute selection which was recorded on tape. The sentence "Joe took father's shoe bench out," read as a statement, and "They have bought a new car," read as a statement, a question, and a confidential communication were selected.
for analysis. The waveforms of each speaker's sentences were displayed on an oscilloscope, and a computer program calculated pitch perturbation by subtracting the duration (in msec) of each period from that of the period immediately preceding it. Results showed that perturbations in excess of 0.5 msec generally occurred at rapid formant transitions for connected speech (e.g., near stops). In contrast, perturbations exceeding 0.5 msec in magnitude almost never occurred within the steady-state portions of vowels where no abrupt formant transitions are expected.

Given this finding, Lieberman (1963) hypothesized that large perturbations might be induced by transients in the pressure drop across the glottis, which result directly from changes in vocal tract configuration. He proposed that perturbations might be attributed to the coupling of the glottis with the vocal tract, rather than solely to activity at the level of the larynx. To test this hypothesis, sustained /æ/’s were uttered by a normal speaker while a variable external acoustic load impinged on his mouth. The nature of this load was not specified. Perturbation values exceeding 0.5 msec in magnitude occurred. The same external load did not induce large perturbations, however, when the vocal tract was excited by an artificial larynx. Lieberman therefore concluded
that large perturbations are due to the coupling of the glottis with the vocal tract.

Another facet of Lieberman's (1963) study was designed to test whether the detection of pathologic larynges might be possible from measures of vocal jitter. It was determined that perturbation factor (the percentage of discrete perturbations exceeding 0.5 msec) was sensitive to small growths on the vocal folds, becoming greater as mass size increased. Lieberman concluded that a diagnostic procedure based on acoustic analysis could be a useful screening test for the early detection of pathologic laryngeal conditions. He added that such a procedure should not replace direct examination of the vocal cords in the diagnostic process.

Doyle et al. (1989) investigated the usefulness of jitter measures in differentiating children with vocal nodules from those with healthy larynges. Subjects were children between the ages of 7 and 12, ten with normal laryngeal mechanisms and ten with small vocal nodules. Each subject sustained the vowels /i/ and /a/ for approximately four seconds. Three productions of each vowel were recorded. A Visi-Pitch and computer interface software were used for data analysis. Results revealed that the dysphonic children exhibited greater jitter.
Kitajima and Gould (1976) were interested in determining whether measures of vocal shimmer, rather than jitter, might provide criteria usable in the detection of laryngeal disorders. Subjects of that study were forty-five men and women with no laryngeal disorders and twenty-five men and women with vocal cord polyps of various sizes and locations. Subjects sustained the vowel /a/ at comfortable pitch and intensity levels. The most stable 360 msec duration of each voice signal was low-pass filtered at 1500 Hz and subsequently digitized at a sampling rate of 20 kHz. Shimmer was defined as the mean absolute amplitude difference between consecutive cycles expressed in dB. The major positive peak and the negative peak immediately following it were the points used for amplitude calculations. Values of vocal shimmer ranged from 0.04 dB to 0.21 dB for subjects with normal larynges and from 0.08 dB to 3.23 dB for subjects with polyps. Kitajima and Gould attributed the overlap in values between the two groups to the fact that the subjects with polyps were selected regardless of size and location of the lesion. They hypothesized that a small polyp located off the free margin of the vocal cord would have little effect upon the regularity of fold ratios for both vowels than the children without vocal nodules.
vibration. Despite the slight overlap between the normal and abnormal voices, Kitajima and Gould asserted that vocal shimmer may nevertheless be a useful parameter for differentiating the two groups.

In contrast to Lieberman (1963) and Kitajima and Gould (1976), some investigators have questioned the validity of using phonatory perturbation measures to detect laryngeal pathology. Ludlow, Bassich, Lee, Connor, and Coulter (1984), for example, found that only 30% of their subjects with confirmed laryngeal pathologies had jitter values which clearly differentiated them from subjects without laryngeal disturbances.

Investigators have also sought to determine the relationship between perturbation and perceived vocal roughness. Smith, Weinberg, Feth, & Horii (1978) investigated vocal roughness and jitter characteristics of vowels produced by a group of nine esophageal speakers. Subjects were instructed to produce the vowel /a/ in as steady a manner as possible at a conversational level of loudness. Audiotape recordings were made of the signals. Two investigators then listened to the recordings of each speaker and selected a sample vowel representing the most constant utterance (i.e., the vowel with minimal variation in pitch and loudness).
One-second segments were spliced from the midsections of each of the selected vowels. An oscillographic analysis system was employed for the period-by-period measurements. Mean jitter values ranging from 0.07 msec to 0.13 msec and derived jitter ratios ranging from 39.53 to 148.88 (comparable to percent jitter values of 3.953 and 14.888) were obtained.

A group of listeners also rated the severity of vocal roughness characterizing each vowel that was subjected to perturbation analysis. Vowels were presented in pairs, and listeners were required to select the member of each pair which they perceived as "more rough." Intercorrelation techniques were then used to assess relationships between scale scores of perceived vocal roughness and acoustic measures of jitter ratio, mean vocal jitter, and mean fundamental frequency. Results indicated that none of the selected acoustic measures were significantly correlated with scale values of vocal roughness. Smith et al. (1978) concluded that none of the measures, including vocal jitter, could serve as useful predictors of perceived severity of vocal roughness.

Deal and Emanuel (1978) attempted to determine the relationships among acoustic measures of jitter, shimmer, spectral noise level and perceived roughness. Data were
obtained from recorded speech samples made in two earlier studies of vowel roughness. Twenty normal-speaking adult males and twenty adult males presenting clinically hoarse voices associated with a medically diagnosed laryngeal pathology were subjects of Deal and Emanuel's investigation. Each sustained the vowels /i/, /u/, /ʌ/, /æ/ and /ə/ for approximately seven seconds. Subjects without laryngeal pathology produced each vowel under two conditions, first normally and then with a simulated abnormal roughness. The central 2-second portion of each vowel production was analyzed using an oscillograph. An amplitude variability index (reflecting vocal shimmer) and a period variability index (reflecting vocal jitter) were calculated using the obtained measures of peak amplitude and period. Results indicated that both pitch and amplitude perturbations were greater for simulated rough and clinically hoarse utterances than for normal vowel productions, but this relationship was not significant across all vowel-types. Moreover, the magnitude of the relationship observed between amplitude variability or period variability and perceived roughness was not significantly large for either to be used as a reliable predictor of roughness. Deal and Emanuel asserted that their findings implied constraints regarding the clinical usefulness of such measures.
Perturbation in Normal Talkers

Lieberman (1961) attempted to present a quantitative description of the rapid fluctuations that occur in fundamental frequency during the speech of normal talkers. Six males without laryngeal pathology or speech deficit read a set of neutral sentences, making different vocal modifications on each utterance to convey the following messages: (a) confidential communication; (b) question of disbelief; (c) message expressing fear, happiness, or boredom; (d) an objective question; and (e) an objective or pompous statement. Each sentence was read three times in each mode. Linguistically naive listeners then selected the most identifiable utterance from all of the categories for each sentence. The sentence "They have bought a new car." was chosen for analysis for each subject.

Analysis procedures involved displaying each waveform on an oscilloscope and measuring (from peak to peak on the waveform) the duration of each period to the nearest 0.2 msec. Frequency by time distributions were plotted for each speaker. A computer program then determined the joint probabilities for the occurrence of various sequences of three periods.

The dominant effect noted was one of almost constant variation. In 86% of the cases, the period duration was
not steady (within 0.1 msec) over a 3-period sample. Considering this finding, and recognizing that the quality of synthesized speech is impaired when certain variations in the signal are removed, Lieberman (1961) concluded that slight variations in fundamental frequency likely contribute to the naturalness of speech.

Horii (1979) measured fundamental frequency perturbation during sustained phonation in a group of normal speakers. Six adult males served as subjects for that investigation. Each produced the vowel /i/ as steadily as possible at eleven different fundamental frequencies, ranging from 98 Hz to 298 Hz, by matching tones presented through headphones at the various frequency levels. A "get ready" signal, the presentation of a series of short tones through the headphones, preceded each target tone. Subjects were required to maintain a 70-78 dB SPL output level on each phonation. Each of the eleven target signals were presented in three randomly ordered series to each subject. Data were subsequently derived from the second and third series productions in order to eliminate practice effects potentially reflected in trial one. Each signal was digitized through a 16-bit analog-to-digital converter at an effective rate of 40,000 times per second. The computer analysis program employed was developed by Horii.
(1975) and utilizes a peak-picking method in measuring individual phases of the signal. The analysis revealed that jitter ranged from .26% to 1.57% for the normal speakers. Moreover, across all eleven frequency levels, there was a tendency for mean jitter to increase as the speaker's fundamental frequency level decreased.

Horii (1980) investigated the parameter of vocal shimmer in sustained phonations. Thirty-one normal speaking adult males served as subjects of that study. Both jitter and shimmer measures were extracted from subjects' sustained phonations of the vowels /i/, /æ/, and /u/. Subjects were instructed to phonate each vowel as steadily as possible, within a 70-80 dB SPL output range. Each vowel was produced three times. Only the most stable vowel, as determined by examining intensity by time and fundamental frequency by time tracings and by listening to the samples, was analyzed. A computerized peak-picking method was utilized (Horii, 1975). Results showed that mean shimmer for the three vowels was 0.39 dB, with /æ/ characterized by the greatest amount of amplitude perturbation. The /i/, on the other hand, was characterized by the greatest amount of jitter. Percentage of jitter, averaged for the three vowels, was 0.64%. Horii also found that a significant correlation existed between jitter and shimmer, as well as between
jitter and fundamental frequency. Horii concluded that similar sets of physical forces (e.g., fold tension, mass, length, and subglottal air pressure) underlie the regulation of fundamental period and intensity of laryngeal sounds.

Horii (1982) attempted to determine if vowel-type influenced jitter and shimmer measures. Twenty adult males were the subjects of that study. An accelerometer (or contact microphone) was placed on each subject's neck between the thyroid notch and the third tracheal ring. Subjects were asked to phonate the vowels /i/, /I/, /A/, /a/, /o/, /u/, and /æ/ as steadily as possible for a duration of at least five seconds. Each vowel was produced three times by each participant. The accelerometer signals were sent to a computer which quantized and stored the middle 3-second segments of each signal. A computerized peak-picking method was implemented to find individual periods of the vowel signals (Horii, 1975). A mean shimmer value for the group was .17 dB, with values ranging from 0.13 to 0.25 dB. Horii (1982) concluded that these shimmer values were lower than those reported in an earlier investigation (Horii, 1980) because an accelerometer was used in this experiment. Values of jitter ranged from 0.66% to 0.89% for the group. No statistical differences
among the means of the eight vowels were noted for jitter.

**Perturbation in Stutterers**

Newman et al. (1988) were the first to report jitter and shimmer values for stutterers. Fourteen stutterers (12 males and 2 females), ranging in age from 12.3 to 46.4, and fourteen controls matched for age and sex with the stutterers were the subjects of that investigation. The experimental group consisted of individuals with "very mild," "mild," and "moderate" degrees of stuttering.

The vowels /i/, /æ/, /u/ and /ɜ/ served as stimuli for the experiment. Subjects sustained each vowel for approximately five seconds at a 75-80 dB intensity level. Each vowel was produced nine times. A miniature accelerometer placed below the thyroid cartilage was used to record the speech samples. The middle 3-second segment of each production was recorded on a cassette tape and subjected to computer analysis. The computer program was developed by Horii (1975) and utilized a peak-picking method to identify individual periods.

A significant difference was found between stutterers and nonstutterers on measures of shimmer but not on measures of jitter. The mean shimmer value for
stutterers was .27 dB (standard deviation of .11) and for normal talkers was .17 dB (standard deviation of .08). Jitter was determined to be .63% (standard deviation of .26) for the group of stutterers and .53% (standard deviation of .19) for the group of nonstutterers. Jitter and shimmer values were not correlated for the group of stutterers. Newman et al. (1988) hypothesized that the stutterers' large standard deviation of jitter measures may have accounted for the lack of significance between the two groups. They also concluded from the differences observed between the stutterers and nonstutterers with respect to shimmer and jitter, coupled with the lack of correlation between the two measures, that the steady state phonations of stutterers are different from those of nonstutterers.
CHAPTER II

INTRODUCTION TO THE INVESTIGATION

Statement of the Problem

The majority of investigations of stutterers described above were designed to evaluate laryngeal function; however, they have provided little information about the more molecular fluctuations or irregularities in the acoustic pattern of the voice that might be implicated in some significant way in stuttering. The perturbation research described may elucidate those critical parameters of production or perception implicated in the vocalizations of both normal talkers and voice disordered individuals. Systematic analysis of those same parameters in a population of stutterers may lead to a better understanding of the processes and causal elements underlying stuttering.

The observations of delays in voice onset time and laryngeal reaction time, and the differences of muscular activity as noted in the electromyographic and fiberoptic research, are evidence of laryngeal dysfunction in stutterers. Such research suggests that additional indices of instability need to be developed to describe
laryngeal activity more precisely in that population. Hopefully, a more complete description of molecular laryngeal behavior during phonation, in conjunction with previously observed findings, will lead to the development of models which will explain the relationship of laryngeal function (or dysfunction) to the onset or maintenance of stuttering.

Purposes of the Investigation

Given the normative data acquired thus far, another study of vocal perturbation for stutterers would provide additional information and important indices of instability of the respiratory, laryngeal, and/or upper articulatory systems. This investigation was designed to address the following questions:

1. Are pitch perturbation measures for stutterers different from pitch perturbation measures for normal talkers?

2. Are amplitude perturbation measures for stutterers different from amplitude perturbation measures for normal talkers?

3. Is the variability of pitch perturbation for stutterers greater than for normal speakers?

4. Is the variability of amplitude perturbation for stutterers greater than for normal speakers?
5. Does the signal-to-noise ratio for a steady-state phonation decrease as pitch and/or amplitude perturbation increases?

6. Does a correlation exist between jitter and shimmer values in stutterers and/or in normal talkers?
CHAPTER III

METHODS

Subjects

Subjects were nine male stutterers and nine male nonstutterers. All stutterers were classified as "moderate/severe" according to the Stuttering Severity Index (Appendix A) developed by Riley (1972) and according to estimates provided by two certified speech-language pathologists. All stutterers had previously received or were currently enrolled in speech therapy.

The stutterers' mean age was 24.6, with a range of 21.0 to 30.0. Mean age of the control group was 25.1, with a range of 22.4 to 27.6. All subjects were high school or college graduates and had no other reported or observed speech or language problems. None had ever received professional vocal training. All subjects had normal hearing sensitivity as indicated by responses to 500 Hz, 1000 Hz, and 2000 Hz tones presented at 20 dB HL in a sound-treated booth.

Procedures for Data Collection

Each subject was seated in a sound-treated room. A directional microphone was positioned 13-16 centimeters
from the subject's mouth. Participants were advised that they would be making several productions of the vowels /a/ and /i/ which would be recorded and analyzed. They were unaware of the purposes of the experiment. Subjects were asked to sustain each vowel for approximately five seconds at pitch and intensity levels which were most comfortable to them. The experimenter used a hand-raising gesture to indicate to the subjects when to begin and when to terminate phonation of the vowel sound. A training period preceded the actual test administration to establish that the task was easily accomplished by all participants. During the experiment, subjects alternately produced sets of each vowel (e.g., 5 /a/'s then 6 /i/'s followed by 6 /a/'s and 5/i/’s). They were allowed to rest for approximately one minute between sets. Eleven trials were completed for each vowel yielding a total of twenty-two responses per subject.

Instrumentation for Data Collection and Reduction

Acoustic signals for the twenty-two vowel productions were recorded via a digital audio processor (Sony PCM-F1) onto a video tape using a video cassette recorder (Sharp XA-120). Record-level gain was adjusted individually for each subject to maximize dynamic range without clipping. A digital recording system was used to
avoid artifacts typically introduced by wow, flutter, and tape hiss that are associated with analog recorders (Doherty & Shipp, 1988; Titze, Horii, & Scherer, 1987). The audio processor converted analog signals into digital signals at a sampling rate of 44.1 kHz.

Before being introduced into the computer system, signals at the output of the PCM-F1 were low-pass filtered at 8 kHz to minimize aliasing effects (Enochson, 1986). The electrical signals (approximately 5 seconds in duration for each vowel) were then digitized at 20 kHz on a PDP 11-73 computer equipped with 12-bit Data Translation A/D and D/A hardware. Gain of the input amplifier was adjusted individually for each token to insure that no less than 85% of the dynamic range was used and that no clipping occurred.

Once digitized, the steadiest 3-second component (in terms of amplitude) of each 5-second vowel sample was determined by means of a computer program. Using this program, perturbation measures were determined by comparing amplitudes of successive 10-msec segments within the speech sample. Amplitude perturbation values for 3000-msec "blocks" of the signal (e.g., from 0-3000 msec, 100-3100 msec, 200-3200 msec) were compared, and the 3-second segment with the lowest amplitude perturbation value was isolated. The exact endpoints of
the steadiest 3-second sample were then identified from visual examination of the displayed signal waveform. The left and right edges of the signal were manually positioned at zero-axis crossings so that the windowed signal contained an integer number of pitch pulses.

Low-pass versions of all signals were derived using an elliptical digital low-pass filter set at 300 Hz. This secondary filtering promotes a more accurate "peak picking" process without significantly altering fundamental frequency measurements (Titze et al., 1987). After filtering, all signals were normalized to maximum peak amplitude within the PDP 11-73 computer.

Procedures for Determining Perturbation Values

Defining Perturbation Measures

Pitch perturbation (vocal jitter) is the cycle-to-cycle variation in voice fundamental frequency (Lieberman, 1961), while amplitude perturbation (vocal shimmer) is the cycle-to-cycle variation in voice amplitude (Koike, 1969). A variety of computational schemas have evolved to measure and describe these phenomena, including mean jitter, mean shimmer, percent jitter, jitter ratio, and jitter factor. Use of different data collection procedures (e.g., accelerometer
measures versus airborn signal recordings) and different computational formulas in perturbation investigations over the years has made the direct comparison of perturbation values very difficult.

The most widely used measures of perturbation are mean shimmer, mean jitter, and percent jitter. Mean jitter tends to be large for low-frequency phonations and small for high-frequency phonations (Heiberger & Horii, 1982). Because fundamental frequency does not affect percent jitter values, this computation is more useful. Perturbation values for this investigation were expressed in terms of mean shimmer and percent jitter as determined by the computational formulas represented below:

\[
\text{Mean Shimmer: } \sum_{i=1}^{N-1} \frac{|A_i - A_{i+1}|}{(N - 1)}
\]

where \( A_i \) is the amplitude of the \((i)\)th pulse in dB, and \( A_{i+1} \) is the amplitude of the \((i+1)\)th pulse in dB. The number of successive glottal pulses is represented in this formula as \( N \).
Mean Jitter:

\[
\sum_{i=1}^{N-1} \frac{|P_i - P_{i+1}|}{(N-1)}
\]

where \(P_i\) is the period of the \((i)th\) pulse in milliseconds and \(P_{i+1}\) is the period of the \((i+1)th\) pulse in milliseconds. Again, \(N\) represents the number of glottal pulses. Percent jitter is derived by dividing mean jitter by the average fundamental period and multiplying that value by 100.

Computer Determination of Perturbation Values

The steadiest 3-second interval of each filtered signal was subjected to computer analysis to extract period measures. An automatic pitch-synchronous autocorrelation tracker was utilized to locate peaks or zero-crossings after pitch estimation (Hillenbrand, 1988). Autocorrelation is a process whereby the original waveform is replicated and compared to itself one data point at a time. Points of maximum correlation (as could be displayed on a correlation x time delay graph) are identified by the program as major peaks within the
signal. The duration of one period is designated as the time (in msec) between adjacent peaks on the waveform.

When pitch estimation is complete, the tracker can return to the original waveform to locate one of four oscillographic landmarks: (1) the first positive-going peak in the period, (2) the first negative-going peak in the period, (3) the zero-crossing preceding the first positive-going peak in the period, or (4) the zero-crossing preceding the first negative-going peak in the period. The majority of perturbation investigations have utilized a peak-picking method. If waveforms are not clearly triangular, determination of the exact positive point in the signal through peak-picking may be inaccurate. This, in turn, could artificially inflate perturbation values. Horii (1979) predicted higher perturbation values for /a/ versus /i/ when a peak-picking method is employed because the /a/ waveform is more "rounded" than the /i/ waveform. For this investigation, the autocorrelation tracker was set to mark the zero-axis crossing immediately preceding the first major positive-going peak in the pitch pulse.

After the automatic pitch tracking process was complete, a computer program which identified cycle-to-cycle differences greater than 0.5 milliseconds was applied to each signal. Waveforms of signals found to
have these large periods were displayed, and the investigator determined whether certain adjustments (e.g., phase inverting the signal) could be made to improve tracking accuracy. Three options were considered. If the dominant peaks of the signal appeared to be negative-going, then the signal was phase inverted, promoting a more accurate identification of the major positive-going peaks (Figure 1).

![Waveform Before Phase Inversion (a) and Following Phase Inversion (b).](image-url)

Figure 1. Waveform Before Phase Inversion (a) and Following Phase Inversion (b).
If the signal appeared to have a number of data points which plateaued at the level of the designated zero axis, the zero-axis line was adjusted to either a higher or a lower level on the waveform, promoting a more accurate identification of the exact point where the waveform crossed before reaching its maximum peak (Figure 2).

Figure 2. Waveform Before Adjustment of the Zero Axis (a) and Following Adjustment of the Zero Axis (b).

Finally, if the periodicity of a signal was so unusual that neither of the first two methods was anticipated to
improve tracking accuracy, the appropriate zero-axis crossings were marked by hand.

Once the pitch tracking process was complete, descriptive statistics, including mean perturbation, percent perturbation, fundamental frequency and signal-to-noise ratio, were calculated using a FORTRAN program called AVR (Hillenbrand, Biggam, & Wilde, 1984). The AVR program is an implementation of the signal-averaging technique described by Yumoto, Gould, and Baer (1982). Measurements of the relative amount of energy in the periodic and aperiodic components of the voice signal are made by repeatedly averaging individual pitch pulses in the signal. A large portion of the noise is cancelled during this averaging process. The amount of aperiodic energy is estimated through a process involving successive subtractions of the average pitch pulse from individual periods of the original signal. This rms value serves as the denominator in the calculation of signal-to-noise ratio, while the rms energy of the average pitch pulse serves as the numerator. This calculation is represented below:

\[
\text{rms(average)} \quad \frac{20 \log \text{-----------}}{\text{rms(noise)}}
\]

The output from AVR was examined for each vowel. Signals which produced any suspicious values
(e.g., unusually large perturbation values, unusually poor signal-to-noise ratios, unusually large differences between minimum and maximum periods) were identified and examined by the investigator. Adjustments in the pitch tracking process were again considered. When values thought to be erroneous did not disappear after tracking alterations, the investigator replaced that suspicious signal with the extra recording (number 11) for that vowel to yield a sample that was less likely to be effected by instrumentation errors.

Reliability of Analysis Procedure

Ten original unfiltered 3-second samples were randomly selected and subjected to computer analysis a second time. Comparisons of values between the two trials were made for all dependent measures (Table 1). Formal computation of a correlation factor was unnecessary because the measures were very similar.
Table 1

A Comparison of Values for Percent Jitter, Mean Shimmer, Fundamental Frequency, and Signal-to-Noise Ratio for two Analysis Trials

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<th>Sample Number</th>
<th>Analysis Trial</th>
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</table>

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CHAPTER IV
RESULTS

Data were subjected to statistical analyses using a computer program (Crunch: Version 3, 1987). The initial step of data analysis involved calculating means for each vowel and each dependent measure (percent jitter, mean shimmer, fundamental frequency, signal-to-noise ratio) according to subject. Mean and standard deviation values of percent jitter and mean shimmer for individual subjects are displayed in Appendices B and C.

Group means for percent jitter, mean shimmer, fundamental frequency and signal-to-noise ratio were calculated for each vowel. Results are displayed in Table 2. Group standard deviations for the four dependent measures are shown in Table 3.

The group means listed in Table 2 and Table 3 were subjected to statistical analyses in order to determine if main effects or interactions for group or vowel type existed for the dependent measures of interest. A total of eight two-way ANOVAs (group x vowel) were calculated. Four ANOVAs (one for each dependent measure) were calculated to determine differences between means, and four (one for each dependent measure) were undertaken.
### Table 2

Group Mean Values for Percent Jitter, Mean Shimmer, Fundamental Frequency, and Signal-to-Noise Ratio Averaged for ten Productions of /a/ and /i/

<table>
<thead>
<tr>
<th>Variable</th>
<th>Vowel</th>
<th>Parameter</th>
<th>Stutterers</th>
<th>Nonstutterers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter</td>
<td>/a/</td>
<td>Mean</td>
<td>1.3622</td>
<td>0.6510</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>1.2323</td>
<td>0.3061</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>0.6357</td>
<td>0.3788</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.3374</td>
<td>0.1124</td>
</tr>
<tr>
<td>Shimmer</td>
<td>/a/</td>
<td>Mean</td>
<td>0.2246</td>
<td>0.1352</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.0944</td>
<td>0.0424</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>0.1742</td>
<td>0.1119</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.0592</td>
<td>0.0381</td>
</tr>
<tr>
<td>FO</td>
<td>/a/</td>
<td>Mean</td>
<td>123.70</td>
<td>126.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>16.36</td>
<td>14.49</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>130.30</td>
<td>132.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>19.96</td>
<td>16.77</td>
</tr>
<tr>
<td>S/N Ratio</td>
<td>/a/</td>
<td>Mean</td>
<td>15.27</td>
<td>18.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>3.08</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>16.64</td>
<td>19.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>2.18</td>
<td>1.42</td>
</tr>
</tbody>
</table>

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Table 3
Group Standard Deviations for Percent Jitter, Mean Shimmer, Fundamental Frequency, and Signal-to-Noise Ratio Averaged for ten Productions of /ɔ/ and /i/

<table>
<thead>
<tr>
<th>Variable</th>
<th>Vowel</th>
<th>Parameter</th>
<th>Stutterers</th>
<th>Nonstutterers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter</td>
<td>/ɔ/</td>
<td>Mean</td>
<td>0.5594</td>
<td>0.1706</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.8994</td>
<td>0.0610</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>0.2292</td>
<td>0.0844</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.2748</td>
<td>0.0686</td>
</tr>
<tr>
<td>Shimmer</td>
<td>/ɔ/</td>
<td>Mean</td>
<td>0.0550</td>
<td>0.0227</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.0530</td>
<td>0.0165</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>0.0520</td>
<td>0.0270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.0163</td>
<td>0.0223</td>
</tr>
<tr>
<td>FO</td>
<td>/ɔ/</td>
<td>Mean</td>
<td>3.77</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>2.48</td>
<td>2.03</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>4.35</td>
<td>4.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>3.21</td>
<td>3.61</td>
</tr>
<tr>
<td>S/N Ratio</td>
<td>/ɔ/</td>
<td>Mean</td>
<td>2.01</td>
<td>2.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.99</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>/i/</td>
<td>Mean</td>
<td>1.99</td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>0.52</td>
<td>0.98</td>
</tr>
</tbody>
</table>

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to analyze differences between standard deviations. Tables 4 through 7 display the summary values for the ANOVA analyses. Results from the mean and standard deviation ANOVAs for each dependent measure are represented together. An alpha level of .05 was selected a priori as the level for determination of significant differences.

Results of the ANOVA for percent jitter are represented in Table 4. The analysis yielded only one significant F-ratio. Mean values for percent jitter were larger for /a/ than for /i/. F-ratios for percent jitter between groups approached (p = .07), but did not reach, significance. Stutterers and nonstutterers, as a group, did not differ from one another on measures of pitch perturbation. Similarly, the groups did not differ in the degree of variability.

Results from the ANOVA for mean shimmer, as represented in Table 5, showed significant differences for both group and vowel comparisons. Stutterers, as a group, had more vocal shimmer than nonstutterers and also evidenced more variability on the shimmer measure than nonstutterers. A comparison of mean values revealed that the vowel /a/ was produced with higher levels of vocal shimmer than the vowel /i/.
Table 4
Summary of ANOVA Statistics for Group and Vowel Comparisons for Percent Jitter

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>df1</th>
<th>df2</th>
<th>ss</th>
<th>mss</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group (G)</td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>2.108</td>
<td>2.108</td>
<td>3.54</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.641</td>
<td>0.641</td>
<td>1.87</td>
<td>0.19</td>
</tr>
<tr>
<td>Vowel (V)</td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>2.245</td>
<td>2.245</td>
<td>8.22</td>
<td>0.01*</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.390</td>
<td>0.390</td>
<td>3.74</td>
<td>0.07</td>
</tr>
<tr>
<td>G x V</td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>0.464</td>
<td>0.464</td>
<td>1.70</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.134</td>
<td>0.134</td>
<td>1.29</td>
<td>0.27</td>
</tr>
</tbody>
</table>

*Significant at the .05 level.

The ANOVA for fundamental frequency (Table 6) yielded only one significant F-ratio. Fundamental frequency for the vowel /a/ was significantly lower than that for the vowel /i/. No significant group differences were determined. Moreover, neither group nor vowel comparisons produced significantly different standard deviations on measures of fundamental frequency.
Table 5
Summary of ANOVA Statistics for Group and Vowel Comparisons for Mean Shimmer

<table>
<thead>
<tr>
<th>Means and Standard Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Group (G)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Vowel (V)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>G x V</td>
</tr>
</tbody>
</table>

*Significant at the .05 level.

The ANOVA results for signal-to-noise ratio are reported in Table 7. Mean values for signal-to-noise ratio were significantly lower for stutterers than for nonstutterers. Ratios for vowels or standard deviation values were not significantly different.

Three Pearson product-moment correlations were calculated to determine relationships of percent jitter vs. mean shimmer, percent jitter vs. signal-to-noise ratio, and mean shimmer vs. signal-to-noise ratio. Jitter

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Table 6
Summary of ANOVA Statistics for Group and Vowel Comparisons for Fundamental Frequency

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>df1</th>
<th>df2</th>
<th>ss</th>
<th>mss</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>49.09</td>
<td>49.09</td>
<td>0.09</td>
<td>0.77</td>
</tr>
<tr>
<td>Group (G)</td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.012</td>
<td>0.012</td>
<td>0.00</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>336.1</td>
<td>336.1</td>
<td>21.59</td>
<td>0.01*</td>
</tr>
<tr>
<td>Vowel (V)</td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>1.671</td>
<td>1.671</td>
<td>0.33</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>2.170</td>
<td>2.170</td>
<td>0.14</td>
<td>0.71</td>
</tr>
<tr>
<td>G x V</td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.183</td>
<td>0.183</td>
<td>0.04</td>
<td>0.85</td>
</tr>
</tbody>
</table>

*Significant at the .05 level.

and shimmer were strongly correlated \((r = .87)\) in a positive direction. Signal-to-noise ratios were moderately correlated with jitter \((r = .68)\) and shimmer \((r = .77)\) in a negative direction, indicating that signal-to-noise ratios tended to increase as jitter and/or shimmer were reduced.
Table 7

Summary of ANOVA Statistics for Group and Vowel Comparisons for Signal-to-Noise Ratio

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>df1</th>
<th>df2</th>
<th>ss</th>
<th>mss</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group (G)</td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>61.79</td>
<td>61.79</td>
<td>9.90</td>
<td>0.01*</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.910</td>
<td>0.910</td>
<td>0.80</td>
<td>0.38</td>
</tr>
<tr>
<td>Vowel (V)</td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>11.25</td>
<td>11.25</td>
<td>2.80</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.744</td>
<td>0.744</td>
<td>1.77</td>
<td>0.20</td>
</tr>
<tr>
<td>G x V</td>
<td>Means</td>
<td>1</td>
<td>16</td>
<td>0.579</td>
<td>0.579</td>
<td>0.14</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1</td>
<td>16</td>
<td>0.659</td>
<td>0.659</td>
<td>1.57</td>
<td>0.23</td>
</tr>
</tbody>
</table>

*Significant at the .05 level.

In summary, the ANOVA analyses revealed that significant differences existed between the group means of stutterers and the group means of nonstutterers for mean shimmer, signal-to-noise ratio, and variability of mean shimmer. Significant vowel differences were also observed for measures of percent jitter, mean shimmer, and fundamental frequency.

A comparison of means (displayed in Table 2 and Table 3) with ANOVA results revealed that stutterers had significantly more vocal shimmer than nonstutterers.
Similarly, stutterers showed more variability on the shimmer measure than nonstutterers. The vowel /a/ also was produced with higher levels of both vocal jitter and vocal shimmer than the vowel /i/. Fundamental frequency of vowel /i/, however, was significantly higher than that of the vowel /a/. Finally, as a whole, signals produced by stutterers showed poorer signal-to-noise ratios than those produced by nonstutterers.
CHAPTER V

DISCUSSION OF FINDINGS

Limitations of the Present Study

A variety of factors potentially limit the findings of this study. Although the ANOVA calculations took this into account, one primary limitation is the small size of the subject sample. Additionally, only adult stutterers with "moderate/severe" levels of disfluency were included. Therefore, findings may not be applicable to populations of disfluent children or to stutterers with differing degrees of severity. Similar analyses, undertaken with children or with individuals who exhibit varying levels of severity, may eventually provide information that implicates specific changes of the vocalization process in the onset and development of stuttering or links them to specific levels of severity. It is also possible, due to sampling error, that the small group of stutterers who participated may represent a distinct subgroup within the stuttering population. Perhaps laryngeal instability, as reflected in higher perturbation values, is unique to or more typical of a subgroup of stutterers. Third, the fact that all
stuttering subjects had received speech therapy may have biased the sample in a different way. Therapeutic intervention may have effected a change in laryngeal stability within these individuals. An investigation of perturbation in stutterers who have not received fluency training may yield findings that differ from those described in the present study.

The investigation was limited to the study of isolated productions of only two vowels. Given reports of consistency for perturbation values across other vowel types (Horii, 1982), additional vowel comparisons would likely have produced similar patterns across groups for each of the dependent measures. However, because only steady-state vowel productions were analyzed, findings of this study may not be applicable to connected speech.

Subjects were required to alternate productions of the vowels /a/ and /i/. Such alternations precluded a straightforward assessment of adaptation effects across the eleven utterances of a given vowel. If a fatigue factor is implicated in changes of perturbation, it would be reasonable to hypothesize that an increase of perturbation values would be observed over a large number of repeated vowel productions. On the other hand, if practice effects or reductions of adverse emotional inputs occur over a large number of repeated measures, a
reduction of perturbation would be hypothesized. While statistical analysis procedures were not implemented to determine whether perturbation systematically changed from the first to the last vowel productions, cursory examination of each subject's values suggested that adaptation probably did not occur.

Comparison of Results With Previous Research

Comparison of Results With Other Perturbation Research

Although instrumentation and perturbation formulas have not been consistent across investigations, some comparisons can be made between the results of this experiment and results of earlier perturbation studies. Previously reported perturbation values for sustained vowel productions for normal talkers and stutterers are summarized in Table 8. Group values for percent jitter and mean shimmer for subjects in this investigation (Bamberg, 1989) are also displayed in Table 8.

An examination of Table 8 reveals that the control group in this experiment obtained perturbation values comparable to those previously reported for normal talkers. In general, perturbation values of this investigation were equal to or lower than those of other studies. Mean shimmer values, for example, were lower
Table 8

A Comparison of Perturbation Values for Normal Talkers (N) and Stutterers (S) From Previous Studies and From the Present Study

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Group</th>
<th>Vowel Type</th>
<th>Percent Jitter</th>
<th>Mean Shimmer (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horii (1979)</td>
<td>N</td>
<td>/i/</td>
<td>.26 - 1.57</td>
<td>Not Measured</td>
</tr>
<tr>
<td>Horii (1980)</td>
<td>N</td>
<td>/a/</td>
<td>.61</td>
<td>.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/i/</td>
<td>.72</td>
<td>.37</td>
</tr>
<tr>
<td>Horii (1982)</td>
<td>N</td>
<td>/a/</td>
<td>.66</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/i/</td>
<td>.68</td>
<td>.17</td>
</tr>
<tr>
<td>Newman et al. (1988)</td>
<td>N</td>
<td>Combined</td>
<td>.53</td>
<td>.17</td>
</tr>
<tr>
<td>Bamberg (1989)</td>
<td>N</td>
<td>/a/</td>
<td>.65</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/i/</td>
<td>.38</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined</td>
<td>.52</td>
<td>.12</td>
</tr>
<tr>
<td>Newman et al. (1988)</td>
<td>S</td>
<td>Combined</td>
<td>.63</td>
<td>.27</td>
</tr>
<tr>
<td>Bamberg (1989)</td>
<td>S</td>
<td>/a/</td>
<td>1.36</td>
<td>.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/i/</td>
<td>.64</td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined</td>
<td>1.00</td>
<td>.20</td>
</tr>
</tbody>
</table>
than any previously reported. Therefore, Horii's (1982) assertion that signals collected via an accelerometer are likely to be characterized by smaller amplitude perturbation than measures extracted from airborne signals is not supported by the present findings. The zero-axis marking method utilized in this study yielded lower perturbation values than the peak-picking method (Horii, 1975) employed in the other investigations.

Newman et al. (1988) reported values of .27 dB for mean shimmer and .63% for jitter for stutterers. Mean shimmer values measured in this study were lower than those values, and percent jitter values for stutterers in this study were slightly higher. Consistent with the findings of Newman et al., however, stutterers' shimmer values were significantly higher than values for normal talkers. Jitter differences between the two groups approximated (p = .07), but did not reach a statistically significant level (p = .05).

The relationships of signal-to-noise measures to jitter and shimmer values were also considered in this investigation. According to Hillenbrand (1987), signal-to-noise ratios decrease as perturbation increases for a given signal. This relationship existed in the present study as well. Such relationships have not been reported, however, for other perturbation studies.
The influence of vowel type on perturbation has previously been considered. According to Heiberger and Horii (1982), some investigators have reported vowel differences and others have not. In this study, /a/ was characterized by significantly more perturbation than /i/, supporting the notion that perturbation values are vowel-dependent. It may well be the case that vowel dependency is sensitive to a variety of methodological details, such as the oscillographic landmark used for pitch marking, the type of transducer used, the low-pass filtering implemented, and the calculation method used to estimate perturbation.

The results of this investigation can also be considered in relation to perturbation values obtained for speakers with pathologic voices (e.g., Doyle et al., 1989; Kitajima & Gould, 1976; Lieberman, 1963). These particular studies yielded perturbation values that are much larger than those reported for stutterers. This suggests that differences in laryngeal instability evidenced by perturbation data are larger for individuals who have various types of voice disorders than for stutterers.
Comparison of Results With Other Stuttering Research

A number of investigators have sought to identify physiologic causes for fluency breakdown in stutterers. Some have noted differences in laryngeal activity and voicing characteristics during fluent and stuttered utterances.

One line of inquiry has focused on stutterers' ability to initiate voicing. The majority of investigations of voice onset time (VOT) and laryngeal reaction time (LRT) have determined that stutterers are less able than nonstutterers to rapidly initiate voicing during fluent speech production (Adams, 1987; Adams & Hayden, 1976; Agnello, 1975; Agnello, Wingate, & Wendell, 1974; Hillman & Gilbert, 1977; Reich et al., 1981; Starkweather et al., 1976). These data have led to the hypothesis that fluency breakdown is related to deviant laryngeal action which reduces the stutterer's ability to initiate vocalization with the speed, precision, or stability characteristic of normal talkers. While not contradicting that assumption, results of this investigation indicate that differences in phonation between stutterers and nonstutterers extend beyond the onset of glottal vibration. Laryngeal instability, initially reflected in voice onset difficulties, is also manifested as vocal perturbation after phonation is
initiated. Additionally, the present findings suggest that perturbation differences exist in the absence of stuttering. Thus, if perturbation is used as an index of instability, the present findings suggest that instability is present during fluent productions and may increase the likelihood that disfluency will occur.

A recurrent theme throughout voice onset time (VOT) and laryngeal reaction time (LRT) studies (e.g., Cross & Luper, 1979; Watson & Alfonso, 1982) has been that the laryngeal behaviors of stutterers are in many ways similar to those of normal talkers (e.g., LRT greater for visual compared to auditory reaction cues; LRT values decrease as age increases). This may suggest that stutterers differ in subtle ways from nonstutterers in terms of laryngeal function. Results of this investigation are in agreement with that notion. Perturbation values of stutterers were much more like those obtained for normal talkers than those previously reported for pathologic voices (e.g., Kitjima & Gould, 1976; Smith et al., 1978). Some VOT and LRT investigations (Metz et al., 1979; Watson & Alfonso, 1982) have failed to find significant group differences between stutterers and nonstutterers because of large intersubject variability within the stuttering group. Although stutterers were more variable on measures of
mean shimmer, significant differences of within-subject variability between stutterers and nonstutterers were not obtained for the other dependent measures in this study.

Investigations have also reported values for individual stutterers which are comparable to those of normal talkers. Although stutterers as a group evidenced higher perturbation values than nonstutterers in this study, individual mean values (as reported in Appendices B and C) overlapped between the two groups. Thus, increased perturbation may not be a "necessary condition" for fluency breakdown. Instead, perturbation may be an outcome of specific aberrant adjustments made at other levels of the speech production system. Whether such adjustments reflect a subtype of stutterer or a characteristic of a specific systematic maladjustment is an empirical issue yet to be resolved.

Some investigations have determined that laryngeal muscle reciprocity is disrupted during moments of stuttering (Conture et al., 1977; Freeman & Ushijima, 1975, 1978). This line of inquiry could lead to the speculation that disrupted muscle forces, possibly related to a stiffness parameter or motor control strategy, may contribute to increased levels of perturbation in stutterers. Alternately, frequent irregular vibrations of the vocal folds may induce timing
breakdowns in laryngeal muscles through either reflexogenic disruption or perturbation of aerodynamic forces in ways that impose arrhythmic forces on the vibratory mechanism. Regardless of the specific mechanism, results of this experiment and those of muscle function studies are congruent in that stutterers' larger perturbation values and uncoordinated muscle actions are indices of laryngeal instability.

Perturbation values have been reported for the stuttering population (Newman et al., 1988). In that study, stutterers exhibited significantly more vocal shimmer than nonstutterers. Results demonstrated a large standard deviation of the jitter measure across subjects. Newman et al. hypothesized that extreme variability may have masked differences between the two groups. Findings of the present investigation are consistent with Newman et al.'s study with respect to vocal shimmer. Similarly, jitter values were not significantly different between the groups in either study. High variability of measures obtained by Newman et al., however, was not observed in this investigation.
Potential Applications of Findings to Applied Research

Proposed Studies for Normal Talkers

Determination of how one "destabilizes" the normal voice may lead to the identification of physical and/or emotional variables that interact to increase vocal perturbation. Given the interrelatedness of phonation, respiration, and articulation in the speech process, the influence of selective changes in laryngeal tension levels, lung volumes, and articulatory loads on perturbation measures might be studied in a population of normal talkers. Such an investigation might identify physiologic variables common to both vocal perturbation and disfluency. Similarly, given that psycho-emotional variables may influence stuttering behavior, a study of normal talkers under a variety of emotional states to determine selective effects of emotional stimuli on perturbation might be valuable. It may be beneficial to determine if a systematic increase in anxiety level produces a systematic change in vocal perturbation.

Proposed Studies for Stutterers

Future investigations should be undertaken to make additional measures of perturbation within the stuttering population. Additional data must be gathered to either
support or refute the present conclusion that stutterers have higher vocal perturbation values than nonstutterers. Subsequent perturbation investigations with stutterers which include children and differing severity levels might be useful. A study of stutterers' perturbation values during connected speech might better indicate the significance of jitter and shimmer in inducing fluency breakdown in more complex speech tasks.

Larger, more variable perturbation values for stutterers suggest that fluent speech efforts of stutterers are characterized by instability at the level of the larynx. Future research efforts might seek to determine if systematic relationships exist between various therapeutic strategies and changes in perturbation. Strategies designed to alter subglottal air pressures, the degree of adductor tension at voice onset, or the mean fundamental frequency of vibratory patterns should be explored to determine if increased or decreased perturbation occurs. Therapy techniques designed to decrease instability of motoric speech processes in stutterers (e.g., teaching clients to initiate phonation with slightly abducted folds) could be systematically investigated to determine whether or not changes in perturbation occur. The degree and quality of change, when compared to the performance of normal
talkers, might reflect the usefulness of certain strategies in altering unstable patterns.

Future investigations of perturbation in stutterers may lead to new approaches for stuttering therapy. For instance, alterations in fundamental frequency could affect perturbation for given individuals. It may be that the habitual pitch levels of normal talkers are "ideal" for their vocal mechanism and therefore serve to maintain or increase stability of laryngeal function. Stutterers, on the other hand, may use habitual pitch levels which are either higher than or lower than that which is physiologically "ideal" for them. The end product may be a decrease in laryngeal stability. If so, training stutterers to speak at an optimum or "ideal" pitch level may be a useful therapy approach for increasing laryngeal stability and reducing disfluency. Assuming that a relationship exists between the amount of subglottic air pressure and vocal perturbation, an investigation of the effects of systematic alterations in vocal intensity upon laryngeal stability might also be relevant. Perhaps "ideal" intensity levels could be identified for disfluent speakers that would serve to increase laryngeal stability during speech.
Implications of Perturbation Data for the Stuttering Population

While stutterers' larger perturbation values can be considered as another index of laryngeal instability, the present findings should not be interpreted to support causal notions that inherent malfunction of the larynx is the primary effector of stuttering. Relationships between neurological and muscular influences and the effects of psycho-emotional variables on perturbation need to be investigated further.

While specific neurological or muscular correlates of jitter and shimmer have not yet been adequately determined, initial attempts have been made to explain the phenomena in neuromuscular terms. Baer (1979) suggested that neural pulses which trigger contractions of muscle fibers in the larynx and other parts of the body are inherently asynchronous. The asynchronous patterns, triggered by asynchronous pulse trains, produce "noisy" variations in vocal fold tension. Vocal fold tension, subglottal air pressure, and other effects (e.g., airflow turbulence, assymetry of muscle structure) were identified as contributing to perturbation. Baer also suggested that such perturbations would be exacerbated under stress. If Baer's account of the neuromuscular influence on perturbation is valid, then it would seem reasonable to hypothesize that stutterers, who
frequently exhibit elevated muscle tension levels under various speaking conditions, and who typically show extreme emotional reactions to speech and stressful speaking situations, would exhibit larger perturbation values than normal talkers under such conditions. Such extreme perturbations, if functionally linked to neuromuscular activity, may approach some threshold which, if exceeded, might trigger reflexogenic responses that lead to the occurrence of stuttering behavior.

Larson, Kempster, and Kistler (1987) observed firing patterns of single motor units in the cricothyroid and thyroarytenoid muscles of four adults with normal voices. Results indicated a relationship between somewhat arhythmic firing patterns of single motor units and oscillations of fundamental frequency of the voice signal. Such oscillations may underlie at least one component of jitter. The authors proposed that changes in single motor units firing patterns are one direct source of vocal jitter. They suggested that for certain values of fundamental frequency, single motor unit patterns can trigger a series of damped oscillations of vocal fold muscle tissue. Additionally, they suggested that independent vibrations of the mucosa and laryngeal muscles they cover, triggered by changes in discharge patterns of motor units, may increase at higher levels of
muscle stiffness. The authors proposed, therefore, that a transient change in the stiffness of a muscle (i.e., a muscle twitch) may cause a transient change in the vibratory characteristics of the mucosal covering of the larynx, thus producing vocal shimmer.

It should be carefully noted that vocal perturbation, or even evidence of aberrant muscle activity underlying perturbation, may be an "a posteriori" fact determined by maladjustments of higher level neural, subcortical, or cortical activity (Kelso, 1980; Zimmermann & Hanley, 1983; Zimmermann, Smith, & Hanley, 1983). The acoustic differences noted may merely be consequences of speech system dynamics. Therefore, data acquired from this level of analysis must ultimately be related to other systematic changes in speech production dynamics before they can have explanatory value.

In summary, results of this investigation support the hypothesis that stutterers evidence more vocal perturbation than nonstutterers. The potential usefulness of vocal jitter and shimmer measures in understanding, diagnosing, and treating the disorder of stuttering has yet to be fully determined.
Appendix A

Riley's (1972) Stuttering Severity Index
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These consist of pages:

77–78
Appendix B

Table of Subject Means and Standard Deviations for Percent Jitter
Means and Standard Deviations (SD) for Percent Jitter for Stutterers (S) and Nonstutterers (N) Averaged for ten Productions of /a/ and /i/

<table>
<thead>
<tr>
<th>Group</th>
<th>Subject</th>
<th>Mean /a/</th>
<th>SD /a/</th>
<th>Mean /i/</th>
<th>SD /i/</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>1.267</td>
<td>0.111</td>
<td>0.621</td>
<td>0.232</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>0.629</td>
<td>0.256</td>
<td>0.151</td>
<td>0.020</td>
</tr>
<tr>
<td>S</td>
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<td>1.256</td>
<td>0.431</td>
<td>0.923</td>
<td>0.241</td>
</tr>
<tr>
<td>S</td>
<td>4</td>
<td>4.590</td>
<td>2.946</td>
<td>1.231</td>
<td>0.934</td>
</tr>
<tr>
<td>S</td>
<td>5</td>
<td>1.106</td>
<td>0.271</td>
<td>0.576</td>
<td>0.140</td>
</tr>
<tr>
<td>S</td>
<td>6</td>
<td>0.769</td>
<td>0.276</td>
<td>0.216</td>
<td>0.064</td>
</tr>
<tr>
<td>S</td>
<td>7</td>
<td>0.895</td>
<td>0.311</td>
<td>0.619</td>
<td>0.123</td>
</tr>
<tr>
<td>S</td>
<td>8</td>
<td>1.046</td>
<td>0.266</td>
<td>0.854</td>
<td>0.208</td>
</tr>
<tr>
<td>S</td>
<td>9</td>
<td>0.702</td>
<td>0.167</td>
<td>0.530</td>
<td>0.101</td>
</tr>
<tr>
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<td>1</td>
<td>0.276</td>
<td>0.080</td>
<td>0.255</td>
<td>0.047</td>
</tr>
<tr>
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<td>1.384</td>
<td>0.290</td>
<td>0.377</td>
<td>0.052</td>
</tr>
<tr>
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<td>3</td>
<td>0.577</td>
<td>0.150</td>
<td>0.295</td>
<td>0.050</td>
</tr>
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<td>N</td>
<td>4</td>
<td>0.682</td>
<td>0.166</td>
<td>0.583</td>
<td>0.226</td>
</tr>
<tr>
<td>N</td>
<td>5</td>
<td>0.418</td>
<td>0.107</td>
<td>0.405</td>
<td>0.058</td>
</tr>
<tr>
<td>N</td>
<td>6</td>
<td>0.644</td>
<td>0.200</td>
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<td>0.175</td>
</tr>
<tr>
<td>N</td>
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<td>0.700</td>
<td>0.213</td>
<td>0.438</td>
<td>0.081</td>
</tr>
<tr>
<td>N</td>
<td>8</td>
<td>0.609</td>
<td>0.159</td>
<td>0.286</td>
<td>0.047</td>
</tr>
<tr>
<td>N</td>
<td>9</td>
<td>0.569</td>
<td>0.170</td>
<td>0.275</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Appendix C

Table of Subject Means and Standard Deviations for Mean Shimmer
Means and Standard Deviations (SD) for Mean Shimmer (dB) for Stutterers (S) and Nonstutterers (N) Averaged for ten Productions of /a/ and /i/

<table>
<thead>
<tr>
<th>Group</th>
<th>Subject</th>
<th>Mean /a/</th>
<th>SD /a/</th>
<th>Mean /i/</th>
<th>SD /i/</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>0.279</td>
<td>0.040</td>
<td>0.210</td>
<td>0.062</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>0.172</td>
<td>0.035</td>
<td>0.072</td>
<td>0.018</td>
</tr>
<tr>
<td>S</td>
<td>3</td>
<td>0.204</td>
<td>0.034</td>
<td>0.240</td>
<td>0.060</td>
</tr>
<tr>
<td>S</td>
<td>4</td>
<td>0.438</td>
<td>0.194</td>
<td>0.244</td>
<td>0.073</td>
</tr>
<tr>
<td>S</td>
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<td>0.138</td>
<td>0.027</td>
<td>0.167</td>
<td>0.061</td>
</tr>
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<td>S</td>
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<td>0.165</td>
<td>0.049</td>
<td>0.099</td>
<td>0.047</td>
</tr>
<tr>
<td>S</td>
<td>7</td>
<td>0.204</td>
<td>0.044</td>
<td>0.165</td>
<td>0.050</td>
</tr>
<tr>
<td>S</td>
<td>8</td>
<td>0.263</td>
<td>0.050</td>
<td>0.209</td>
<td>0.059</td>
</tr>
<tr>
<td>S</td>
<td>9</td>
<td>0.113</td>
<td>0.022</td>
<td>0.162</td>
<td>0.038</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>0.079</td>
<td>0.010</td>
<td>0.070</td>
<td>0.018</td>
</tr>
<tr>
<td>N</td>
<td>2</td>
<td>0.195</td>
<td>0.008</td>
<td>0.096</td>
<td>0.013</td>
</tr>
<tr>
<td>N</td>
<td>3</td>
<td>0.091</td>
<td>0.017</td>
<td>0.078</td>
<td>0.010</td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>0.161</td>
<td>0.030</td>
<td>0.133</td>
<td>0.052</td>
</tr>
<tr>
<td>N</td>
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<td>0.083</td>
<td>0.010</td>
<td>0.156</td>
<td>0.020</td>
</tr>
<tr>
<td>N</td>
<td>6</td>
<td>0.167</td>
<td>0.016</td>
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</tr>
<tr>
<td>N</td>
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<tr>
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<td>8</td>
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<td>0.093</td>
<td>0.012</td>
</tr>
<tr>
<td>N</td>
<td>9</td>
<td>0.133</td>
<td>0.018</td>
<td>0.069</td>
<td>0.006</td>
</tr>
</tbody>
</table>

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Appendix D

Table of Subject Means and Standard Deviations for Signal-to-Noise Ratio
Means and Standard Deviations (SD) for Signal-to-Noise Ratio for Stutterers (S) and Nonstutterers (N) Averaged for ten Productions of /æ/ and /i/

<table>
<thead>
<tr>
<th>Group</th>
<th>Subject</th>
<th>Mean /æ/</th>
<th>SD /æ/</th>
<th>Mean /i/</th>
<th>SD /i/</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>1</td>
<td>14.262</td>
<td>1.471</td>
<td>17.178</td>
<td>1.875</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>19.583</td>
<td>1.341</td>
<td>21.327</td>
<td>1.346</td>
</tr>
<tr>
<td>S</td>
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<td>13.888</td>
<td>1.409</td>
<td>13.212</td>
<td>1.461</td>
</tr>
<tr>
<td>S</td>
<td>4</td>
<td>10.656</td>
<td>4.381</td>
<td>17.337</td>
<td>2.753</td>
</tr>
<tr>
<td>S</td>
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<td>11.480</td>
<td>1.551</td>
<td>16.490</td>
<td>2.716</td>
</tr>
<tr>
<td>S</td>
<td>6</td>
<td>17.702</td>
<td>2.093</td>
<td>16.192</td>
<td>1.803</td>
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<tr>
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<td>7</td>
<td>16.867</td>
<td>1.639</td>
<td>17.036</td>
<td>2.243</td>
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<td>1.486</td>
<td>14.966</td>
<td>1.550</td>
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<tr>
<td>S</td>
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<td>18.363</td>
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<td>16.014</td>
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<td>17.441</td>
<td>1.636</td>
</tr>
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<td>2.603</td>
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<td>2.621</td>
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<td>1.809</td>
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<tr>
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<td>N</td>
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<td>16.653</td>
<td>1.895</td>
<td>19.762</td>
<td>1.000</td>
</tr>
</tbody>
</table>

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Appendix E

Approval Letter From the Human Subjects
Institutional Review Board
TO: Carmen M. Bamberg  
FROM: Ellen Page-Robin, Chair  
RE: Research Protocol  
DATE: October 17, 1989

This letter will serve as confirmation that your research protocol, "An Investigation of Pitch Perturbation and Vocal Intensity Characteristics of Stutterers and Nonstutterers" has been approved as exempt by the HSIRB.

If you have any further questions, please contact me at 387-2647.
Appendix F

Subject Consent Form
INFORMED CONSENT RELEASE FORM

I _______________________________ FREELY AND VOLUNTARILY CONSENT TO PARTICIPATE IN THE EXPERIMENT DESCRIBED ON THE ATTACHED PAGE.

I ALSO UNDERSTAND THAT I MAY WITHDRAW FROM THIS EXPERIMENT AT ANY TIME, AND THAT MY PARTICIPATION OR WITHDRAWAL WILL IN NO WAY AFFECT MY STANDING WITH THIS UNIVERSITY OR MY ROLE AS A CONSUMER OF ITS CLINICAL OFFERINGS.

I UNDERSTAND THAT I WILL NOT BE EXPOSED TO ANY EXPERIMENTAL PROCEDURE WHICH WOULD IN ANY WAY BE DETRIMENTAL TO MY PHYSICAL OR PSYCHOLOGICAL WELL BEING.

I UNDERSTAND THAT OTHER INDIVIDUALS WILL BE PARTICIPATING IN THE EXPERIMENT WITH ME. HOWEVER, I ALSO UNDERSTAND THAT NONE OF MY RESPONSES WILL IN ANY WAY BE ASSOCIATED WITH ME OR WITH MY NAME.

I ENGAGE IN THIS STUDY FREELY, WITHOUT MONETARY PAYMENT AND WITH NO OTHER CONTINGENCIES BEING PLACED ON MY PARTICIPATION. I ALSO UNDERSTAND THAT I WILL NOT DIRECTLY BENEFIT PERSONALLY FROM THE RESULTS OF THIS STUDY.

I UNDERSTAND THAT I HAVE HAD AND WILL HAVE THE OPPORTUNITY TO ASK QUESTIONS ABOUT THE NATURE AND PURPOSE OF THE STUDY, AND I UNDERSTAND THAT UPON COMPLETION OF THIS STUDY AT MY REQUEST, I CAN OBTAIN ADDITIONAL EXPLANATION ABOUT THIS STUDY AND ITS IMPLICATIONS.

DATE __________;_____________ SIGNED

___________________________ WITNESS

___________________________ WITNESS
BIBLIOGRAPHY


