PROPERTIES OF STUTTERED SPEECH

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1.0 INTRODUCTION

The purpose of this study was to compare the fluent and nonfluent speech of stutterers with the fluent speech of nonstutterers in terms of their prosodic features and spectrogram analyses. Three adult stutterers were matched with three nonstutterers and were asked to perform three tasks: passage reading, wordlist reading, and free speech. Results demonstrated that polysyllabic words and stressed syllables were more often stuttered, and speaking rate was slower in stutterers fluent and nonfluent speech. No differences were found between content and function words or in consecutive readings of the same passage. Spectrogram analysis showed increased glottal tension, more abrupt onsets and greater intensity of vowels within a stuttered segment. These findings suggest that glottal tension plays a role in the prolongation of phonemes and repetition of segments.

This paper is organized as follows: Section 2.0 presents a historical perspective on stuttering; Section 3.0 outlines the typical characteristics of stutterers' speech; Section 4.0 presents the methodology and results of the experiment and finally Section 5.0 presents the overall conclusions.

2.0 HISTORICAL PERSPECTIVES ON STUTTERING

From Ancient Greek philosophy to modern medicine, stuttering has been examined, discussed, and studied, and yet no firm causes nor cures have been discovered. In 384 B.C., Aristotle theorized that the tongue of the stutterer was too sluggish to keep up with his/her thoughts (Fiedler, 1983). In the Roman Era (4 B.C.) Celsus devised a treatment for these weak tongues. Gargling and massaging the tongue, he thought, would revitalize it, causing the stutterer to speak normally. Moving into the Middle Ages, Mercurialis believed the tongue to be either too wet or too dry, thus the stutterer should be treated accordingly with either blistering substances or gargles. In 1627, the stiff tongue theory was supported when it was noted that during periods of drunkenness, stuttering decreased. It was concluded that alcohol relaxed and loosened the tongue and therefore alleviated stuttering. One of the more horrific treatments for stuttering was developed in 1841. An Austrian surgeon believed the cause to be neurological spasms of the tongue. In order to relieve the stutterer of those spasms, and consequently of stuttering, the nerves of the tongue had to be severed. This technique lasted for approximately ten years before it was finally realized that this procedure was creating worse speech disturbances than the one it was supposed to cure (Hulit, 1985).

Once into the 20th century, the focus of study moved to the central nervous system. Theories revolved around motor centres in the brain sending incorrect messages to the muscles of the tongue or to the respiratory system which controls breathing. In the 20's and 30's, the question of insufficient cerebral dominance arose (Hulit, 1985). Without dominance, neither hemisphere would impose its timing on language production. Thus, the signals from the two hemispheres would not be properly coordinated, causing stuttering. Other theories suggest that stuttering is some other kind of central nervous system disorder such as aphasia or epilepsy. This is no doubt due to the seeming lack of muscular control, erratic breathing, and facial tension that often accompany a stuttered event. During the 1950's, it was suggested that the auditory feedback system of the stutterer was delayed (Fiedler, 1983). Experiments had shown that nonstutterers' speech was impaired when their auditory feedback was artificially delayed, and thus the same feedback delay must happen in stutterers. Other studies suggested the problem originated in the larynx: inappropriate vocal fold vibration and difficulty in controlling air flow. In addition to the physiological theories of stuttering, others have proposed that stuttering is a symptom of a psychological problem: a response to a traumatic experience, or a learned behavior associated with fearof a specific event (Hulit, 1985).

Most recently, researchers have combined physiological, psychological, and neurological approaches, attributing stuttering to "the dynamic interaction and co-ordination of four neural systems" (Nudelman, 1992). Three of those systems involve the muscle groups for respiration, laryngeal activity, and articulation, all of which must be in sync with one another. The fourth system is a complex and intricate "cognitive" system that is comprised of many subsystems. These subsystems are responsible for such things as cognition and other psychological functions which select words from the lexicon and monitor the speech that is produced. A stuttered event occurs when there is a breakdown in the dynamic coordination of these systems (Nudelman, 1992).

Regardless of the multiple domains suggested as the origin of stuttering, there is no one position which can clearly explain the differences among stutterers. Stuttered events vary in the ways and situations in which they are expressed. Obviously, a complex interaction exists between physiological, neurological, and psychological factors. Treatment of stuttering has come a long way since the severing of tongues, and yet the most we can ask for now is that it be controlled by the many therapeutic methods available. And stuttering can only be overcome if the processes and properties involved in stuttered speech are understood.

3.0 CHARACTERISTICS OF STUTTERED SPEECH

One problem that is encountered in researching stuttering is how to qualify a stuttered event, as it is a complex and variable disorder that is hard to delimit. "Most speech-language pathologists regard part-word repetitions and silent or audible prolongations as the essential characteristics of stuttering" (Wingate, 1976). The occurrence of these speech dysfluencies are highly correlated with linguistic stress. Stressed syllables and words demand greater effort from the vocal system than those that are unstressed, and therefore are more likely to be stuttered (Bergmann, 1986). Prins, Hubbard, and Krause (1991) analyzed the various aspects of stress associated with dysfluency by having subjects read a short passage. The properties of the stuttered events were then analyzed and it was found that stuttered events occurred on syllabic stress peaks twice as frequently as on unstressed peaks, more often on polysyllabic words than on monosyllabic words, and more on content words than on function words. Although linguistic stress is highly correlated with occurrences of stuttered events, the segmental speech errors of normal speakers tend to occur at the same locations as stuttered events (Prins, Hubbard, and Krause, 1991). Thus, we have not distinguished stuttering entirely from occurrences of natural dysfluency. Van Riper (1971) provides an analogy to understand the difference between natural dysfluency and stuttering: we all stumble occasionally when we walk, but when it occurs frequently to the point where it inhibits our forward motion, then we would classify it as a "problem" or disorder.

Two features that have been found to differ between stutterers and nonstutterers are rate of speech and frequency of dysfluent utterances. Bakker and Brutten (1990) found that "stutterers exceeded the nonstutterers in the number of stuttering-type dysfluencies, frequency of normal dysfluencies, and the time needed to complete the oral reading". Other physical/acoustical differences exist as well, such as voice onset time (VOT), vowel length, and stress, which will be discussed in turn.

Some prosodic differences do not actually involve a stuttered event, but are found in the fluent speech of stutterers. A study by Prossek and Runyan (1982) involved presenting an audiotape recording of speech samples from stutterers and nonstutterers to a panel of judges whose task was to indicate which utterance was that of a stutterer. The speech samples "contained no instances of overt stuttering, audible respirations, or inappropriate voicing" (Prosek and Runyan, 1982). The judges were accurate in determining which was the stutterers' speech 85% of the time. Measurements of the speech samples were then made. These samples revealed significant differences between the groups for speaking rate (4.3 syllables per second in stutterers' speech compared to 5.2 syllables in nonstutterers speech) and average vowel duration (170.6 ms versus 144.1 ms), but not for average pause duration or number of pauses. Other studies have found stutterers' vowels exceed nonstutterer's vowels by 120-200 ms in duration (Disimoni, 1974).

The quality of the vowel in stuttered speech has also been questioned. The stuttered syllable appears to contain a neutralized vowel. "Almost universally the schwa vowel can be heard in the stutterers' abortive speech attempts" (van Riper, 1971). Two different hypotheses have emerged to explain the occurrence of the schwa-like vowel. Van Riper claims that stutterers produce an "incorrect" vowel in their speech and so discontinue their attempt at finishing the word. They then restart the word and repeat the process until they achieve the correct vowel. On the other hand, Howell and Vause (1985) report that the spectral properties of the stuttered vowel are similar to the following fluent vowel, thus the vowel is being articulated appropriately. It is the short duration of the stuttered vowel which tends to make it sound like schwa (Freeman et al., 1976). Unfortunately, analyses of the vowel in a stuttered event only applies to the speech of a syllable repetition stutterer, and does not account for other types of stuttering such as phoneme blocking: an inaudible prolongation of the onset of a phoneme, or whole word repetitions.

The present study was undertaken to determine if any generalizations could be made about stuttered speech, regardless of the type of stutter produced. Specifically, we wanted to see if spectrogram analyses of stuttered events would provide any insight into the physical and acoustical properties of stuttering. Additionally, we wanted to see if the results found in previous studies of prosodic features of stuttered speech could be duplicated.

4.0 THE EXPERIMENT

4.1 Subjects

Three adult stutterers: two males and one female; and three nonstutterers, matched in age and gender, were tested in this study. The average age of the stutterers was 25.6 years, and 24 years for the nonstutterers. Another male stutterer had been tested but his data had to be discounted. Since English was not his native language, this subject could not perform the required tasks in the same manner as the other subjects. All the stutterers had been diagnosed at some point by a Speech Therapist but only one subject, HP, had been through extensive therapy. Both experimenters were present during the testing. Each subject was recorded on a reel to reel recording device and then portions of their speech were transferred to the KAY Digital Sona-Graph 7800 for spectrogram analysis.

4.2 Procedure

The experiment was divided into three sections so that various aspects of stuttered speech could be analyzed. The first task involved reading a short nonsense passage, adapted from

Shakespeare's "A Midsummer Night's Dream" (Appendix A). The passage contained twenty-nine words and forty-one syllables. The subjects were asked to read it three times to test the hypothesis that as familiarity increased, rate of stuttering would decrease. Between each reading, the subjects were asked to read aloud one word list. The first list consisted of forty monosyllabic words (Appendix B). The words were carefully selected so that the voiced and voiceless counterparts of each place of articulation were represented. The consonants used were [p,b,f,v,t,d,t,č,ǰ,k,g] and each was positioned in front of four different vowels [i,e,u,o]. The second list (Appendix C), contained twenty polysyllabic words, consisting of either two or three syllables. The initial consonants of these words included the ones mentioned above in addition to nasals, vowels, and the remaining fricatives. The vowel following the consonant was not controlled. The important aspect of this list was the position of stress in the word. Thirteen of the twenty words were stressed on the first syllable. The final portion of the experiment involved a free speech component. The subjects were asked to talk spontaneously for two or three minutes. The first 150 words for each subject were used in the analysis.

Once the testing had been completed, the tapes were analyzed. The stuttered events from each section were recorded by each experimenter. All phoneme prolongations, silent or audible, and repetitions, whole words or syllables, were considered stuttered events. Whole words were considered stuttered, as opposed to natural thinking repetitions, when an obvious struggle occurred with the word. There were audible features associated with these struggles which will be discussed later in this paper. The results from the two experimenters were then compared. If there were any disagreements, the tape was reanalyzed until a consensus was reached.

4.3 Results

4.3.1 Passage Reading, Word Lists, and Free Speech Tasks

The results obtained from the analysis of the passage and word reading tasks for the stuttered events did not concur with all of the previous research. The passage reading task did not show conclusively that consecutive readings result in adaptation: a "decline in stuttering frequency that accompanies consecutive oral readings of the same material" (Prins and Hubbard, 1990). As shown in Table 1, only subject SC improved over the three trials. DM and HP remained constant, with HP recording no episodes of stuttering in any of the trials.

PASSAGE REPETITIONS	SUBJECT SC	DM	HP
1	4	2	0
2	1	2	0
3	1	1	0

TABLE 1: The number of words stuttered (out of a total of twenty-nine words) by each stutterer on the three consecutive readings of the same passage.

This data was inconsistent with previous research that found stuttering declined with consecutive readings. Prins and Hubbard (1990) had subjects read a passage five times. There was a reduction of about 50% in stuttering frequency from the first to the fifth reading. Though our subjects show a 50% improvement, the numbers are not significant enough to show that adaptation occurs.

The passage readings do show that the stutterer's speech is longer in duration than nonstutterers, which is what we expect to find. The average duration of the passage was 12.4 seconds for the stutter group and 10.3 seconds for the controls: a difference of 2.1 seconds. SC's first reading was not included in the averaging as her four episodes of stuttering would skew the results. The rest of the stuttered events would not independently cause such a difference in duration. It should be noted that although the controls did not register any stutters, normal periods of dysfluency, such as pauses, did occur.

The word lists were used to see if stuttering rates corresponded with the initial segment of the word or the following vowel, or if it was affected by the number of syllables in the word. The results are shown in Table 2.

	SC	DM	HP
WORDLIST 1: /40	13, 33%	0	\
WORDLIST 2: /20	6, 30%	2, 10%	\

TABLE 2: The number and percentage of words stuttered on the monosyllabic and polysyllabic wordlists, respectively.

Again no generalizations can be made about rate of dysfluency or types of segments stuttered from the data obtained in this exercise. Subject SC stuttered on one third of the words in both lists whereas DM stuttered only twice on the polysyllabic words. Perhaps the idiosyncrasies of our subjects, i.e. level of nervousness and the types of activities they are comfortable doing, can account for these differences. Both this test and the previous one show that SC's and DM's stutters occur on a variety of segments, and thus no conclusions can be made about the type of segments more frequently stuttered. All the stutters that occurred on the polysyllabic words occurred on the first syllable, which was also stressed. This supports previous research which shows an increased rate of stuttering on stress peaks. The data obtained from HP was not used as he has been through extensive therapy and can apply techniques to control his stuttering, especially on a reading task. On his first repetition of the lists he did not stutter at all. But when he indicated that he could "turn off" the techniques he had learned, and then repeated the lists, he stuttered on all the words. Thus it is not felt that analysis of the prosodic features of his stuttered speech would adequately reflect the patterns of a "normal" stutterer.

The free speech component of this experiment provided interesting data with which to compare previous research. The data collected from the stutterers' free speech is shown in Table

FREE SPEECH	SC	DM	HP
# OF WORDS STRD	14	12	14
TOTAL # OF WORDS	150, 9.3%	150, 8%	150, 9.3%
# OF POLY WORDS STRD	3	5	5
TOTAL # OF POLY WORDS	20, 15%	23, 22%	33, 15.2%
# OF MONO WORDS STRD	11	7	9
TOTAL # OF MONO WORDS	130, 8.5%	127, 5.5%	117, 7.7%
# OF CONTENT WORDS STRD	8	6	7
TOTAL # OF WORDS STRD	14, 57%	12, 50%	14, 50%
# OF FUNCTION WORDS STRD	6	6	7
TOTAL # OF WORDS STRD	14, 43%	12, 50%	14, 50%

TABLE 3: The number of words stuttered on different types of words, and the percentage associated with these numbers.
(STRD=stuttered,POLY=polysyllabic,MONO=monosyllabic)

The percentage of words stuttered supports previous research which found the frequency of stuttering ranged "from 2% to 23% of words spoken, with a mean of 8.3% stuttering" (Healy and Ramig, 1986). The data found for polysyllabic and monosyllabic words reinforces studies that show polysyllabic words are more likely to be stuttered than are monosyllabic words. An average of 17.4% of the total number of polysyllabic words in the subjects' free speech were stuttered, whereas only 7.2% of stutters occured on monosyllabic words. A major difference found in this experiment and others is in the occurrence of stuttering on content and function words. These subjects demonstrated an even distribution of stuttering on content and function words, whereas Prins, Hubbard, and Krause, 1991, found that content words were twice as likely as function to be stuttered.

4.3.2 *Spectogram Analysis*

Stuttering has been described as speech that is "interrupted by a motorically disrupted sound" (Perkins, 1990). Therefore, stuttering must be looked at from a perspective which can exemplify the motor and acoustic properties of dysfluent speech. By analyzing a spectrogram, one can compare a fluent and non-fluent segment, and easily decipher one from the other. Stuttered speech is characterized by certain acoustic properties. Some of these features are: a sharp increase in articulatory power, constriction of the glottis, and an increase in length of closure before the release of the segment. Each of these will be discussed in the spectogram analysis.

We propose to distinguish the onset of a stuttered segment from a nonstuttered segment by introducing the terms 'gentle onset' and 'abrupt onset'. Characteristics of an 'abrupt onset' are: a long closure before the onset of the segment that acts as a block, increased intensity of the vowel formants following the stuttered event, and increased aspiration following a voiceless stop and short bursts of scattered energy following the release of voiced stops. These three characteristics are dynamically dependent on one another. The release of the segment exerts a powerful energy burst which causes an increase in intensity throughout the syllable in which the stuttered event occurs. The power is exemplified by the amplitude marker on the spectrogram and the dark vowel formants following the stuttered event. The formant which seems to be most affected is the second formant in the spectrogram. This second formant is generally believed to be associated with the natural mode of vibration of the air in the mouth in front of the highest point of the tongue (Rogers 1991). It is speculated that when the air is released after a long glottal closure, the pressure of the air is forced through the oral cavity at a rapid pace, illustrated by dark second formants on our spectrograms. Unfortunately, recent theories believe that the vocal tract vibrates as a whole system and it is impossible to treat the throat and mouth cavities as independent (Ladefoged, 1962). Thus, further conclusions regarding F_2 require more intense study that are beyond the scope of this paper.

'Gentle onsets' are what we find in most fluent speech. Gentle onsets are characterized by a constant intensity in the vowel formants and a constant airflow through the production of a sound.

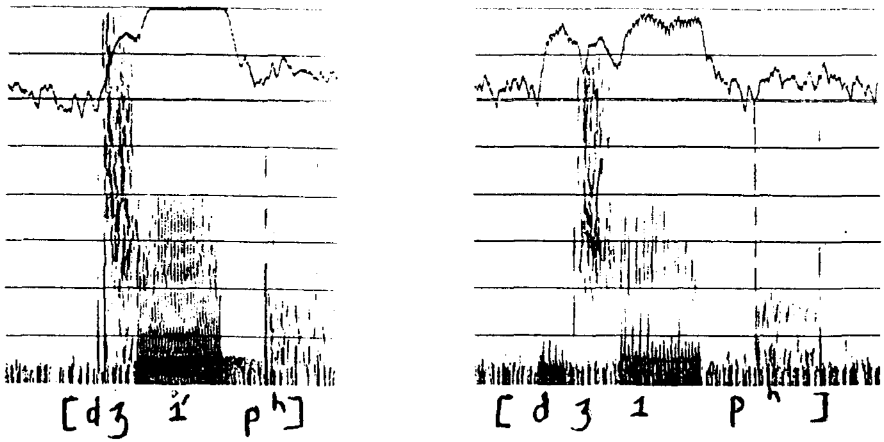

FIGURE 1: a) "abrupt onset" of dysfluent affricate in first segment of the word "jeep"
b) "gentle onset" of fluent affricate in the first segment of the word "jeep" spoken by subject HP.

Figure 1 demonstrates the distinction between 'gentle onset' and 'abrupt onset'. The dysfluent onset of 1a) is marked by an abrupt release, while the fluent release of the segment in 1b) shows a 'gentle onset'.

Glottal tension and constriction are characteristic of stuttered speech. The tension and constriction of the glottis is manifested in the spectrograms by the increased distance between the glottal pulses. Glottal tension can be demonstrated by the alteration in the glottal pulses of fluent and dysfluent speech. In fluent speech the glottal pulses are evenly distributed, whereas in dysfluent speech the glottal pulses are irregular and the distance between them is longer than in fluent speech. Each individual glottal pulse is also wider. Furthermore, we hypothesize that this constriction prevents the production of a sound or word from being completed and therefore, the word or syllable is attempted again. To summarize, the two properties of stuttered speech that are apparent in the analysis of the spectrograms are glottal constriction and the differing types of onsets: 'gentle' and 'abrupt'.

Two different types of stuttering occur in human speech: repetitions, which are either repetition of a syllable or of a word, and prolongations which are either audible or silent (Wingate 1976). The silent prolongations are also referred to as "blocks". These "blocks coincide to the momentary occlusion of the airway" (van Riper, 1971). This closure may occur at the level of the vocal cords or within the mouth. In order to emit the air, the stutterer compresses his or her abdomen and forces the air to overcome the blockade (van Riper 1971). This explains the abrupt onset demonstrated in the release of stuttered events, described as "blocks".

The following analysis of the spectograms will be concerned with the two subtypes and the four manifestations of stuttering.

SONORANTS Our data concluded that dysfluent vowels are found only in word initial position. Moreover, they also shared another feature with one another: all stuttered vowels were silent prolongations. These silent prolongations were manifested in long pauses preceding the abrupt onset of the vowel. The sudden burst of energy released by the onset of the vowel caused the formants of the vowel to be more intense when compared to the other vowels in the word or phrase that followed the stuttered event. The sonorants were also characterized by glottal tension in some instances. In Figure 2, glottal tension was found after the first attempt on the initial syllable. The syllable was then re-attempted. This is consistent with our glottal tension hypothesis which states that glottal constriction enables the speaker to complete the word. Therefore, the articulation must be attempted again.

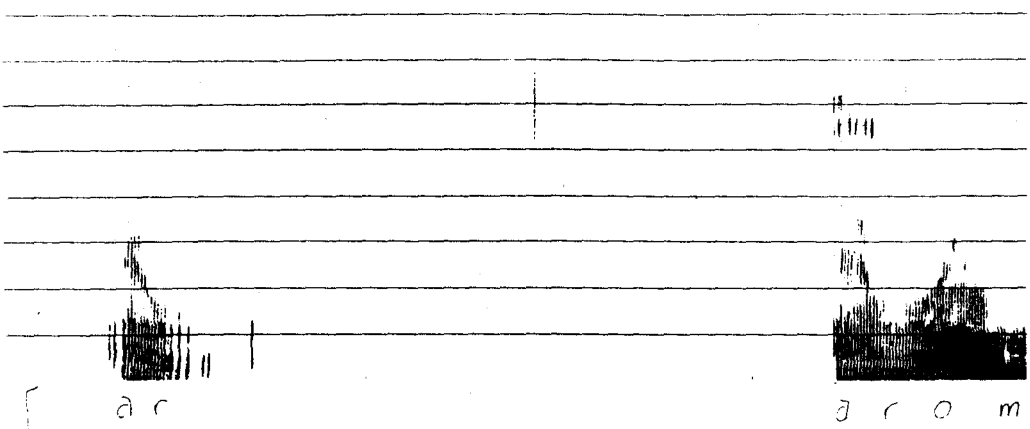

FIGURE 2:. "Aroma". Syllable repetition of two sonorants.

As stated above, the repetition in Figure 2 is characterized by glottal tension manifested in increased distance between the individual glottal pulses. Glottal tension forces the syllable to be re-attempted.

A marked difference was found in the length of dysfluent nasals. Release of dysfluent nasals are preceded by a long voicing bar. The dysfluent nasal stop is comparatively longer than the fluent nasal stop of both the person who stutters and the person who does not stutter.

OBSTRUENTS The class of obstruents includes fricatives, affricates, and oral stops. Each of these subclasses were represented in our dysfluent data. Voiced and voiceless counterparts of each subclass were also represented with one exception: voiced fricatives were not stuttered on.

Stuttered events concerning fricatives would be generally classified as audible prolongations. This infers that the fricative is held for a longer than normal duration. Figure 3. shows an audible prolongation that is attempted twice, therefore, it has both the features of the two types of stuttering. The two attempts at the phoneme are different; the first attempt has scattered activity concentrated at approximately 4000 to 7000 Hz, and the second attempt has activity throughout the spectrogram (1000 to 8000 Hz). Van Riper (1971) stated that a person who stutters formulates the lip posture of a schwa when a stuttered event occurs. This produces a neutral, isolated /s/ instead of the allophonic /s/ dependent on the following vowel in the word. This appears to account for the first prolongation on the spectrogram. The second attempt has a concentration of activity where the formants of the following vowel occur.

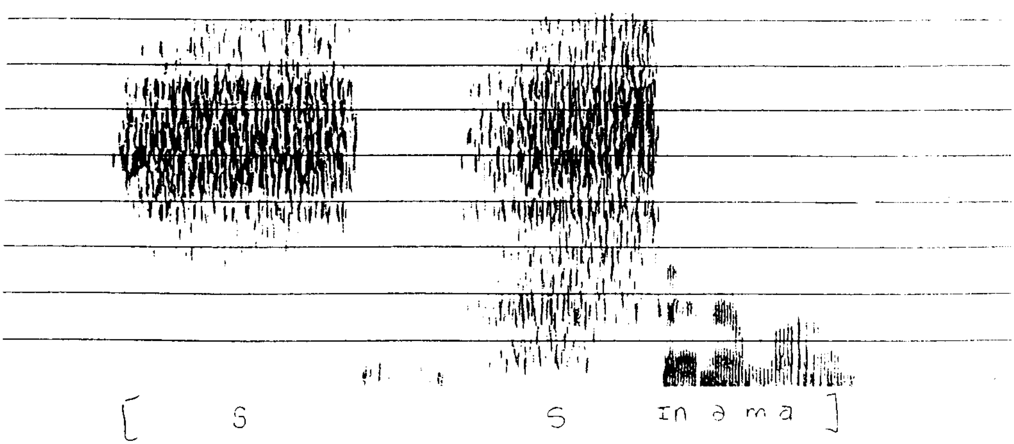

FIGURE 3:. Audible prolongation and repetition of the phoneme /s/ in the initial segment of the word "cinema"

Duration is the most prevalent aspect of stuttered fricatives. Dysfluent fricatives are approximately two to three times longer than fluent fricatives. Duration is an accepted indicator of the severity of this speech disorder. Thus, the longer the duration, the more severe the disorder.

Our data concerning voiced oral stops is congruent with our hypothesis stated earlier that there is increased glottal tension at stuttered events. Oral stops can be characterized within the two subtypes of stuttered events: they are either manifested as audible or inaudible prolongations, or phoneme repetitions. Inaudible prolongations are shown to have a long closure period before the onset of the oral stop. Moreover, when this long closure is released, it produces an abrupt onset of the consonant, causing increased intensity in the vowels of the syllable containing the stuttered event. Audible prolongations are exhibited in the spectrogram by a prolonged voicing bar before the release of the oral stop. This indicates a negative voice onset time (VOT). The long voicing bar also displays glottal tension. Glottal tension, a short period of voicing characterized by extreme vocal fold tension, is demonstrated by 'he individual glottal pulses above the voicing bar. Figure 4 shows a prolonged voicing bar before the release of the phoneme /g/. contrasted with a fluent reading of the same word.

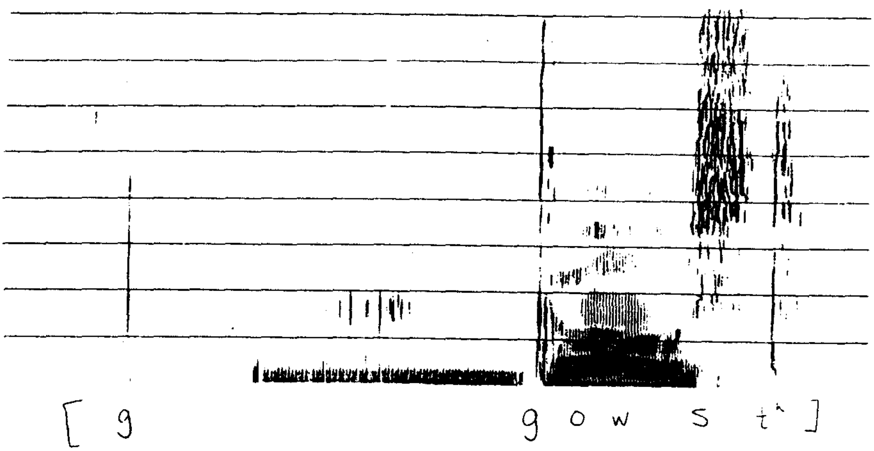

FIGURE 4: a) Audible prolongation demonstrated by long voicing bar before onset of oral stop /g/ in the word "ghost". Glottal constriction is manifested above the voicing bar.
b) Fluent reading of the word "ghost".

5.0 CONCLUSION

This study was undertaken to look at the linguistic realization of stuttered events (i.e. stress placement, within a sentence and within a word, monosyllabic versus polysyllabic words, and individual phonemes), and the physical properties involved, as determined by spectrogram analysis. Our results did not show any correlation between the occurrence of stuttering and linguistic stress. Analysis of phonemes within the spectrograms shows that glottal tension is involved in stuttered speech. The differences found between nonfluent and fluent speech are: 'abrupt onset', dark second formants (in vowels), and prolongation of the sound (in fricatives). Due to equipment limitations, a small sample, and time restrictions, we were not able to investigate these findings in depth, nor can we draw any firm conclusions. But further research in time may prove our data significant.

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APPENDIX A

PASSAGE

Be kind and courteous to this gentleman
hop in his walks and gamble in his eyes,
feed him with apricots and dewberries,
with purple grapes, sour figs, and mulberries

APPENDIX B

WORDLIST 1

1. feed
2. bait
3. pooch
4. June
5. phone
6. tail
7. poke
8. toot
9. jeep
10. boat
11. choose
12. keep
13. pace
14. fame
15. goop
16. beat
17. tease
18. dopt
19. voom
20. vain
21. cheap
22. gate
23. ghost
24. coop
25. veep
26. vote
27. douche
28. peace
29. case
30. boot
31. choose
32. taupe
33. deep
34. Jake
35. chain
36. joke
37. food
38. geek
39. coast
40. date

APPENDIX C

<u>WORDLIST 2</u>

1. pizza
2. pizzazz
3. suppose
4. cabinet
5. cinema
6. aroma
7. maintain
8. charity
9. super
10. velocity
11. fundamental
12. xanadu
13. difficult
14. negative
15. superior
16. judgment
17. testament
18. zombie
19. beaker
20. bountiful