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The Effects of Auditory Feedback on Articulation in Normal Speakers and Speakers Who Stutter

by

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ABSTRACT

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Five CVC words in a carrier phrase were read by five stutterers and five nonstutterers under six conditions: (1) no alteration in auditory feedback; (2) frequency altered feedback one-half octave lower; (3) frequency altered feedback one-half octave higher; (4) delayed auditory feedback of 50 ms.; (5) 85 dB pink noise; and (6) self-monitoring under noise. Under the control condition, stutterers had longer phrase, voicing, and movement durations, and lower peak velocity than the normal speakers. The variability of duration, distance, displacement, and peak velocity was higher among the stutterers than nonstutterers. The stutterers had less horizontal differentiation between /s/ and /ʃ/ than the nonstutterers. Tongue position was lower for the consonants and higher for the vowels among the stutterers. Under the experimental conditions, both groups increased acoustic and movement duration, decreased peak velocity, and positioned vowels and consonants higher. The variability of movement duration increased in both groups, while the variability of displacement and peak velocity decreased in both groups, However, except for horizontal position of /s, ʃ/, the variability of the stutterers remained higher than that of the normal speakers for all variables under all conditions. Changes were more consistent within subjects than within conditions.

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DEDICATION

This dissertation is dedicated to all who stutter, and especially to those who graciously volunteered to participate in this study.

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CHAPTER ONE

INTRODUCTION

1.1. STATEMENT OF THE PROBLEM

Alterations in auditory feedback, such as delayed auditory feedback, frequency altered feedback, and masking noise, improve the fluency of people who stutter, at least temporarily. Delayed auditory feedback is the return of the speech signal to the speaker's ears after a delay of 50 to 250 milliseconds. Frequency altered feedback is the increase or decrease, by as much as an octave, of all the frequencies in the signal, without changing the temporal characteristics of the signal. Masking noise is broadband noise which prevents the speaker from hearing his own speech.

Although we know that these types of feedback effectively improve fluency in speakers who stutter, we do not understand specifically what speech production changes occur as a result of changes in auditory feedback. Up to the present time, due to a lack of suitable technology, there have been few studies of the effects of auditory feedback on articulation. In order to understand the nature of stuttering and to improve therapeutic intervention, it is important to understand in detail what effect various types of fluency enhancing auditory feedback have on the speech of people who stutter.

For example, if it were found that auditory feedback tends to produce the same effects on speech production as behavioral stuttering therapy, that would provide increased support for supposing that these behaviors contribute to fluency. However, if it were found that auditory feedback produces different effects than behavioral stuttering therapy, then it would appear that there are a variety of ways to increase fluency. This study extended previous work in three ways. First, previous studies of articulatory movement primarily used optical tracking devices to record lip and jaw movement. The use of the recently developed electromagnetic articulometer enabled measurement of movement and position of the tongue as well as the lip and jaw (Ackermann, Grone, Hoch, & Schonle, 1993; Hoole, Nguyen-Trong, & Hardcastle, 1993; Perkell, Matthies, Svirsky, & Jordan, 1993; Matthies, Svirsky, Perkell, & Lane, 1996; Horn, Goz, Bacher, Mullauer, Kretschmer, & Axmann-Kremar, 1997; Recasens & Romero, 1997). Second, the effects of auditory feedback were examined in speakers who stutter as well as in normal speakers. Third, previous studies examined the effects of only delayed auditory feedback on articulation. In this study, three different types of fluency enhancing auditory feedback were compared for similarities in their effects on articulatory movement and positioning.

This study asks two questions: (1) Is the fluent articulation of people who stutter different from that of normal speakers when there is no alteration in auditory feedback? (2) Does fluency enhancing auditory feedback alter the articulation of normal speakers and speakers who stutter, and if so, in what way?

1.2 REVIEW OF THE LITERATURE

1.2.1. Characteristics of Stuttered Speech

Early researchers assumed that the fluent speech of speakers who stutter was similar to that of nonstutterers. However, Love and Jeffress (1971) first found evidence that the fluent speech of stutterers was different from that of normal speakers, when they identified a significantly larger number of brief pauses in the speech of the speakers who stutter. Since that time, a number of studies have examined characteristics of the fluent speech of speakers who stutter. Most of these studies found that the fluent speech of speakers who stutter differs from that of normal speakers in a variety of ways.

1.2.1.1. Acoustic Duration

Di Simoni (1974) reported that six stutterers had longer acoustic durations than normal speakers for vowels in CVC syllables and /s/ in VsV syllables in a carrier phrase. In addition, he found that stutterers had greater intrasubject variance in vowel duration than normal speakers.

Hillman and Gilbert (1977) found that the average speaking rate during a reading of the Rainbow Passage was slower in ten moderate-severe stutterers than in ten nonstutterers. The stutterers also had longer voice onset times for unvoiced stops. Adams (1987) found that five preschool stutterers had longer segment durations and longer voice onset times during the production of single words than matched normal preschool speakers.

1.2.1.2. Duration of Phonation

Colcord and Adams (1979) measured the duration of voicing during the reading of a passage by eight speakers who stutter and eight normal speakers who were age and gender matched. The stutterers had a longer voicing duration and a higher standard deviation of voicing duration than the normal speakers.

Janssen and Wieneke (1991) measured the variability of the duration of phonation recorded by electroglottography. Nineteen stutterers and twenty normal speakers read ten repetitions of a sentence under each of five conditions: normal oral reading (control condition), chorus reading, metronome set at 100 beats per minute, delayed auditory feedback of 200 milliseconds, and masking noise generated by an Edinburgh Masker. Under the control condition, the stutterers were significantly more variable in phonation duration than the normal speakers. However, variability of the two groups did not differ significantly under any of the fluency enhancing conditions. Relative to their performance under the control condition, the normal speakers were significantly more variable under all the fluency enhancing conditions. The stutterers were significantly more variable under delayed auditory feedback, and significantly less variable under the choral reading and metronome conditions.

Jancke (1994) also examined duration as well as variability of phonation in 18 speakers who stutter and 16 normal speakers who spoke 100 repetitions of the nonsense words /papapas, tatatas, kakakas/. Contrary to the findings of other researchers, Jancke found no differences between the two groups in means or standard deviations of duration of phonation or voice onset time. However, the "mean intraindividual variation" (100* standard deviation/mean), was significantly greater among the stutterers than the normal speakers for phonation duration for the initial syllable, and for voice onset time for all three syllables.

Boutsen (1995) compared voice onset time of the first /t/ in stressed and unstressed productions of the syllable "stat" in 12 speakers who stutter and 12 normal speakers. The stutterers had longer voice onset times than the normal speakers, and in both groups, voice onset time was longer in the unstressed stressed syllables than in the stressed syllables.

Peters and Boves (1988) examined voicing duration in 1125 mono- and polysyllabic words uttered by 10 stutterers and 7 normal speakers. First syllable duration and average syllable duration were only insignificantly longer in speakers who stuttered and normal speakers.

In summary, most studies found that speaking rate is slower in stutterers than nonstutterers. However, there are conflicting results as to whether speakers who stutter vary from normal speakers in duration and standard deviation of voicing. One reason for the lack of consistency may be the type of stimuli used. A large number of repetitions of a small number of nonsense words may normalize duration and variability in speakers who stutter.

1.2.1.3. Articulatory Positioning

Spatial measures have also been found to differ in speakers who stutter from normal speakers. Klich and May (1982) examined formant frequencies in seven stutterers who read sentences and produced the words /hid, hæd, hud/. From the sentences, measurements were made from spectrograms of fluently produced words that contained the vowels /ɪ, æ, u/ between plosives or fricatives. A total of 25 to 33 utterances under each condition were analyzed. The F1 and F2 formants of the stutterers were more centralized than the averages reported in the literature for normal speakers, although within normal range.

However, Blomgren, Robb, and Chen (1998) did not obtain consistent results from spectrographic analysis of CVt monosyllables uttered by three groups of speakers: five stutterers who had recently completed a course of fluency shaping therapy; five stutterers who had not received therapy within the past five years; and five normal speakers. Only the formants for /i/ in C+/it/ were more centralized among the untreated stutterers than the other two groups.

In an electropalatographic study, Wood (1995) compared production of alveolar plosives and fricatives in three speakers who stutter and one normal speaker during reading of sentences and paragraphs, and during free conversation. He found that the speakers who stutter made greater lingua-palatal contact for alveolar plosives and less contact for alveolar fricatives than the normal speakers. He also found greater intrasubject variability in alveolar contacts among the stutterers than the normal speakers. Occasional abnormal articulatory gestures were also noted in the stuttering speakers. Successive repetitions of sentences showed more variability of contact patterns within the stuttering speakers than in the normal speaker.

Thus, for spatial measures, the speakers who stutter have articulation that is perceptually similar to that of normal speakers; however, there is some evidence of greater variability, and that vowels may be more centralized than in the normal speakers.

1.2.1.4. Articulatory Movement

Up to the present time, there have been relatively few studies that examined articulatory movement in the fluent speech of speakers who stutter. Duration, displacement, and peak velocity are three variables that have been most often described.

Zimmerman (1980) measured lip and jaw movements during three CVC syllables, /mɑm, bɑb, pɑp/, each of which were repeated ten times in a row, by seven normal speakers and six adult stutterers. Utterances that were dysfluent, or immediately followed a dysfluent utterance, or which showed "aberrant" movement patterns were not included in the analysis. The stutterers had longer vowel opening and transition movement durations, smaller displacements, and lower peak velocities than the normal speakers. In addition, the speakers who stutter had larger variances for most of the duration measures.

Similarly, Jancke, Bauer, Kaiser, and Kalveram (1997) measured jaw movement during production of the nonsense word /papapas/ by twelve speakers who stutter and twelve normal speakers. The speakers who stutter had longer jaw movement durations, smaller maximum jaw displacements, and lower peak velocities than the normal speakers.

Ward (1997) examined upper lip, lower lip, and jaw movement in the nonsense words /pɑpɑp, paɪpaɪp/ produced in a carrier phrase by five stutterers and five nonstutterers. The speakers who stutter had greater variability in mean phase angle of lip and jaw closure than the normal speakers. The variability of the stutterers increased on stressed syllables and at a fast rate, while the variability of the normal speakers remained unchanged.

In summary, most previous studies have found that speakers who stutter differ significantly from normal speakers in the fluent production of single words. The stutterers tend to have longer movement duration, decreased displacement, lower peak velocity, and greater variability.

1.2.1.5. Effects of Therapeutic Intervention

McClean, Kroll, and Loftus (1990) studied upper lip, lower lip, and jaw movement during the closing movement for /p/ in fluent productions of "sapapple" in three groups: eight stutterers who had recently completed a course of therapy; ten stutterers who had not had therapy in the previous three years, and ten nonstutterers. Fifteen movement variables were examined, including duration of movement, displacement, peak velocity, and relative timing patterns for the three articulators. No differences were found between the normal speakers and the stutterers who had not recently received therapy. Four of the fifteen measures were significantly longer in the stutterers who had recently completed therapy than in the other two groups. The measures that reached significance were duration of jaw movement, and duration from the onset of the initial /æ/ in the acoustic signal to the peak velocity of upper lip, lower lip, and jaw movement. McClean et al. concluded that differences between the speech of stutterers and nonstutterers were due to therapy, not to the underlying fluency disorder.

Interestingly, McClean, Levandowski, and Cord (1994) found that subjects who were more dysfluent had less variability in movement durations than subjects with fewer dysfluencies. They examined lip and jaw movement in 15 stutterers who had recently completed a course of behavioral therapy, and 16 stutterers who had a history of little or no treatment. The subjects produced a variety of words in a carrier phrase. Subjects who had received therapy and were highly dysfluent were more variable in movement durations than the low dysfluency speakers. Remarkably, the subjects who had not received therapy and were highly dysfluent were less variable in movement durations than the low dysfluency speakers. McClean et al. suggested that highly unstable systems may be less variable than more stable systems.

In a study of 17 stutterers, none of whom had received speech therapy in the past three years, McClean, Kroll, and Loftus (1991) measured upper lip, lower lip, and jaw movement in fluent productions of "sapapple". There was a positive correlation between stuttering severity and upper and lower lip duration, and a negative correlation between stuttering severity and average peak velocity.

Articulatory duration, displacement and peak velocity of the upper lip, lower lip and jaw were measured in three speakers who stutter before and after participation in a Precision Fluency Shaping type program (Story, 1994; Story, Alfonso, & Harris, 1996). After completion of therapy, all three of the stuttering subjects had longer movement durations, decreased displacement and decreased peak velocity for lower lip and jaw movements.

Kalinowski (1994) examined on upper lip, lower lip and jaw movement in the fluent utterances of four speakers who stutter before and after treatment by Van Riperian type therapy. Duration did not change consistently in these speakers: after completion of therapy, one speaker spoke more slowly, one spoke more quickly, and two had speech rates that were unchanged. Three of the four speakers had reduced displacement and decreased peak velocity after treatment.

In summary, there is a tendency for fluency treatment to decrease speech rate. Displacement and peak velocity were either decreased or unchanged by the various forms of therapy.

1.2.2. Auditory Feedback

During speech, the brain receives acoustic, kinesthetic, and tactile feedback. In 1950, Lee observed that recording engineers had difficulty speaking fluently when listening to delayed tape recorder playback. It was discovered that a delay of about 200 milliseconds causes repetitions in the speech of normal speakers (Lee, 1950; Atkinson, 1953; Black, 1955; Fairbanks, 1955; Tiffany & Hanley, 1956; Butler & Galloway, 1957).

Interest in the relationship between stuttering and the auditory system began when Backus (1938) and Albright and Malone (1942) documented that deaf and hard of hearing children were less likely to stutter than normally hearing children.

Since then, three very different types of types of auditory feedback, delayed auditory feedback, frequency altered feedback and noise, have been studied in both normal speakers and people who stutter. Delayed auditory feedback results a disparity in the time of arrival of the acoustic signal with regard to the time of arrival of the kinesthetic and tactile signals. Frequency altered feedback creates a disparity between the expected frequencies of harmonics and formants, and those which are actually heard. Noise masks all auditory feedback, both air conducted and bone conducted, to the speaker.

1.2.2.1. Delayed Auditory Feedback

More research has been done on delayed auditory feedback than on other types of auditory feedback. Delays in auditory feedback in the range of 50 to 200 milliseconds are effective in increasing fluency in people who stutter (Soderberg, 1959;

Chase, Harvey, Standfast, Rapin, & Sutton, 1961; Lotzman, 1961; Webster, Schumacher, & Lubker, 1970, Burke, 1975a, 1975b; Sark, Kalinowski, Armson, & Stuart, 1993; Kalinowski, Stuart, Sark, & Armson, 1996). The intensity of presentation of delayed auditory feedback affects the degree of fluency achieved: higher intensities are more effective than lower intensities (Gibney, 1973).

Delayed auditory feedback slows speech rate. Most researchers have found that delays of 180-200 milliseconds produced the most profound changes in speaking rate (Black, 1951; Fairbanks, 1955; Howell & Archer, 1984). However, delayed auditory feedback does not affect all portions of the speech signal to the same degree. Spilka (1954) found that in normal subjects increases in syllable duration were primarily due to increases in phonation time. In contrast, Lechner (1979) found that, although under delayed auditory feedback the duration of phonation increased in both stutterers and normal speakers, the percentage of vocalized time did not increase significantly in either group. The intensity of the delayed auditory feedback signal affects the speech rate. Intensity interacts with delay time: the more intense the feedback, the slower the rate of speech at a given delay (Howell, Powell, & Khan, 1983; Howell & Archer, 1984).

Relatively few studies have focused on the articulatory effects of delayed auditory feedback. Sussman and Smith (1971) examined the effect in normal speakers of delays in auditory feedback of 0, 100, 200, 300, and 400 milliseconds on jaw movement during production of the phrase "That's a pVp a month." Vowels of three different heights were used. Jaw movement distance, duration, and velocity were examined. Duration of jaw movement was longest at 100 ms. delays, and shorter at longer delays; however, jaw velocity was not significantly affected by delayed auditory feedback. Jaw opening overshoot for the target vowel was noted at the 300-millisecond delay.

1.2.2.2. Frequency Altered Feedback

Raising or lowering the frequency of the signal by one half octave or one octave are all equally effective in enhancing fluency (Howell, El-Yaniv, & Powell, 1991; Hargrave, Kalinowski, Stuart, Armson, & Jones, 1994; Kalinowski, Armson, Roland-Mieszkowski, Stuart, & Gracco, 1993; Armson, Foote, Witt, Kalinowski, & Stuart, 1997; Zimmerman, Kalinowski, Stuart, & Rastatter, 1997). Recently, frequency altered feedback has been shown to improve fluency as much as delayed auditory feedback (Howell et al., 1991; Kalinowski et al., 1993; Hargrave et al., 1994).

To date one study has examined the effects of frequency altered feedback on formant frequencies, and two studies have examined the effects of alterations in feedback frequency on phonation.

Houde and Jordan (1998) altered formant frequencies returned to normal speakers who whispered single words. The whispering task was chosen to avoid bone conduction feedback. The speakers altered their formant frequencies in the direction opposite to the manipulations of the formant frequencies; that is, they compensated for the shifts in formant frequencies in order to stabilize the feedback that they received. This compensation carried over from training words to test words.

Howell (1990) studied the effect on intensity of phonation of frequency altered feedback which lowered all frequencies by one octave. Twelve stutterers and twelve nonstutterers read words from a phonemically balanced word list embedded in a carrier phrase. The effects were compared to those from speech amplification, noise, and delayed auditory feedback of 100 milliseconds. Subjects responded to frequency altered feedback and to speech amplification by decreasing vocal intensity; in contrast, they responded to delayed auditory feedback and noise with increased vocal intensity.

The second study examined the effects of perturbation of fundamental frequency information on phonation. Normal speakers were asked to match a 200-Hertz tone. Auditory feedback was increased or decreased by 2, 3, 5, and 7.3 Hertz. Speakers altered their fundamental frequency in the direction opposite to the perturbation, so that the perceived auditory feedback was restored to match the tone (Kawahara, 1994). Both this study and the previous study by Howell (1990) found that speakers responded to frequency altered feedback in the same way as they did to changes in their own speech. In contrast, Howell (1990) found that speakers responded to delayed auditory feedback as they did to noise.

1.2.2.3. Noise

Noise masking also improves fluency (Cherry & Sayers, 1956; May & Hackwood, 1968; Webster & Lubker, 1968; Barr & Carmel, 1969; Conture, 1974; Conture & Brayton, 1975; Garber & Martin, 1977; Brayton & Conture, 1978, Martin & Haroldson, 1979; Andrews, Howie, Dozsa, & Guitar, 1982; Howell, Powell, & Khan, 1991; Webster, 1991; Kalinowski, Armson, Roland-Mieszkowski, Stuart, & Gracco, 1993). Several factors influencing the effectiveness of noise masking have been studied. Higher intensities of noise are more effective at improving fluency than lower intensities (Maraist & Hutton, 1957; Adams & Hutchinson, 1974; Conture, 1974; Martin, Siegel, Johnson, & Haroldson, 1984). Over longer periods (100 minutes), Garber & Martin (1974) found that stutterers varied in their responsiveness to noise (see also Ingham, Southwood, & Horsburgh, 1981).

In normal speakers speech rate is slower and syllable duration increases under noise (Hanley & Steer, 1949; Winchester & Gibbons, 1958; Van Summers, Pisoni, Bernacki, Pedlow, & Stokes, 1988). Interestingly, the speech rate of stutterers is not slower under masking noise (Adams & Hutchinson, 1974; Conture, 1974; Garber & Martin, 1977). However, these researchers did not distinguish whether the faster speech rate of the subjects who stuttered was actually due to shorter syllable durations or due to decreased dysfluencies. There have been no studies of the effect of noise masking on articulatory movement.

1.2.2.4. Self-Monitoring Under Noise

Only one previous study examined self-monitoring, in order to disambiguate the effects of noise and vocal intensity on fluency of speakers who stutter. Garber and Martin (1977) had four conditions: speaking in quiet at a normal vocal level, speaking in quiet at 12 dB above normal, speaking under 100 dB masking noise at a normal vocal level, and speaking under 100 dB masking noise at 12 dB above normal. The masking noise decreased stuttering, regardless of the subject's vocal intensity. Vocal intensity had no effect on stuttering frequency.

1.2.3. Theories of stuttering

All movements involve sensorimotor integration. One theory of stuttering is that stuttering is a disorder of motor control. Sensory perception and processing is normal in people who stutter, and stuttering results directly from a disorder in motor control only. A contrasting theory is that stuttering results from a disorder in the processing of auditory feedback. People who stutter have a normal motor control system that is responding to perturbations that arise from disordered processing of the stutterer's own speech. The difficulty in disambiguating these two positions arises from the intimate connection between perception and motor control. Those who believe that stuttering is a disorder of motor control point out in support of their position that intentionally and directly altering speech production directly improves fluency, for example, slowed speech (Perkins, Bell, Johnson, & Stocks, 1979), prolonged phonation time (Wingate, 1969), and singing (Colcord &c Adams, 1979). They also point out that stuttering frequently occurs on initial sounds, before any auditory feedback arrives to the system. On the other hand, those who believe that stuttering is a result of a disorder in auditory feedback processing point out that alteration of speech feedback produces immediate fluency without conscious intent to change speech production.

1.2.3.1. Motor Control Theories of Stuttering

Those who believe that stuttering is a disorder in motor control have various theories about the precise locus of the motoric impairment. One theory is that stuttering is caused by difficulty with producing rapid articulatory movements. Several studies found that stutterers have longer phonation times than normal speakers (Di Simoni, 1974; Adams & Hayden, 1976; Hillman & Gilbert, 1977; Colcord & Adams, 1979). Therefore, Wingate (1969) and Brayton and Conture (1978) suggested that people who stutter have difficulty with rapid phonatory adjustments. Perkins, Bell, Johnson, and Stocks (1979), Andrews, Howie, Dozsa, and Guitar (1982), and Andrews, Craig, Feyer, Hoddinott, Howie, and Neilson (1983) suggested that delayed auditory feedback improves fluency because it slows speech. Fluency enhancing conditions are thought to work by prolonging phonation time, and so decreasing the number or rapidity of the phonatory adjustments required.

Another motor control theory is that people who stutter have "dysrhythmic" speech. A number of researchers have found greater variability among stutterers than nonstutterers. Di Simoni (1974) and Janssen and Wieneke (1991) found greater variability in voicing measures. Wood (1995) and Ward (1997) found greater variability in articulatory measures. Thus, fluency enhancing interventions are thought to decrease intrasubject variance in speech production by supplying an external temporal framework for the coordination of articulatory movements.

If the various motor control theories are correct, then under control conditions the speech of subjects who stutter would be expected to differ in some way from that of normal speakers. Furthermore, therapy which focuses exclusively on changing articulatory behavior should produce the same motor behaviors as fluency enhancing auditory feedback. For example, if Perkins, Bell, Johnson, and Stocks (1979) are correct in suggesting that people who stutter have difficulty with rapid articulatory movements, then delayed auditory feedback, frequency altered feedback, and noise should all cause the speech movements of people who stutter to have decreased peak velocity. If

Wingate (1969) is correct in stating that stuttering is caused by difficulty with rapid phonatory adjustments, then delayed auditory feedback, frequency altered feedback and noise should all produce longer periods of phonation. If Di Simoni (1974) is correct in suggesting that people who stutter have more intrasubject variance in the duration of vowels, then delayed auditory feedback, frequency altered feedback and noise should all decease intrasubject variance in vowel duration.

1.2.3.2. Auditory Feedback Processing Theories of Stuttering

An alternative theory is that stutterers have abnormal auditory feedback processing (Hall & Jerger, 1978; Toscher & Rupp, 1978; Wynne & Boehmler, 1982). The auditory feedback processing theory was originally formulated to try to explain why delayed auditory feedback reduces stuttering in stutterers, but produces dysfluency in normal speakers. According to this theory, in normal speakers delayed auditory feedback causes auditory feedback to arrive later than expected, causing dysfluency. Consistent with this theory, Zimmerman, Brown, Kelso, Hurtig, and Forrest (1988) found that normal subjects under delayed auditory feedback experienced speech breakdown (syllable repetition or prolongation) when auditory feedback overlapped with the subsequent articulatory gesture. By extension, speech breakdown in stutterers also occurs when auditory feedback overlaps with the subsequent articulatory gesture. Harrington (1988, 1991) hypothesized that the delayed arrival time of auditory feedback under DAF is compensating for an abnormal feedback processing system that causes feedback to arrive sooner than "expected". This early arrival time presumably overlaps with the subsequent articulatory gesture, thus interfering with articulatory progress.

Delayed auditory feedback restores a normal timing relationship between speech production and auditory feedback in speakers who stutter. If the auditory feedback processing theory is correct, then delayed auditory feedback would be expected to cause movement in speakers who stutter to more closely resemble that of normal speakers under the control condition, and to interfere with normal movement in normal speakers.

According to the auditory feedback processing theory, masking noise works by eliminating abnormally timed auditory feedback entirely (Maraist & Hutton, 1957; Garber & Martin, 1977). Since it is relatively new, there is no theory of how frequency altered feedback affects the auditory feedback processing system. However, one theory that might apply is the "distraction" theory (Barber, 1940). This theory suggests that anything that interferes with the ability of the stutterer to monitor his natural auditory feedback will increase fluency.

A variation of the auditory feedback processing theory is the Adaptive Model theory (Neilson & Neilson, 1991). Neilson and Neilson theorized that people who stutter have decreased processing resources for sensory modalities that provide feedback for speech. They predicted that more stuttering would occur in situations in which decreased resources are available to handle sensory feedback.

If the auditory feedback processing theory is correct, then we would expect to see consistent relationship between auditory feedback and speech production. For example, the timing of speech might be slower under delayed auditory feedback, or tongue positioning might be altered under frequency altered feedback.

Moreover, if people who stutter have a defective auditory feedback processing system, then their speech production should change in a different way from normal speakers, who presumably have normal auditory feedback processing. Furthermore, if the altered auditory feedback is enabling the speakers who stutter to compensate for auditory feedback processing problems, then their speech under altered auditory feedback would be expected to more closely resemble the speech of normal speakers who are speaking with no change in auditory feedback.

1.3. RESEARCH QUESTIONS

The present study advances the work of previous studies in three ways. First, this study examines movement of the tongue tip and tongue rear as well as that of the upper and lower lip. This enables us to determine whether all the articulators behave in similar fashion, or whether the movement variables vary among the articulators. Second, tongue movement is measured in the horizontal as well as the vertical dimension. Previous studies of lip and jaw movement focused on movement in the vertical dimension only. Third, movement variables are compared under a variety of fluency enhancing conditions. This allows us to determine whether the various fluency enhancing conditions have a similar effect on articulation, or whether the effects vary by condition.

This study asked five basic questions with regard to the means and variance of acoustic and articulatory variables in the speech of speakers who stutter and normal speakers. For each variable, the following questions were asked:

1. Under control conditions is the fluent speech of speakers who stutter different from that of normal speakers?

   If the fluent speech of people who stutter is like that of normal speakers, then stuttering would appear to be an intermittent problem in movement control. If the fluent speech of people who stutter is different from normal speakers, then stuttering would appear to result from a constant problem of motor control which intermittently results in articulatory breakdown.

2. Does altered auditory feedback change the fluent speech of normal speakers?

If auditory feedback changes the speech of normal speakers, this suggests that it does play a role in normal motor control of ongoing speech movements. Conversely, if auditory feedback does not change the speech of normal speakers, then this suggests that normal control of ongoing speech movements is independent of auditory feedback.

3. Does altered auditory feedback change the fluent speech of people who stutter?

If auditory feedback changes the fluent speech of people who stutter, this suggests that it does influence ongoing speech movements in the fluent speech of people who stutter. Conversely, if auditory feedback does not change fluent speech, then this suggests that the fluent speech movements of people who stutter are independent of auditory feedback.

4. Does altered auditory feedback change the fluent speech of people who stutter in the same way that it changes the fluent speech of normal speakers?

If stuttering does not involve an auditory feedback processing problem, then it is likely that people who stutter will respond to auditory feedback in the same way as normal speakers. If stuttering is at least partly an auditory feedback processing problem, then people who stutter might be expected to respond differently to auditory feedback than normal speakers.

5. Does altered auditory feedback change the fluent speech of people who stutter to more closely resemble the fluent speech of normal speakers under control conditions?

If stuttering is primarily a motor control problem, then fluency enhancing auditory feedback should cause speech production in speaker who stutter to more closely resemble that of normal speakers.

CHAPTER TWO

METHODS

2.1. RESEARCH DESIGN

This study examined the effects on two groups of speakers, speakers who stutter and normal speakers, of six types of auditory feedback: no alteration in auditory feedback (Control), low frequency altered feedback, high frequency altered feedback, delayed auditory feedback, noise and self-monitoring under noise. Both means and variability were compared. Under the Control condition, group comparisons were made between the speakers who stutter and the normal speakers; in addition, individual subjects were compared to each other. Under the experimental comparisons, group comparisons were made within each condition; in addition, within-group comparisons of the conditions were made.

2.2. SUBJECTS

Five speakers who stutter (S1 to S5) and five normal speakers (N1 to N5) participated in the study. Subjects were recruited by word of mouth and newspaper advertising, and were paid $100 for participation. The group of speakers who stutter consisted of three men and two women, between the ages of 22 and 52. The group of normal speakers also consisted of three men and two women, aged 22 to 56. The mean age of the speakers who stutter was 35.0 years; the mean age of the normal speakers was 34.8 years. All subjects were native speakers of English with hearing thresholds of 25 dB HL or better in both ears at 500, 1000, and 2000 Hertz. None of the subjects had speech problems other than stuttering. None of the subjects had received speech therapy more recently than 9 months prior to participation in the study. Two of the speakers who stutter had used delayed auditory feedback at some time as part of their speech therapy; none of the subjects had prior exposure to frequency altered feedback. The Stuttering Severity Instrument-3 (Riley, 1994) was given to all speakers, both normal and stuttering, before the experiment began. None of the normal speakers exhibited any abnormal dysfluencies during the study (see Table 1 for a description of the individual speakers).

Although it can be seen from Table 1 that Speaker S5 did not have any perceptible repetitions, prolongations or blocks during administration of the Stuttering Severity Instrument-3, he stuttered with moderate severity during conversation both before and after the experiment, according to the judgment of the experimenter, a speech and language pathologist with experience in the area of stuttering.

2.3. STIMULI

Five CVC target words in the phrase "Say CVC again" were used: sash, pass, shop, tack, cot. These five words were selected to contain voiceless stops and voiceless fricatives in initial and final positions. Each target word was read 10 times in each auditory feedback condition, for a total of 50 phrases under each condition.

2.4. CONDITIONS

Subjects spoke under six listening conditions. In all the conditions, subjects heard their own speech coming back to them through insert earphones. The conditions were as follows:

1. Control. Speech was passed through the microphone, sound effects processor, amplifier, and earphones without any alteration in the signal.
2. Delayed auditory feedback with a 50-millisecond delay (DAF).
3. Frequency altered feedback with all frequencies one-half octave lower (LAF).
4. Frequency altered feedback with all frequencies one-half octave higher (HAF).
5. Pink masking noise presented at 85 dB (Noise).
6. Self-monitoring under pink masking noise. Subjects again heard the 85 dB SPL masking noise, but were requested to keep their voices below 60 dB SPL, to avoid hearing their own voices through bone conduction (Self-Monitoring).

The experimental conditions all involved forms of auditory feedback that have been found to be effective in enhancing fluency in speakers who stutter. The parameters of the conditions were selected with the following considerations. For the delayed auditory feedback condition, a 50 ms. delay was chosen as the shortest delay that has been found to be effective in increasing fluency among stutterers (Black, 1951; Fairbanks, 1955; Sark, Kalinowski, Armson, & Stuart, 1993).

Since the effects of frequency altered feedback on articulation are unknown in both normal speakers and speakers who stutter, it was considered desirable to use one condition with higher auditory feedback and one condition with lower auditory feedback, in order to see if the direction of frequency change affected speech different ways. One half octave lower and one half octave higher were chosen.

Masking noise has been found to improve fluency (Andrews, 1982; Garber & Martin, 1977; Kalinowski, Armson, Roland-Mieszkowski, Stuart, & Gracco, 1993;

Postma & Kolk, 1992). Pink noise was used in the present experiment because it contains more energy in the region below 1000 Hz, and therefore masks speech effectively at a lower and more comfortable intensity than the white noise that has been used in previous studies. Pink noise is created by filtering white noise so that energy per cycle decreases at a rate of 3 dB per octave.

Because speakers tend to raise their voice when speaking under noise (the Lombard effect), they may receive some auditory feedback under the Noise condition. In order to have a condition in which the subject receives as little auditory feedback as possible, another condition called the Self-Monitoring condition was used. Under the Self-Monitoring condition, subjects listened to the same 85-dB pink masking noise as in the Noise, condition, but in addition they were instructed not to raise their voices. In preliminary trials it was found that when the speaking level is held to 60 dB SPL, one's own speech cannot be heard at all under 85-dB pink masking noise.

To help them maintain a normal level in intensity under this condition, three steps were taken. First, a sound level meter that displayed a red light whenever the peak speech intensity rose above 60 dB SPL was placed in view of the subjects while they were reading. Preliminary trials had found that it was impossible to hear one's own voice while listening to 85 dB SPL pink noise if the peak speech levels remained below 60 dB SPL. Second, subjects practiced reading for two minutes while monitoring their speech intensity using the sound level meter. Third, feedback, in the form of hand signals by the investigator, was given both during the practice period and during the reading of the phrases, when the speech intensity rose too high. All subjects were successful in maintaining their intensity at an acceptable level under this condition.

2.5. EQUIPMENT

The acoustic speech signal was transduced by a Sennheiser MKH816T-U microphone placed 12 inches from the lips. Before digitization at 20,000 samples per second (12-bit resolution) the speech signal was lowpass filtered at 9.6 kHz (see Whalen, Wiley, Rubin, & Cooper, 1990 for details).

Lip and tongue movements in the midsagittal plane were transduced using a custom electromagnetic midsagittal articulometer (EMMA) located at Haskins Laboratories. This device records movement in two dimensions, vertical and horizontal (anterior-posterior), of transducers, three to four millimeters in size, that are affixed to the lips and tongue. Three electromagnets are located in a hood around the subject's head. Each of the electromagnets generates an alternating magnetic field that fluctuates at a unique frequency that ranges from 60 kHz to 80 kHz. As the transducers move through the magnetic field generated by the electromagnets, the voltage generated in the transducers varies as a function of their distance from each of the three magnets. (For further information on this device, see Perkell, Cohen, Svirsky, Matthies, Garabieta, & Jackson, 1992; Perkell, Svirsky, Matthies, & Manzella, 1993; Gracco & Nye, 1993; Löfqvist, Gracco, & Nye, 1993; Lofqvist, 1994).

Each transducer was connected by a very fine wire to one channel of the EMMA electronics. Up to ten channels can be used at one time. Movement signals were obtained from the upper lip, lower lip, tongue tip, and the tongue rear. Each articulator point was sampled at a rate of 625 samples per second. Data were digitized using the same Digital Acquisition in Real Time (DART) system used for the acoustic data. See Figure 1 for a diagram of the equipment setup.

The delayed auditory feedback and frequency altered feedback conditions were created with a Yamaha Professional Multi Effects Processor SPX1000. The altered signal then passed through an Optimus SCT-55 Professional Series amplifier and introduced to the speaker via Eartone 3A insert earphones.

Masking noise was produced with a custom noise generator (see Broecker, Yeung, & Chant, 1988). The noise was then amplified using the same Optimus SCT-55 amplifier and again introduced to the speaker via the same Eartone 3A insert earphones.

The sound level meter was a custom made device. It was adjusted so that a red light came on whenever the speaker's voice exceeded 60 dB. During the Self-Monitoring condition, the device was placed 18 inches from the subject in such a way that the subject could see the red light whenever it came on.

2.6. DATA COLLECTION

Data were collected at Haskins Laboratories, over a period of 19 months, from February 1995 to September 1996. Data from each subject were collected in single session that lasted approximately three and a half hours. Of this time, one half hour was spent providing information, obtaining consent, and administering the SSI-3. It took one hour to apply the transducer coils to the subject. Data collection took approximately two hours.

2.7. PROCEDURES

2.7.1. Calibration of Transducers

The EMMA system was calibrated prior to the arrival of each subject. The

EMMA system requires two calibrations. The first calibration compensates for variations in the magnetic field at various points within the articulatory space. These calibration values had been previously obtained (Gracco & Nye, 1993), and were inserted into the experimental log file using a software calibration routine.

The second calibration compensates for variations in individual transducers. This calibration was done on the day of each experimental run, prior to the arrival of the subject. An Inaki plate, containing 89 holes at 1.5 cm. intervals, was placed inside the hood. The transducers to be used during the session were placed one at a time into the Inaki plate at the anticipated extreme edges of articulator movement for that pellet. Sagittal plane coordinates were obtained for each pellet. These coordinates were then used to calculate gain and offset values used to adjust the calibration values.

After completion of calibration, the transducers were sterilized in preparation for placement on the subject.

2.7.2. Equipment Setup

Prior to each session, the acoustic equipment was connected in the following manner. The output from the microphone was connected to an amplifier and gain control which were part of the DART system. A fixed amount of amplification and gain by the DART system was found during preliminary trials to be optimal to maximize the signal while minimizing clipping, and used for all the sessions. Then the acoustic signal was split, with part of the signal going into the DART system for digitization, and part going into Yamaha Multi Effects Processor. Both the Yamaha Multi Effects Processor and the custom noise generator were attached to an Optimus SCT-55 amplifier. After amplification, the modified acoustic signal or the pink noise was again split, with part of the signal going to the DART system for digitization of the feedback signal and part going to the Eartone 3A insert earphones.

The amplifier was adjusted before each session using a sound level meter to return 85 dB of masking noise from the noise generator to the Eartone 3A insert earphones. The same amplification was found to produce a comfortable level of loudness under Control, delayed auditory feedback and frequency altered feedback conditions, so the same level of amplification was used throughout the entire session. During the Control condition, the bypass on the Yamaha Multi Effects Processor was used, so that no change was made to the speech signal as it passed through the processor. During the two noise conditions, the Yamaha Multi Effects Processor was turned off, so that no speech was returned through the earphones to the subjects during these conditions. If the subjects heard their own speech under the noise conditions, it was by air or bone conduction only.

The custom sound level meter for the Self-Monitoring condition was placed 18 inches from the subject. Prior to the beginning of each recording session, the custom sound level meter was calibrated in the following way. The custom sound level meter was placed 18 inches from the chair, and the investigator sat in the chair with a sound level meter held three inches from the lips. The sensitivity level of the custom sound level meter was adjusted so that when the sound level meter that was near the lips peaked over 60 dB SPL, the red light on the custom sound level meter came on.

2.7.3. **Preparation of Subject**

After the subject was informed about the experiment and written consent was obtained, the SSI-3 was administered to all subjects. The subjects were videotaped as they read a paragraph and produced a two-minute monologue. During the administration of the SSI-3, the subjects sat in the chair that was to be used during the experiment, but no equipment was attached at this time except for a lapel microphone for the videotaping.

After completion of the SSI-3, an otolaryngologist placed the transducers on the midline of the following locations: tongue rear, tongue tip, the gum line of the upper teeth, the upper part of the nose between the eyes, the vermilion border of the upper lip, and the vermilion border of the lower lip. The tongue rear and tongue tip transducers were affixed with oral epoxy (Ketac Bond). The rest of the transducers were affixed with dental adhesive (Isodent).

During placement of the tongue transducers, an effort was made to place the tongue tip and tongue rear transducers on or close to where the tongue would make contact with the hard palate during production of /t/ and /k/. No attempt was made to place them at a specific distance from each other.

The transducers that were placed on the gum line of the upper teeth and on the upper part of the nose between the eyes were used as reference points to detect and correct for head movement. Since their locations were fixed and did not change as a result of speech, any movement in the signals from these two transducers could be attributed to head movement.

Two additional transducers were used to identify the occlusal plane. These two transducers were placed on a polyethylene plate that was held between the subject's teeth with one pellet located inside the mouth and the other just external to the lips. Thus the two transducers were in line with the bite plane.

The earphones were inserted into the subject's ears. The hood containing the electromagnets of the EMMA system was then lowered over the subject's head and adjusted to fit snugly. The hood allowed the subject to turn his or her head slightly, while maintaining the transducers in a fixed position relative to the subject's head. A counterweight supported the hood.

After the session, subjects had the opportunity to discuss their experience and to ask any questions that they had. Several of the subjects reported that the Noise and Self-Monitoring conditions were unpleasant, although not painful. No other complaints were noted by any of the subjects.

2.7.4. Presentation of the Conditions

Each subject began by reading essay material for two minutes under the Control condition. Then each subject read 50 randomly ordered phrases containing 10 tokens of each of the target CVC words.

After the Control condition, LAF, HAF, DAF, and Noise were presented, the order of these conditions being counterbalanced across subjects. At the beginning of each experimental condition, the subject read essay material for two minutes without hearing any change to his or her speech (as in the Control condition) to prevent carry over of auditory feedback effects from one condition to the next. Next, in order to become accustomed to the experimental auditory feedback condition, the subject read essay material for two minutes under the experimental condition. Lastly, the subject read the 50 randomly ordered CVC phrases under the experimental condition. For each of the conditions, the subject was instructed to "Read in a relaxed, natural way, at your normal pitch, intensity, and speaking rate."

Self-Monitoring was the only condition that required the subject to consciously modify his or her speech. In order to prevent unwanted self-monitoring during the other experimental conditions, Self-Monitoring was always the last condition to be presented. The same procedure was followed as during the experimental conditions, but this time the subject was instructed to avoid speaking loudly while hearing the noise. During the two minutes of reading while hearing noise, the subject was instructed to monitor his or her speech by making sure that the red light on the sound level meter was not on. In addition, the subject was cued with a gesture whenever a perceptible rise in intensity was noted by the experimenter. After the two minutes of practice, the subjects read the 50 phrases. On the few occasions when the subject increased intensity while reading the 50 phrases, gesturing was successful in reminding the subject to reduce speaking intensity.

2.8. ADAPTATION

Adaptation is a decrease in stuttering that occurs after repeated reading of the same passage (Frank & Bloodstein, 1971. It is reasonable to assume that adaptation did occur in the large number of repetitions of "Say CVC again." The following provisions were made to help equalize the effects of adaptation over the experimental conditions. First, new paragraph reading material was read at the start of each new condition. This helped prevent adaptation from continuing from one condition into the next. Second, the fifty phrases were presented in random order under each condition. Therefore, all phrases were equally affected by the opportunities for motor rehearsal. Third, the experimental conditions were counterbalanced across speakers, so that no one condition would have more adaptation than another.

2.9. DETECTION OF STUTTERING

Only fluent utterances were analyzed. Stuttered utterances were separated from fluent utterances in the following way. After saying each phrase, both the normal speakers and the speakers who stutter indicated whether each utterance was stuttered or not. Any utterance that the speaker thought was stuttered was discarded.

After data collection was completed, the investigator and a second speech and language pathologist, both familiar with stuttering, listened to each utterance of every subject, both normal speakers and stutterers. Any utterance that was identified as stuttered was discarded. The investigator judged all the utterances; four speech and language pathologists, who were unacquainted with the subjects or with the purpose of the experiment, served as second judges. Each of these four speech and language pathologists listened to one quarter of the utterances. The number of utterances discarded because they were judged to be stuttered are listed by condition in Table 2.

2.10. SIGNAL PROCESSING

Data from four articulators were acquired: upper lip, lower lip, tongue tip, and tongue rear. The voltage data were converted to distance from the transmitters; then distance was converted to position in the midsagittal plane of the device.

Next, data were corrected for head motion during the course of the experiment. For this purpose, the data collected from the transducers placed on the gum line of the upper teeth and on the upper part of the nose between the eyes were used.

Data were then rotated to the occlusal plane, with the horizontal axis representing the occlusion. This was accomplished using data from the two transducers dedicated to collection of occlusal plane information.

The movement signals were smoothed using a 25 sample triangular window before further signal processing was carried out.

The signals for the vertical upper lip and lower lip positions were combined into a single variable called lip aperture, reflecting the distance between the two lip transducers. This was done so that measurements of lip movement would be comparable to those in previous studies, particularly Story (1994), Story, Alfonso and Harris (1996) and Kalinowski (1994).

2.11. MISSING DATA

Signals were missing for several of the subjects due to problems with data recovery. In addition, the subject occasionally misread the word or substituted one target word for another. When this happened, no correction was made at the time of the experiment, but if word was misread, it was not included in the analysis. For this reason, occasionally there were less than 10 tokens of a particular word under a particular condition. However, if the subject substituted another one of the target words from the experiment, this was included in the analysis, so on rare occasions there were more than 10 tokens of a particular word under a condition. The number of signals used from each subject under each condition for the acoustic signal, and tongue tip, tongue rear, and lip aperture movement are listed in Tables 3 to 6.

After the data were analyzed, it was discovered that in some of the subjects evidently some movement of the head within the hood occurred between conditions during the course of the experiment. The amount of movement was on the order of one to two centimeters, and was not detected during data collection. As a result, the position of /p, s, ʃ, t/ in the vertical dimension was more than a centimeter lower in the last conditions than in the first conditions. This was far greater than the difference in means that occurred within conditions, or that was detected between conditions in other subjects where no detectable head movement occurred. Standard deviation was similar in early and later conditions even where the means were notably different, indicating that this was not a problem that occurred during the reading of the phrases, but appeared to have occurred during the four minutes of reading that occurred between the conditions. For this reason, conditions were excluded from the position measures if they were the last conditions for that particular subject, and the means of the last conditions were consistently more than a centimeter different than mean of the Control condition. The number of signals used from each subject under each condition for tongue tip and tongue rear position are listed in Tables 7. and 8.

Since the amount of head movement was small, and since there was no apparent impact on movement duration, distance or peak velocity within conditions, data for the movement variables from conditions in which head movement had occurred were retained, even though data for the position variables was excluded.

For most of the subjects, only three or four tokens were lost during computer data inputting. However, for two subjects whole conditions were lost. Specifically, it was not possible to recover any of the tongue tip or tongue rear signals for speaker S4. Signals in all channels were missing for the high frequency altered feedback condition only of speaker N4. In addition, signals for the Noise condition was missing for tongue tip and tongue rear for speaker S5.

The articulator for which the most data was missing was tongue rear, due the difficulty in maintaining adhesion in the moist conditions at the back of the tongue. In total, for tongue rear, there was one speaker missing from the Control condition, two from LAF, four from HAF, three from DAF, two from Noise, and four from the Self-Monitoring condition (See Table 5).

2.12. EVENT IDENTIFICATION AND LABELING

2.12.1. Acoustic Signal

Speech signals were analyzed using Haskins Analysis, Display, and Experiment System in-house software. Each digitized utterance was viewed on a graphics workstation and events of interest were identified and saved for subsequent analysis. Events can be labeled with an accuracy of 0.1 millisecond for the acoustic signal, and 1.6 milliseconds for the movement signals. Events of interest will now be described in more detail.

2.12.2. Acoustic Event Identification

A waveform representation of the acoustic signal was used to identify the following events of interest. See Figures 2 to 6 for typical acoustic and movement signals marked with the events of interest.

1. The beginning of the /s/ of "say." This was labeled at the point where the amplitude of the noise of /s/ began to exceed the amplitude of the ambient room noise, as seen in the waveform.
2. The transition from the /s/ of "say" to the /e/ of "say." This was the point at which the noise of the /s/ ended and the complex periodic motion of the /e/ began. There was never any pause at this point. Sometimes there was overlap between the two sounds for a period or two, with noise superimposed on periodic motion. In these cases, the beginning of the vowel was considered to be where harmonics were first visible.
3. The end of the /e/ of "say." This was judged to be where complex periodic motion of the vowel ended.
4. The beginning of the target CVC word. When the first sound of the target CVC word (C1) was a stop, the beginning of C1 was judged to coincide with the end of complex periodic motion for the /e/ of "say." When C1 was a fricative, the beginning of C1 was judged to be where the amplitude of the noise of the fricative began to exceed that of the ambient room noise. In most cases, the noise of the fricative began immediately upon cessation of the complex periodic motion for the /e/ of "say." In this case, C1 was judged to begin at the end of the /e/ of "say."

   In some cases there was some overlap between end of the /e/ of "say" and the onset of the noise of frication. The beginning of C1 was considered to be where harmonics of the /e/ of "say" were last visible. In other cases, there was a silent period between the end of the /e/ of "say" and the onset of the noise of frication. In this case the end of the /e/ was labeled separately from the beginning of C1.

5. C1 always ended with noise, either the noise of frication of /s, ʃ/ or the noise burst of /p, t, k/. The end of C1 always coincided with the beginning of complex periodic vibration for the vowel of the CVC target word. The same criteria were used as for the end of the /s/ of "say."
6. The transition from the vowel to the second consonant of the CVC word (C2) was similar to the transition from the end of the /e/ of "say" to C1 of the CVC target word. However, in this transition there were never any pauses.

   Because postvocalic /t/ of "cot" was at various times actualized as a conventional alveolar stop, a glottal stop, or a flap, this target had a very high variability of tongue tip movements into and out of the target. For this reason, movements into and away from the final /t/ of "cot" were discarded from the analysis of the movement data.
7. The transition from C2 to the /ə/ of "again." When C2 was a fricative, the same criteria were used as in the transition from /s/ to /e/ in "say." When C2 was a stop, the end of the noise burst was judged to be the end of C2. In a number of tokens, C2 did not have a noise burst. In these tokens, the end of C2 was judged to coincide with the beginning of voicing for "again."

   In most tokens the beginning of voicing for "again" coincided with the end of the noise of C2. In some tokens, there was a brief pause between the end of the noise of C2 and the beginning of the complex periodic motion for "again." In these tokens, the end of C2 and the beginning of "again" were judged to be separate events and were labeled separately.

8. The end of "again." This was judged to occur where the movement of the waveform for /n/ of "again" had no greater amplitude than the ambient room noise.

2.12.3. Articulatory Movement Onset and Offset

Tangential velocity is used in the study of movement in more than one dimension (Morasso, 1981, 1983a, b; Atkeson & Hollerbach, 1985). Although the term "tangential velocity" is customarily used, tangential velocity is actually tangential speed, since it is not a vector, and its value is not affected by direction of movement. Velocity tangent is derived by obtaining the velocity of the separate horizontal and vertical movements, and then summing the velocity of both the horizontal and vertical dimensions. Squaring and then taking the square root removes directional information.

Calculation of Tangential Velocity

For each articulator, velocity was derived for each signal on a sample by sample basis using a two-point central-difference algorithm (Kay, Munhall, V.-Bateson, & Kelso, 1985) to create a velocity signal.

The central difference algorithm is:

(1) velocity of a sample = $(x^{(t+1)} - x^{(t-1)}) / 2h$

where x = amplitude, t = the sample, and

h = interval between samples

Using the velocity tangent prevented excessive weight being given to movement onset in either the horizontal or vertical dimension alone. The formula for velocity tangent is:

(2) velocity tangent = $\sqrt{X^2 + Y^2}$ for each sample in the movement signals

where X = velocity of the sample in the horizontal dimension,

Y = the velocity of the sample in the vertical dimension

Typically, there was one velocity minimum for each speech sound. This velocity minimum was located more or less in the temporal center of the speech sound seen in the acoustic signal. However, in some movements, there was more than one minimum in one speech sound. When this occurred, only the lowest minimum was labeled.

In other movements, there was a slope that connected minima located in the adjacent speech sound, but no minimum or peak located within the speech sound. This occurred particularly when the articulator was not active for a given consonantal sound, for example, tongue tip during /p/ or /k/. In these movements, no minimum was labeled. The articulatory movement that began in the previous speech sound was judged to extend through the following speech sound which contained no minimum, up to the next visible minimum.

The lip aperture signal contained only information from the vertical dimension. Therefore, the onset and offset of changes in lip aperture were measured using a simple velocity signal. Lip aperture changes were identified as beginning or ending when the velocity signal achieved zero.

The following movement events were identified:

Tongue Tip Signal

1. The onset of tongue tip elevation from the /e/ of "say" to the following C1 of the CVC target word.
2. The onset of tongue tip lowering from C1 to the vowel of the CVC target word.

3. The onset of tongue tip elevation from the vowel to C2 of the CVC target word
4. The onset of tongue tip lowering from C2 to the /ə/ of "again."
5. The offset of tongue tip lowering for the /ə/ of "again."

Tongue Rear

1. The onset of tongue rear elevation from the vowel prior to the /k/ of the target word.
2. The onset of tongue rear lowering from /k/ to the following vowel.
3. The offset of tongue rear lowering from /k/ to the following vowel.

Lip Aperture

1. The onset of lip aperture closing from the vowel previous to the /p/ of the target word.
2. The onset of lip aperture opening from the /p/ to the following vowel.
3. The offset of lip aperture opening from the /p/ to the following vowel.

2.13. DEPENDENT VARIABLES

A total of seven dependent variables were measured. Duration of voicing and of the unvoiced segments were measured from the acoustic signal; movement duration, tongue tip, movement distance, and peak velocity were measured from the tongue tip, tongue rear, and lip signals. Vertical and horizontal tongue positions were measured from the tongue tip and tongue rear signals. See Figure 7 for examples of movement duration, distance and peak velocity.

2.13.1. Voicing Duration

Phonation duration was found by adding the duration of the /e/ of "say", the vowel of the CVC target word, and the duration of "again" from the acoustic signal. Since there was rarely any pause in phonation for the /g/ of again, the entire word was considered to be voiced.

2.13.2. Duration of Unvoiced Segments

Duration of unvoiced segments was calculated as the sum of the initial and final consonants of the CVC target word.

2.13.3. Movement Duration

Movement duration was defined as the difference between the time of movement onset and the time of movement offset from the tongue tip, tongue rear, and lip signals.

2.13.4. Movement Distance

Distance is the total path length of movement traveled in the combined horizontal and vertical dimensions. Distance was found by summing the differences between successive points in the combined horizontal and vertical dimensions. The formula for distance is:

(3) $$\text{distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

where x_1 and x_2 are successive points from the horizontal signal, and y_1, and y_2 successive location points from the vertical signal of an articulator.

The distance of individual movements was measured between the same movement onsets and movement offsets that were used for movement duration.

Distance measures were obtained from the tongue tip and tongue rear articulators.

2.13.5. Movement Peak Velocity

Peak velocity is the highest amplitude in the tangential velocity signal between the onset and offset of a movement.

2.13.6. Tongue Position

Tongue position is the value of the tongue tip and tongue rear signals in the horizontal and vertical dimensions of the articulator at a particular point in time. Since the values for tongue position are arbitrary, depending on the position of the articulator within the device, the data were normalized by subtracting the vertical or horizontal mean of the tongue tip data under the Control condition from all the vertical or horizontal values of each subject. Thus, the position values of each subject represent the distance from the mean for that subject of each consonant or vowel under the various conditions. For tongue tip, position was measured at the onset of /s, ʃ, t/. For tongue rear, position was measured at the onset of /k/. Position was also measured at the point of maximum opening (minimum value in the vertical dimension) for the vowel in the tongue tip signal.

CHAPTER THREE

RESULTS UNDER THE CONTROL CONDITION

3.1. INTRODUCTION

This chapter will describe the behavior of both the normal speakers and the speakers who stutter under the Control condition. The following chapter will describe the behavior of the two groups under the experimental conditions. In each chapter, acoustic duration will be described first; then movement duration, distance, and peak velocity; and lastly vertical and horizontal position. A two way ANOVA procedure was used to make group comparisons; a one way ANOVA procedure was used to compare individual speakers who stutter to the normal group.

3.2. ACOUSTIC DURATION

As found in previous studies, the durations of voicing and of the unvoiced segments were significantly longer among the speakers who stutter than among the normal speakers. The duration of voicing was longer than the duration of the unvoiced segments; there was no group by voicing type interaction. (see Figure 8 and Table 9 for further descriptions of means and standard deviations, and for the significance of the comparisons).

The difference in variability of the four group by voicing type cells was significant: the variability of the speakers who stutter was greater than that of the normal speakers for both voiced and unvoiced segments. In addition, in both groups the variability of voicing, like the duration of voicing, was greater than that of the unvoiced segments (see Figure 9 and Table 9).

3.3. DURATION OF MOVEMENT

The opening and closing movements for the vowel of the CVC target word were grouped together and termed the vowel-related movements. The closing movement for the initial consonant and the opening movement for the final consonant of the CVC target word were also grouped together and called the transitional movements (see Figure 7 for an example of transitional and vowel-related movements).

As previously seen for the acoustic durations, both transitional and vowel-related movements were significantly longer in the speakers who stutter than in normal speakers (see Figure 8 and Table 10 for further description of means and standard deviations, and for the significance of the comparisons). In both groups of speakers, the vowel-related movements were significantly longer than the transitional movements. There was no interaction between group and movement type.

Variability differed significantly among the four group by movement type cells. In both groups, the variability of the transitional movements was greater than the variability of the vowel-related movements, even though the duration of the vowel-related movements was longer. The variability of both types of movements was greater among the speakers who stutter than among the normal speakers (see Figure 9 and Table 10).

3.4. DISTANCE OF MOVEMENT

The distance of the vowel-related movements was significantly longer than the distance of the transitional movements in both groups of speakers. There was no significant group effect on distance; however, there was an interaction between group and movement type. The distance of the transitional movements was longer among the speakers who stutter than the normal speakers, while vowel-related distance was shorter. Thus, the stutterers did not create as great a contrast between the two types of movement as the normal speakers did (see Figure 10 and Table 11 for further description of the means and standard deviations, and for the significance of the comparisons).

Variability differed significantly among the four cells. For both types of movements, the variability was greater among the speakers who stutter than the normal speakers. Among the normal speakers, the variability of the transitional movements was greater than that of the vowel-related movements, even though the mean distance of the transitional movements was less than that of the vowel-related movements. Among the stutterers, both the mean and variability of distance were greater for the vowel-related than the transitional movements. These results suggest that the normal speakers controlled vowel-related distances more tightly than transitional distances; however, this did not appear to be true for the speakers who stutter (see Figure 10 and Table 11).

Distance of movement was only mildly correlated with duration. For normal speakers, the correlation was $r = 0.460, p < 0.00, N = 888$; for stutterers, the correlation was slightly higher, $r = 0.555, p < 0.00, N = 701$.

3.5. PEAK VELOCITY OF MOVEMENT

In both groups, the peak velocity of the vowel-related movements was significantly greater than that of the transitional movements. There was an interaction effect: transitional peak velocity of the stutterers was higher than that of the normal speakers, while vowel-related peak velocity was lower among the stutterers than the normal speakers. The latter finding is consistent with the longer durations and shorter distances of the vowel-related movements of the stutterers. Thus, once again, the speakers who stutter did not create as great a contrast between the vowel-related and transitional movements as the normal speakers did (see Figure 11 and Table 12 for further description of means and standard deviations, and for the significance of the comparisons).

Variability differed significantly among the four cells. Variability of peak velocity was, as for duration and distance, higher among the speakers who stutter than the normal speakers. In both groups, the variability of the vowel-related movements was higher than the variability of the transitional movements. Variability of the vowel-related movements of the stutterers was markedly higher than the variability of the other three cells (see Figure 11 and Table 12).

Peak velocity correlated well with distance; among the normal speakers, $r = 0.866$, $p < 0.00$, $N = 888$, and among the speakers who stutter, $r = 0.670$, $p < 0.00$, $N = 701$. The correlation between peak velocity and duration was quite low in both groups: for normal speakers, $r = 0.081$, $p = 0.016$, $N = 888$, and for speakers who stutter, $r = -0.073$, $p = 0.054$, $N = 701$.

3.6. ARTICULATOR POSITION

3.6.1. General Considerations

Horizontal and vertical position were measured at the acoustic onset of the initial and final consonants in the CVC target word, and at the point of maximum opening in the vertical dimension for the vowel. Since position was provided by the computer software in terms of distance in centimeters from an arbitrary reference point which varied with each subject, according to the position of the magnetometer hood relative to the head, the data was normalized for each speaker in each dimension. The mean of the Control condition tongue tip data of each speaker was subtracted from each data point. Thus, the position measures give the distance from a central articulation point that is unique to each speaker, and the mean of the position measures within each speaker under the Control condition is zero. In the vertical dimension, lower values indicate a relatively more inferior position, while higher values indicate a more relatively superior position. In the horizontal dimension, lower values indicate a relatively more anterior position, while higher values indicate a relatively more posterior position.

3.6.2. Vertical Position

The speakers who stutter were significantly lower in tongue tip position than the normal speakers for /s, ʃ, t, k/, and significantly higher than the normal speakers for /æ, ɑ/. This agrees with the previously discussed findings of smaller vowel-related movements among the stutterers than the normal speakers (See Figure 12 and Table 13 for means and standard deviations, and for the significance of the various comparisons).

In contrast to the findings for other movement variables, variability of vertical position was lower among the stutterers than the nonstutterers for all the phonemes except /k/ (see Table 13). The reason for the higher variability of /k/ among the stutterers is unclear, but may be related to the lower means of the stutterers. The standard error of measurement of vertical position of /k/ was 0.0546 among the stutterers, and 0.0683 among the normal speakers.

3.6.3. Horizontal Position

The normal speakers produced /s/ more anteriorly than the speakers who stutter; the remaining phonemes, /ʃ, t^1, k/ were produced more posteriorly among the normal speakers. There was no effect of group on vowel position in the horizontal position (see Figure 12 and Table 14 for means and standard deviations, and for the significance of the comparisons).

Consideration of the individual tongue tip consonants resulted in an unexpected finding. The stutterers did not differentiate the horizontal positions of /s/ and /ʃ/, as did the normal speakers. Both sounds were produced by the stutterers in a position intermediate to those of the normal speakers. Variability of horizontal location of /s, ʃ, t^1/ was lower among the stutterers than the normal speakers. The vowels and /k/ did not differ significantly in variability in the two groups (see Table 14).

3.7. INDIVIDUAL SPEAKERS WHO STUTTER

The speakers who stutter, as individuals, were more variable than the normal speakers. Moreover, the stutterers varied more from each other than the normal speakers did. The stutterers had a greater range of voicing duration than the normal speakers (see Figure 13). Two of the stutterers (S1, S2, S3) had mean voicing durations that were significantly longer than the mean of the normal group, while the other two stutterers had voicing means that were significantly shorter than the normal group (see Tables 15 and 16 for individual means and standard deviations, and for the significance of the comparisons).

In addition, the stutterers had higher standard deviations than the normal speakers (see Figure 14). Although the normal group had a higher standard deviation than any of the individual stutterers, four of the five stutterers had higher standard deviations than any of the normal individuals.

With regard to the duration of the unvoiced segments, the speakers who stutter again had a greater range of means than the normal speakers (see Figure 15). Speakers S1, S2, and S3 had significantly longer mean durations of the unvoiced segments than the mean of the normal group, while the remaining two stutterers had significantly shorter durations than the normal group. Variability was higher in all the stutterers than in any of the normal speakers; two of the stutterers (S1 and S3) each had greater variability than the entire normal group (see Table 16 for the means and standard deviations, and for the significance of the various comparisons).

For movement duration, as for duration of voiced and unvoiced segments, the speakers who stutter varied more than the normal speakers did. The same pattern was found for both transitional and vowel-related duration as for acoustic duration; speakers S1, S2, and S3 had longer movement durations than the normal mean, while Speakers 4 and 5 had shorter durations than the normal mean (see Tables 17 and 18 for the means and standard deviations, and for the significance of the various comparisons). One stutterer, S3, had a longer mean movement duration than any of the normal speakers, while another stutterer, S5, had a shorter mean movement duration than any of the normal speakers (see Figure 17). All of the speakers who stutter had greater variability of movement duration than all of the normal speakers (see Figures 18).

Similarly to the duration measures, the speakers who stutter had a greater range of mean distance than the normal speakers (see Figure 19). With regard to transitional distance, two of the stutterers (S1 and S3) had mean distances that were significantly greater than the mean of the normal group, and one (S2) had a mean distance that was significantly shorter. For vowel-related distance, all of the stutterers had mean distances that differed significantly from that of the normal group. Speakers S1 and S3 again had mean distances that were longer than those of the normal group, while the remaining three stutterers had mean distances that were shorter (see Tables 19 and 20 for the means and standard deviations, and for the significance of the various comparisons). With regard to variability, the female speakers (N2, N4, S2, and S4) had lower variability than the male speakers of their corresponding groups. Furthermore, the female stutterers had the lowest variability of distance of all the speakers. In contrast, Speaker S3 had the highest variability of all the speakers for both transitional and vowel-related distance (see Figure 20).

Peak velocity of the transitional movements was similar to that of distance: speakers S1 and S3 had significantly higher mean peak velocities than the mean of the normal group, while S2 had a significantly lower mean peak velocity than the normal group (see Table 21 for the means and standard deviations, and for the significance of the various comparisons). Examination of individual means shows that speaker N1 had the highest mean peak velocity of all the speakers; the remaining normal speakers were similar to each other (see Figure 21). The peak velocities of the vowel-related movements paralleled those of distance, but did not always achieve significance. The variability of the peak velocity of the stutterers was generally lower than that of the normal speakers (see Figure 22 and Table 23 for the means and standard deviations, and for the significance of the various comparisons).

In summary, under the Control condition, the individual speakers who stutter varied more in their means than the normal speakers for the duration, distance and peak velocity measures. Variability of the durational measures was higher among the speakers who stutter than the normal speakers, while variability of distance and peak velocity was generally less.

As previously discussed, the speakers who stutter did not produce as great a contrast between transitional and vowel-related durations and displacements as the normal speakers did. Comparison of transitional and vowel-related durations in individual speakers shows that the normal speakers followed a variety of patterns: two of them produced a strong contrast between the transitional and vowel-related durations, two produced a slight contrast, and one produced a strong reverse contrast (the transitional movements being longer than the vowel-related movements). None of the speakers who stutter produced as great a contrast as the two most strongly contrasting normal speakers. One stutterer produced a reverse contrast, but it was not as great as that of the reversing normal speaker (see Figure 23).

The contrast of transitional and vowel-related distance was even stronger than that for duration. Four of the normal speakers produced a strong contrast between transitional and vowel-related movements, and one normal speaker produced a strong reverse contrast. None of the speakers who stutter produced a strong distance contrast (see Figure 24).

CHAPTER FOUR

RESULTS UNDER THE EXPERIMENTAL CONDITIONS

4.1. INTRODUCTION

This chapter will describe the behavior of both the normal speakers and the speakers who stutter under the experimental conditions: one half octave lower frequency altered feedback (LAF); one half octave higher frequency altered feedback (HAF), delayed auditory feedback of 50 milliseconds (DAF); and 85 dB Noise. A further condition of Self-Monitoring under noise was also included in order to examine the effects of preventing speakers from hearing their own voices via bone conduction while under the Noise condition.

As in the previous chapter, acoustic durations will be described first; then movement duration, distance and peak velocity; and lastly vertical and horizontal position. Within each section, the effects on condition in the two groups will be compared using repeated measures ANOVA; then the effects of condition on individual speakers will be examined using one way ANOVA.

In order to create the equal numbers of tokens under each condition necessary to perform the repeated measures ANOVA, values were removed using a random numbers table, within speaker, speech segment, and position in the word, until there were equal numbers of values in each condition. For the movement variables, to the extent possible, equal numbers of closing and opening movements were removed. Speaker N4 was excluded from the repeated measures ANOVA because the HAF condition was missing. Because of the number of missing conditions for /k/ position, differences among the conditions appeared to result more from the presence or absence of particular speakers in each of the conditions than from the effects of the conditions themselves. Therefore, only within-subject comparisons were made of tongue rear position.

4.2. ACOUSTIC DURATION

The durations of both voicing and the unvoiced segments of the acoustic signal were significantly affected by both group and condition; both movement types also had a significant interaction effect between group and condition. The speakers who stutter had longer durations of both voicing and the unvoiced segments than the normal speakers under every condition. Voicing duration was longer in both groups under all the experimental conditions than under the Control condition. Although in both groups voicing duration was longest under Noise and Self-Monitoring, among the normal speakers duration was longest under Noise, and among the stutterers duration was longest under Self-Monitoring (see Figure 25 and Table 29 for means and standard deviations, and for the significance of the comparisons).

Variability of voicing duration among the normal speakers was higher under all the experimental conditions (except DAF) than under the Control condition. The speakers who stutter had higher variability than the normal speakers under all the conditions. However, the stutterers' variability was lower under all the experimental conditions (except Self-Monitoring) than under the Control condition (see Figure 26).

The durations of the unvoiced segments of the normal speakers were also longer under all the experimental conditions than under the Control condition. However, among the speakers who stutter, the durations of the unvoiced segments were longer only under DAF and Self-Monitoring; duration under Noise was shorter, and the durations under LAF and HAF did not differ significantly from the duration under the Control condition (see Figure 27 and Table 30 for description of means and standard deviations, and for the significance of the comparisons).

Variability of the unvoiced segments among the normal speakers was greater under all the experimental conditions (except HAF) than under the Control condition. The speakers who stutter again had higher variability than the normal speakers under all the conditions. For the stutterers, variability decreased under LAF, DAF, and Self-Monitoring relative to their variability under the Control condition.

4.3. DURATION OF MOVEMENT

As was reported for the acoustic durations, the durations of both transitional and vowel-related movements were significantly affected by both group and condition. For both movement types, the durations of the speakers who stutter were longer than those of the normal speakers under every condition. Furthermore, in both groups, the duration of both transitional and vowel-related movements increased under all the experimental conditions. For the transitional movements only, there was a significant interaction effect between group and condition (see Figures 29 to 32, and Tables 31 and 32 for further description of means and standard deviations, and for the significance of the various comparisons).

Variability of movement duration was higher among the speakers who stutter than the normal speakers under every condition for both transitional and vowel-related movements (see Figures 30 and 32). Among the normal speakers, the variability of both movement types increased under all the experimental conditions. Among the stutterers, the two movement types did not share a consistent pattern. Variability of the transitional movements was higher under HAF and the Noise condition than under the Control condition; in contrast, variability of the vowel-related movements decreased under LAF and DAF.

4.4. DISTANCE OF MOVEMENT

The distance of transitional movement was significantly affected by both group and condition; in addition, there was a significant group by condition interaction. The speakers who stutter had longer mean transitional distances under every condition than the normal speakers. In both groups, transitional distance increased under Noise, and decreased under the other experimental conditions, with the greatest decrease occurring under the Self-Monitoring condition (see Figure 33 and Table 33 for means and standard deviations, and the significance of the comparisons).

Vowel-related distance was not significantly affected by group; however there was a significant effect of condition, and a significant group by condition effect. In both groups, vowel-related distance was longest under Noise and shortest under the Self-Monitoring condition (see Figure 35 and Table 34 for means and standard deviations, and the significance of the comparisons). This corresponded to the increased intensity under the Noise condition, and decreased intensity under Self-Monitoring.

Variability of distance in both groups was lower under the experimental conditions than the Control condition for both transitional and vowel-related movements. For transitional movements, the speakers who stutter were more variable than the normal speakers under the Control condition, HAF, DAF and the Self-Monitoring condition; the normal speakers had greater variability under LAF and Noise (see Figure 34). Variability of the vowel-related movements was greater under all the conditions among the speakers who stutter than the normal speakers (see Figure 36).

4.5. PEAK VELOCITY OF MOVEMENT

Transitional peak velocity was significantly higher among the speakers who stutter than the normal speakers; however, for vowel-related peak velocity there was no significant effect of group. Condition had a significant effect: peak velocity was higher under the Control and Noise conditions than under the other conditions in both groups for both movement types. There was also a significant group by condition interaction for both movement types. In both groups, peak velocity was lowest under the Self-Monitoring; however, under this condition, the normal speakers had a much lower peak velocity than the stutterers (see Figures 37 and 39, and Tables 35 and 36 for means and standard deviations, and for the significance of the various comparisons).

Variability in both groups was highest under the Control and Noise conditions. The normal speakers had the lowest variability under the Self-Monitoring condition for both movement types; the stutterers did not show this effect (see Figures 38 and 40).

4.6. POSITION

Tongue position was measured at (1) the onset of frication for /s, ʃ/, or at the onset of silence for /t^1/; and (2) at the point of maximum opening of the vowel for /æ, ɑ/. For the statistical analysis, the phonemes were collapsed into two groups, the consonants /s, ʃ, t^1/ and the vowels /æ, ɑ/. As previously noted, the position of /k/ was not analyzed because of the number of missing conditions.

Both vertical and horizontal position of the consonants, and the vertical position of the vowels showed a significant effect of group; however, the horizontal position of the vowels did not. Among the stutterers the consonants were lower and the vowels were higher under all conditions than among the normal speakers. It is interesting that this was not reflected in the distance measures, which showed no significance between the two groups in vowel-related distance. In the horizontal dimension, the consonants were more anterior among the stutterers than the normal speakers.

There was a significant effect of condition on all four measures. Both groups were higher under the experimental conditions than the Control condition for both consonants and vowels, except for the vowels under the Noise condition, which were lower in both groups. The latter finding was consistent with the longer vowel-related distances under Noise. Vowel position was more posterior in both groups under the experimental conditions, except under the Self-Monitoring condition (see Tables 37 to 39, and Figures 41, 43, 45 and 47 for means and standard deviations, and for the significance of the various comparisons). A summary of the differences in position between the Control and experimental conditions is seen in Figure 49.

Variability was affected differently in the two groups. Among the normal speakers, vertical variability was not affected in a consistent way by the experimental conditions. Among the speakers who stutter, vertical consonant variability increased under all the experimental conditions. In contrast, vertical vowel variability decreased under all the conditions except for Self-Monitoring. Horizontal variability among the normal speakers was higher under all the experimental conditions for both consonants and vowels. In contrast, horizontal variability decreased under all the experimental conditions among the speakers who stutter, for both consonants and vowels (see Figures 42, 44, 46 and 48).

4.7. INDIVIDUAL SPEAKERS

All of the speakers were affected by the experimental conditions. However, individual speakers in both groups varied in their susceptibility and direction of response to the various feedback conditions. Although individuals varied from each other in the direction of their response to the experimental conditions, one of the most striking features was that the direction of response within each individual was almost always consistent in all the conditions that were effective (see Tables 41 to 69). Out of 130 speaker by variable comparisons, only eight showed different effects of condition: voicing duration of N1 and N2, vowel-related distance of N3 and N5, vowel-related peak velocity of S2, vertical and horizontal position of the vowel of S2, and vertical position of /s, ʃ, t^l/ of S3. This consistency of effects was unexpected, since it was originally anticipated that the auditory feedback conditions would vary in their effects on speakers. For example, it was expected that durations would be longer under DAF and perhaps Noise; and unaffected or perhaps even shortened by frequency altered feedback. Instead, it appeared that any alteration in auditory feedback had effects on speech that varied more with the speaker than with the type of feedback.

Duration generally increased under the experimental conditions (see Table 69 for a summary of the percentage of speaker by condition comparisons showing significant changes from the Control condition). Sixty-nine out of 196 (35%) speaker by condition by duration comparisons showed a significant effect of condition on duration, and all but six of these had durations that were longer. Speaker S3, who was the slowest speaker, was the only speaker whose durations were not affected by the experimental conditions.

Movement distance was less consistently affected by condition. Out of 98 speaker by condition by distance comparisons, 33 (34%) showed effect of condition: twenty four had longer distances and nine had shorter distances than under the Control condition.

Peak velocity tended to be lower under the experimental conditions. Out of 98 speaker by condition by peak velocity comparisons, 37 (38%) showed an effect of condition; thirty two were lower and only five were higher in peak velocity than under the Control condition.

Vertical position was affected in 28 out of 89 (31%) of comparisons. Both vowels and consonants were more likely to be raised than lowered (twenty two comparisons were higher, and six were lower). Sixteen of the eighteen significant comparisons were more posterior under experimental conditions than under the Control condition.

CHAPTER FIVE

DISCUSSION AND CONCLUSIONS

5.1. THE EFFECT OF AUDITORY FEEDBACK ON NORMAL SPEAKERS

Under the experimental conditions, the normal speakers demonstrated greater difficulty with motor control than under the Control condition, as evidenced by longer durations of voiced and unvoiced acoustic segments, and transitional and vowel-related movements, and lower peak velocity of both transitional and vowel-related movements. Moreover, the normal speakers had increased variability of all durational measures under the experimental conditions.

Peak velocity and the variability of peak velocity decreased under all the experimental conditions except the Noise condition for both the transitional and vowel-related measures. The greatest decreases in both peak velocity and variability of peak velocity was under the Self-Monitoring condition for both movement types. This was consistent with the longer durations and shorter distances under this condition.

In contrast to the findings for the durational and peak velocity measures, distance was not consistently affected by changes in auditory feedback. The greatest effect on distance was under the Self-Monitoring condition, which decreased both transitional and vowel-related distances. This was most likely due to the effort to reduce intensity. The variability of distance decreased under both DAF and the Self-Monitoring conditions.

Thus, interference with auditory feedback produced smaller and more controlled movements. The contrast in the effects of auditory feedback on duration and peak velocity versus spatial measures suggests that normal speakers are more dependent on auditory feedback for the regulation of timing of movement than for distance of movement.

5.2. COMPARISON OF SPEAKERS WHO STUTTER TO NORMAL SPEAKERS

The findings of this study support the theory that speakers who stutter have ongoing difficulty with motor control of articulation. Under the Control condition, speakers who stutter had longer acoustic and movement durations, and decreased distance and peak velocity of the vowel-related movements compared to the normal speakers. Consistent with decreased vowel-related distance, vertical position for the consonants was lower and vertical position for the vowels was higher among the stutterers than the normal speakers. These findings suggest that stutterers not only slow down, but also reduce the spatial extent of movement in order to maintain control of speech. In spite of these strategies, variability was higher among the stutterers than the normal speakers for all acoustic and movement measures.

The speakers who stutter did not differentiate the horizontal position of the tongue tip for /ʃ/ from that for /s, t^1/, as the normal speakers did. Although their production of /ʃ/ was not perceptibly distorted, the stutterers produced /ʃ/ in a more advanced position than that of the normal speakers. The lack of differentiation of /ʃ/ from /s, t^1/ suggests that the speakers who stutter tightly constrain movement of the tongue tip in space. When viewed in the context of the longer durations and lower peak velocities of the speakers who stutter, this relative lack of movement in space suggests that, in spite of (or perhaps because of) the high degree of variability in the movement measures, articulatory movement is rigidly controlled.

The findings of this study are consistent with those of a number of previous studies of the speech of speakers who stutter. Longer durations were described by Di Simoni (1974), Hillman and Gilbert (1977), Colcord and Adams (1979), Zimmerman (1980), Adams (1987), Peter and Boves (1988), McClean et al. (1990, 1991), Boutsen (1995), De Nil (1995), and Jancke et al. (1997). Decreased displacement and peak velocity were described by Zimmerman, (1980) and Jancke et al. (1997). The higher variability among speakers who stutter than normal speakers is also in agreement with the results of previous studies. Greater variability of voicing duration was found by Di Simoni (1974), Adams (1987), Janssen and Wieneke (1991), and Jancke (1994); Zimmerman (1980) found greater variability of movement duration; and Bergmann (1986) found greater variability in the timing of stressed syllables.

The speakers who stutter did not produce as great a contrast between the transitional and vowel-related movements as the normal speakers did. Although both types of movements had longer durations among the stutterers than the normal speakers, the duration of the transitional movements was proportionately greater than the duration of the vowel-related movements. As a result, the stutterers did not produce as great a contrast between transitional and vowel-related durations as the normal speakers did (see Figure 51).

It is noteworthy that this tendency towards equalization of transitional and vowel-related movements was not reflected in the durations of the acoustic segments with which they overlapped. Within the CVC target word, the duration of the vowel was relatively longer in comparison to the duration of the consonants among the stutterers than among the nonstutterers (see Figure 50). This simultaneous lengthening of transitional movements and voicing for the vowel was achieved by a greater overlap between voicing and the transitional movements.

Like movement duration, movement distance and peak velocity also showed less contrast between transitional and vowel-related movements among the stutterers than the normal speakers (see Figures 52 and 53). This decreased contrast between transitional and vowel-related movements suggests that speakers who stutter may have difficulty in producing rapid alternations of movements. This is intriguing for several reasons.

First, production of alternating movements is not a direct target of therapeutic intervention, in the same way that slow rate is. Therefore, the decreased differentiation of these two movement types is not a consciously learned therapeutic technique, but is either a part of the stuttering complex of behaviors, or a perhaps an unconsciously learned motoric strategy to avoid stuttering.

Second, this finding is consistent with the suggestions of Wingate (1969) and Brayton and Conture (1978) that people who stutter have difficulty with rapid adjustments of phonation. For this reason, Perkins et al. (1979) and Andrews et al. (1982 and 1983) suggested that delayed auditory feedback improves fluency because it slows speech, and thus decreases the rapidity of with which phonatory adjustments must be made. However, since some of the stutterers in this study did have relatively rapid rates of fluent speech, perhaps it is not so much the actual rate of speech that is critical, as it is the interaction between rate and relative durations of the segments. Slowing the overall rate would enable the production of normal alterations in duration without the necessity for rapidity in alternating long and short movements. Alternately, a more rapid rate could be achieved by making the long and short movements relatively equal in duration. Fluency enhancing interventions that supply an external temporal framework, such as choral reading or use of a metronome, may actually also be lengthening the durations of transitional speech movements, and thus reducing stress contrast. Behavioral interventions such as prolongation may also be effective because they reduce temporal contrast between stressed and unstressed syllables.

The decreased contrast between transitional and vowel-related movements may also be related to another motor control theory, which states that people who stutter have "dysrhythmic" speech (Wendahl & Cole, 1961; Brown & Colcord, 1987). The exact nature of the speech behaviors that give rise to the perception of less normal speech rhythm is not clear, but previous researchers have related this subjective perception of dysrhythmia to the greater variability found among stutterers than nonstutterers, or to the greater number of brief pauses found in the speech of speakers who stutter (Wendahl & Cole, 1961; Love & Jeffress, 1971). Thus, fluency-enhancing interventions are thought to decrease intrasubject variance in speech production by supplying an external temporal framework for the coordination of articulatory movements. However, it is possible that what listeners are perceiving is a mild form of the "excess and equal stress" found in speakers with more severe forms of motor speech disorders (Darley et al., 1975).

Based on the results of this study, stuttering has a more pervasive effect on speech than is evident in intermittent dysfluencies. This study cannot establish whether the differences between the stutterers and the normal speakers are part of an underlying motor control problem that produces both dysfluencies and differences in movement and position variables, or whether the stutterers are changing their behaviors in order to avoid dysfluencies. Since the target word and carrier phrase in this study were not intended to elicit alternations in emphasis of production, further investigation using stimuli that employ stressed and unstressed syllables in a systematic manner is needed before the findings of this study can be regarded as valid with respect to the production of transitional and vowel-related movements in general.

5.3. INDIVIDUAL SPEAKERS

Under the Control condition, the individual speakers who stutter varied more in their means than the normal speakers for the duration, distance and peak velocity measures. Variability of the durational measures was higher among the speakers who stutter than the normal speakers, while variability of distance and peak velocity was generally less.

Previous participation in behavioral therapy did not necessarily result in prolonged durations. Three of the speakers who stutter, S1, S2, and S5, had previously participated in behavioral therapy that included the targets of prolonged phonation, gentle onsets, and light articulatory contacts. However, of these three speakers, only S2 had significantly longer mean voicing duration than the normal speakers. Speaker S1 did not differ significantly from the normal speakers, while S5 had significantly shorter acoustic and movement durations than the normal speakers.

The speaker with longest phrase, voicing and movement durations was the oldest speaker. This subject had received only "elocution style" therapy when in school, more than 30 years prior to participation in this study. However, his slow rate of speech might have been a self-learned coping strategy to decrease the occurrence of stuttering.

Speakers who stutter are not a homogenous group. Perhaps one reason why past studies have often resulted in contradictory and inconclusive findings is because of this variability among individual speakers. Researchers who are studying the speech of stutterers should describe the characteristics of individual speakers as well as group results. At this point of our knowledge in this field, more data on individual speakers would assist considerably in our understanding of the speech characteristics of speakers who stutter.

5.4. THE EFFECT OF AUDITORY FEEDBACK ON SPEAKERS WHO STUTTER

The effect of auditory feedback on the speakers who stutter was similar to its effect on normal speakers. Under the experimental conditions, both groups increased acoustic and movement duration, and decreased peak velocity. Both groups responded inconsistently with regard to distance under the experimental conditions. The greatest effect on spatial measures came from the Noise and Self-Monitoring conditions, which also involved alterations in speech intensity.

Vertical position of the speakers who stutter under the experimental conditions was higher for both the tongue tip consonants and the vowels, as it was among the normal speakers. Although horizontal position for the tongue tip consonants was not significantly affected, examination of the positions of these consonants showed that /s, ʃ, t^{l}/, which already under the Control condition were not differentiated from each other, were even closer together under the experimental conditions (see Figure 49). This suggests that the stutterers responded to the perturbations in auditory feedback by further reducing their already restricted horizontal excursion.

Interestingly, the variability of vertical position for the vowel, which increased among the normal speakers under the experimental conditions, was unaffected among the speakers who stutter. The reason for this is not clear; however, it should be noted that the variability of the vowel was already extremely high under the Control condition for the stutterers.

Thus it appears that, even for those variables which were not affected by the experimental conditions in the same way in both groups, dysfunctional auditory processing among the speakers who stutter did not cause the differences. This is supported by three other findings:

First, the duration measures were affected by all of the experimental conditions, not just DAF, as would be expected if there was difficulty with the timing of auditory speech processing. Nor did frequency altered feedback affect position more notably than any of the other feedback conditions, as would be expected if the subjects were using formant frequency information to regulate tongue placement.

Second, individual speakers in both groups tended to respond to all the changes in auditory feedback in the same way, despite the fact that the different types of auditory feedback used in this study varied in their alterations of the feedback, i.e., timing information was affected under delayed auditory feedback, frequency information under frequency altered feedback, and all acoustic information under Noise and the Self-Monitoring condition. If the various forms of auditory feedback were compensating for deficiencies in the auditory processing of the stutterers, we would expect to see effects that were condition specific, for example, longer durations under delayed auditory feedback, or position differences under frequency altered feedback. Furthermore, we would expect to see similar changes in the normal speakers, since their presumably normal auditory processing was no doubt being perturbed by the same alterations in auditory feedback.

However, the effects of the various types of auditory feedback were specific to individual speakers, rather than to the type of alteration of feedback. It was notable that, for the most part, speakers were affected in the same direction under all the conditions for which they had significant differences. Out of 130 speaker by variable comparisons, 53 comparisons showed significant effects from more than one condition. Of these 53 comparisons, in 45 comparisons the direction of the effect was the same in all the affected conditions. For example, with regard to distance, speaker S2 had significantly greater distances under the experimental conditions, while speakers S3 and S4 had significantly smaller distances under the experimental conditions.

The fact that individual speakers tended to be affected in the same way by all the forms of auditory feedback suggests that the effects of auditory feedback are more specific to the speaker than to the type of auditory feedback. The effects of auditory feedback reflected a nonspecific interference with normal sensorimotor integration: longer durations and increased variability of durations, lower peak velocity and lower variability of peak velocity, and higher positioning. Since the effects were more specific to the speakers than to the forms of auditory feedback, it suggests that each speaker was responding in an individualistic way to a disruption of the usual sensorimotor feedback system.

The third argument against the theory that the speakers who stutter have a dysfunctional auditory system is that the stutterers tended to respond in the same way as normal speakers, but to an even greater extent. Under altered auditory feedback, the stutterers controlled articulatory movement was even more rigidly than under the control conditions. The normal speakers increased durations; the stutterers increased duration even more. The normal speakers decreased positional changes; the stutterers decreased them even more. Decreases in variability appear to be not so much the result of improved feedback regulation of the system, as the result of slowed rate and increased constraints on positional changes. It appears that the stutterers, who are experts at responding to a perturbed motor system, reacted to the perturbation of the auditory system by using their coping mechanisms even more extensively than the normal speakers did. If the experimental conditions were improving sensorimotor integration in the speakers who stutter, we would expect to see some release from the rigidity of control that was seen under the Control condition.

The similarities between the responses of the speakers who stutter and the normal speakers to the experimental conditions support the theory that it is only motor control that is impaired in speakers who stutter. If their auditory processing was abnormal, we would expect that the effects of alterations in auditory feedback would be different among the stutterers than the nonstutterers. In particular, if stuttering occurs because of aberrations in auditory processing that are corrected by the various forms of fluency enhancing auditory feedback, we would expect that the speech of the stutterers would more closely approximate that of the nonstutterers under the Control condition. This did not happen.

Instead, the durations of the speakers who stutter, which were already longer than those of the normal speakers under the Control condition, became even longer under the experimental conditions. The peak velocity, which was lower than that of the normal speakers under the Control condition, became even lower under the experimental condition. The variability of all the acoustic and movement measures, which were higher than those of the normal speakers, remained higher under the experimental conditions.

5.5. COMPARISON OF CONDITIONS

Although there was a tendency for each of the speakers to respond to all the conditions in the same way, the conditions that eliminated all auditory feedback, i.e., the Noise and Self-Monitoring conditions, had a greater effect than the other conditions on both normal speakers and speakers who stutter. These two conditions produced longer durations than the frequency altered and delayed auditory feedback conditions.

Although under the Noise condition there was a tendency for distance to be greater in both groups, the increase achieved significance only among the speakers who stutter. The increase in distance under the Noise condition appeared to be part of the increased intensity from the Lombard effect. However, only the speakers who stutter responded to this condition by opening their articulators further under this condition. In contrast, the normal speakers were not significantly affected by the Noise condition. The reason for this difference between the groups is not clear.

Under the Self-Monitoring condition there was a tendency for distance to be less than under the other conditions; however, only among the normal speakers did this decrease achieve significance. This decrease in amplitude of tongue tip lowering appeared to be part of a strategy to decrease intensity. It is unclear as to why the speakers who stutter did not respond as the normal speakers did to the Self-Monitoring condition; it is possible that, since most of the stutterers had participated in therapy, they were more experienced in self-monitoring.

5.6. IMPLICATIONS FOR THERAPY

Story (1994; see also Story et al., 1996) found that after a course of therapy that targeted stretched syllables and slow articulatory transitions, all three stutterers had longer acoustic phrase and vowel durations, decreased displacement of lip and jaw movements, and decreased peak velocity of lip closure.

Kalinowski (1994) examined lip and jaw movement in the fluent utterances of four speakers who stutter before and after treatment by Van Riperian type therapy. Although motor speech behavior did not change as consistently as in Story's study, some articulatory changes did occur: one of the four subjects had longer phrase durations after treatment; and three of the four speakers had reduced displacement and decreased peak velocity after treatment.

In the present study, although not every subject was affected by every condition, the overall effect of the experimental conditions was the same as that found by Story (1994), and to a lesser extent by Kalinowski (1994): longer voicing durations, decreased distance, and decreased peak velocity. Therefore, enhanced fluency, whether it is induced by behavioral therapy or auditory feedback, is often accompanied by longer durations, decreased distance, and lower peak velocity.

It is tempting to claim that the effects of auditory feedback on fluency directly resulted from the observed motoric changes of slowed rate, decreased distance, and resulting decreased peak velocity. However, making such a claim risks oversimplifying the relationship between articulatory movement and fluency. For example, Andrews et al. (1982) were unable to find a common effect of a variety of fluency enhancing conditions.

If such a direct relationship did exist, fluency therapy would be very simple: a simple change in motor speech behavior would eliminate all stuttering. Fluency therapy is usually not that straightforward.

Since at the present time we do not know what triggers stuttering events in speakers who stutter, it is difficult to specify how altered auditory feedback enhances fluency. However, in addition to direct changes in motoric behaviors, there are other two ways in which altered auditory feedback may alter habitual sensorimotor integration.

First, by its novelty, altered auditory feedback may reduce the psychological expectation of stuttering. This in turn may function as a psychological "distracter" or may reduce physical tension associated with the act of speaking. Further research is needed to test the effects of altered auditory feedback on muscular activation, autonomic arousal, and the expectation of stuttering.

Second, altered auditory feedback may alter habitual sensorimotor integration. It is well documented that a large number of changes in motor behavior or sensory feedback can increase fluency, at least temporarily (Bloodstein, 1995). For example, singing, choral reading, shadowing, speaking slowly, speaking at a higher or lower pitch, or changing intensity have all been shown to increase fluency (Andrews et al., 1982). However, a hallmark of these types of alterations is that the benefits on fluency do not persist after the user becomes habituated to them. Since in the past, delayed and frequency altered feedback have rarely been used habitually, there has never really been a test as to whether clients would cease to have improvement if they used auditory feedback habitually. To determine if altered auditory feedback works by disrupting habitual speech, further investigation of the long-term effects of auditory feedback on fluency is needed.

5.7. CONCLUSIONS

Under the Control condition, the speakers who stutter had longer acoustic and movement durations, and greater variability of acoustic and movement duration, distance, and peak velocity. The position of consonants was lower, and position of vowels was higher among the stutterers than the nonstutterers; variability of position was lower among the stutterers than the nonstutterers. In addition, speakers who stutter did not produce as great a contrast between transitional and vowel-related movements as the normal speakers did. These results support the theory that speakers who stutter have an ongoing difficulty with motor control that results in differences from the speech of nonstutterers even during fluent production of short phrases.

Both groups responded to similarly to changes in auditory feedback, with longer acoustic and movement durations, lower peak velocity, decreased distance, and higher tongue tip position for the vowels. Thus, altered auditory feedback perturbed movement timing in both normal speakers and speakers who stutter. Individual speakers tended to respond in the same way to all the experimental conditions. This suggested that the effects of altered auditory feedback on speech production are not specific to the type of perturbation to the system, that is, frequency altered feedback did not selectively affect tongue position, and delayed auditory feedback did not selectively affect speech timing. For this reason, it appears that altered auditory feedback does not selectively compensate for specific disturbance of auditory processing. The effects of auditory feedback are similar to the effects of behavioral therapy on acoustic and movement variables.

Table 1. Description of Speakers

Subject	Age	Gender	SSI Score	Last Therapy	Type of Therapy
N1	56	male	0	n.a.	
N2	22	female	0	n.a.	
N3	34	male	0	n.a.	
N4	33	female	0	n.a.	
N5	29	male	0	n.a.	
S1	32	male	26	18 months	fluency shaping, with DAF
S2	22	female	17	9 months	fluency shaping, with DAF
S3	52	male	13	> 30 years	"relax, slow down"
S4	30	female	17	> 12 months	psychotherapy
S5	39	male	0	9 months	stuttering modification and fluency shaping

Table 2. The Number of Tokens Discarded Because Judged Stuttered

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1							50
N2		1					50
N3						1	50
N4	1						50
N5							50
S1	1		1				50
S2						1	50
S3	5	5	2	1	6	1	50
S4	1						50
S5						1	50

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Max = the maximum possible number of tokens that could occur under each condition

Table 3. Number Of Tokens Used In Acoustic Analysis By Subject And Condition

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1	50	49	49	50	49	48	50
N2	50	50	50	50	50	47	50
N3	50	50	49	49	48	49	50
N4	49	49	0	50	50	48	50
N5	49	50	49	50	49	48	50
S1	49	49	49	50	50	49	50
S2	48	50	50	50	47	49	50
S3	40	41	44	48	38	49	50
S4	48	50	50	50	50	48	50
S5	50	50	50	50	49	46	50

Table 4. Number Of Tongue Tip Tokens Used For Movement Analysis By Subject And Condition

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1	49	49	49	50	49	48	50
N2	50	48	50	50	50	47	50
N3	50	50	49	49	48	49	50
N4	49	49	0	50	50	47	50
N5	49	49	49	50	48	45	50
S1	46	46	48	49	49	49	50
S2	46	50	47	48	44	46	50
S3	40	41	44	48	38	49	50
S4	0	0	0	0	0	0	50
S5	50	50	50	50	0	46	50

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Max = the maximum possible number of tokens that could occur under each condition

Table 5. Number Of Tongue Rear Tokens Used For Movement Analysis By Subject And Condition

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1	20	19	0	0	10	0	20
N2	20	19	20	20	20	20	20
N3	20	20	18	20	20	19	20
N4	20	20	0	20	20	19	20
N5	20	20	19	20	20	18	20
S1	18	20	19	19	20	19	20
S2	19	0	20	20	0	0	20
S3	17	16	18	22	13	19	20
S4	0	0	0	0	0	0	20
S5	20	20	0	0	19	0	20

Table 6. Number of Lip Aperture Tokens Used For Movement Analysis By Subject And Condition

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1	21	20	20	20	19	19	20
N2	20	20	19	20	20	19	20
N3	20	20	21	20	18	20	20
N4	19	21	0	20	20	19	20
N5	19	20	20	20	18	19	20
S1	20	18	19	21	20	20	20
S2	19	20	20	20	19	20	20
S3	19	19	20	19	19	20	20
S4	19	20	21	20	20	20	20
S5	20	20	20	20	20	18	20

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Max = the maximum possible number of tokens that could occur under each condition

Table 7. Number Of Tongue Tip Tokens Used For Position Analysis By Subject And Condition

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1	49	0	0	0	0	0	50
N2	50	50	50	50	50	47	50
N3	50	0	0	49	48	0	50
N4	49	49	0	50	49	48	50
N5	49	50	49	50	48	47	50
S1	49	49	49	50	50	49	50
S2	48	50	50	50	47	49	50
S3	40	0	44	48	38	0	50
S4	0	0	0	0	0	0	50
S5	50	48	0	0	0	0	50

Table 8. Number Of Tongue Rear Tokens Used For Position Analysis By Subject And Condition

Subjects	Con	LAF	HAF	DAF	Noise	Mon	Max
N1	20	19	0	0	0	0	20
N2	20	19	20	20	20	20	20
N3	20	0	0	20	20	0	20
N4	20	20	0	20	20	19	20
N5	20	20	19	20	20	18	20
S1	19	20	19	19	20	19	20
S2	19	0	20	20	0	0	20
S3	17	0	18	20	13	0	20
S4	0	0	0	0	0	0	20
S5	20	20	0	0	19	0	20

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Max = the maximum possible number of tokens that could occur under each condition

Table 9. Acoustic Duration (Milliseconds) Under The Control Condition

Normal Speakers	*Mean*	*SD*	Range	Cases
Voiced	817	102	566 to 994	248
Unvoiced	425	68	269 to 659	248
Speakers Who Stutter				
Voiced	856	176	571 to 1344	234
Unvoiced	458	157	0 to 969	234
Two Way ANOVA	*df*	*MS*	*F*	*p*
Group	1	312032	17.92	$p < 0.01$
Voicing Type	1	37000000	2153.28	$p < 0.01$
Interaction	1	2321.75	0.13	not sig.
Error	960	17408.10		
Levene	3, 960		59.82	$p < 0.01$

Table 10. Duration Of Movement (Milliseconds) Under The Control Condition

Normal Speakers	*Mean*	*SD*	Range	Cases
Transitional	165	61	41 to 367	441
Vowel-Related	183	40	94 to 315	447
Speakers Who Stutter				
Transitional	187	82	38 to 470	363
Vowel-Related	197	66	57 to 540	338
Two Way ANOVA	*df*	*MS*	*F*	*p*
Group	1	130307	33.07	$p < 0.01$
Movement Type	1	75166.70	19.08	$p < 0.01$
Interaction	1	6355.70	1.61	not sig.
Error	1585	3940.27		
Levene	3, 1585		60.57	$p < 0.01$

Table 11. Distance Of Movement (Centimeters) Under The Control Condition

Normal Speakers	*Mean*	*SD*	Range	Cases
Transitional	0.951	0.539	0.059 to 4.012	441
Vowel-Related	1.572	0.49	0.528 to 4.481	447
Speakers Who Stutter				
Transitional	1.022	0.564	0.099 to 3.869	363
Vowel-Related	1.465	0.718	0.151 to 4.402	338
Two Way ANOVA	*df*	*MS*	*F*	*p*
Group	1	0.12736	0.39	not sig.
Movement Type	1	110.886	335.47	$p < 0.01$
Interaction	1	3.09033	9.35	$p < 0.01$
Error	1585			
Levene	3, 1585		26.69	$p < 0.01$

Table 12. Peak Velocity Of Movement (Centimeters Per Second) Under The Control Condition

Normal Speakers	*Mean*	*SD*	Range	Cases
Transitional	10.67	6.44	1.31 to 52.25	441
Vowel-Related	18.08	6.62	6.05 to 48.37	447
Speakers Who Stutter				
Transitional	10.91	6.59	1.10 to 34.59	363
Vowel-Related	15.68	8.04	2.05 to 44.06	338
Two Way ANOVA	*df*	*MS*	*F*	*p*
Group	1	456.99	9.61	$p < 0.01$
Movement Type	1	14525.99	305.47	$p < 0.01$
Interaction	1	681.97	14.34	$p < 0.01$
Error	1585			
Levene	3, 1585		26.69	$p < 0.01$

Table 13. Vertical Position (Centimeters) Of Target Consonants And Vowels Under The Control Condition

Normal Speakers	*Mean*	*SD*	Range	Cases
/s/	0.573	0.377	0.282 to 1.022	97
/ʃ/	0.546	0.342	-0.088 to 1.080	98
initial /t/	0.730	0.207	0.468 to 1.064	50
/k/	1.819	0.473	0.839 to 3.202	100
/æ/	-0.519	0.264	-1.229 to 0.029	147
/ɑ/	-0.694	0.331	-1.425 to 0.541	100
Speakers Who Stutter				
/s/	0.358	0.155	-0.157 to 1.715	74
/ʃ/	0.468	0.247	-0.031 to 1.613	72
initial /t/	0.503	0.165	-0.189 to 0.742	35
/k/	1.253	0.683	0.458 to 2.228	75
/æ/	-0.384	0.234	-1.464 to 0.126	109
/ɑ/	-0.461	0.278	-1.337 to 0.346	78
Two Way ANOVA /s, ʃ, t/	*df*	*MS*	*F*	*p*
Group	1	2.794	39.46	$p < 0.01$
Phoneme	2	0.631	8.91	$p < 0.01$
Interaction	2	0.250	3.53	$p < 0.05$
Error	420	0.0708		
Levene	5, 420		11.46	$p < 0.01$
Two Way ANOVA /æ, ɑ/	*df*	*MS*	*F*	*p*
Group	1	3.479	47.32	$p < 0.01$
Phoneme	1	1.652	22.47	$p < 0.01$
Interaction	1	0.246	3.35	not sig.
Error	430	0.07352		
Levene	3, 430		4.22	$p < 0.01$
One Way ANOVA /k/	*df*	*MS*	*F*	*p*
Between Groups	1	13.694	37.75	$p < 0.01$
Within Groups	173	0.363		
Total	174			
Levene	1. 173		40.70	$p < 0.01$

Table 14. Horizontal Position (Centimeters) Of Target Consonants And Vowels Under The Control Condition

Normal Speakers	*Mean*	*SD*	Range	Cases
/s/	-0.436	0.455	-2.335 to 0.358	97
/ʃ/	0.0164	0.215	-0.621 to 0.533	98
initial /t/	-0.173	0.510	-0.634 to 1.044	50
/k/	3.462	1.299	1.900 to 6.132	100
/æ/	0.057	0.192	-0.302 to 0.629	147
/ɑ/	0.410	0.215	-0.046 to 1.113	100
Speakers Who Stutter				
/s/	-0.305	0.232	-1.183 to 0.021	74
/ʃ/	-0.196	0.237	-1.006 to 0.154	72
initial /t/	-0.319	0.406	-1.299 to 0.520	35
/k/	2.443	1.255	1.184 to 4.601	75
/æ/	0.074	0.193	-0.942 to 0.391	109
/ɑ/	0.509	0.691	-0.049 to 2.715	78
Two Way ANOVA /s, ʃ, t/	*df*	*MS*	*F*	*p*
Group	1	0.536	4.46	$p < 0.05$
Phoneme	2	3.299	27.41	$p < 0.01$
Interaction	2	1.321	10.97	$p < 0.01$
Error	420	0.120		
Levene	5, 420		9.49	$p < 0.01$
Two Way ANOVA /æ, ɑ/	*df*	*MS*	*F*	*p*
Group	1	0.347	2.94	not sig.
Phoneme	1	16.029	135.76	$p < 0.01$
Interaction	1	0.175	1.48	not sig.
Error	430	0.118		
Levene	3, 430		30.17	$p < 0.01$
One Way ANOVA /k/	*df*	*MS*	*F*	*p*
Between Groups	1	44.458	27.12	$p < 0.01$
Within Groups	173	1.639		
Total	174			
Levene	1. 173		0.48	not sig.

Table 15. Duration Of Voicing (Milliseconds) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	817	102	566 to 994	248	
S1	843	70	721 to 1020	48	not sig.
S2	899	69	773 to 1075	48	$p < 0.01$
S3	1173	86	1045 to 1344	40	$p < 0.01$
S4	710	63	571 to 854	48	$p < 0.01$
S5	713	52	605 to 841	50	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	1273167	165.66	$p < 0.01$
Within Subjects		476	7685.513		
Levene		5, 476	476	8.95	$p < 0.01$

Table 16. Duration Of Unvoiced Segments (Milliseconds) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	425	68	269 to 659	248	
S1	556	191	0 to 890	48	$p < 0.01$
S2	487	65	307 to 589	48	$p < 0.01$
S3	605	115	448 to 969	40	$p < 0.01$
S4	384	59	262 to 558	48	$p < 0.01$
S5	291	50	184 to 372	50	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	632354.4	78.38	$p < 0.01$
Within Subjects		476	8067.702		
Levene		5, 476		10.73	$p < 0.01$

Table 17. Duration Of Transitional Movements (Milliseconds) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	165	61	41 to 367	441	
S1	202	68	79 to 394	89	$p < 0.01$
S2	191	80	68 to 470	94	$p < 0.05$
S3	230	82	108 to 422	70	$p < 0.01$
S4	165	71	80 to 264	19	not sig.
S5	139	74	38 to 380	91	$p < 0.05$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	93622.748	20.21	$p < 0.01$
Within Subjects		798	4632.368		
Levene		5, 798		4.10	$p < 0.01$

Table 18. Duration Of Vowel-Related Movements (Milliseconds) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	183	40	94 to 315	447	
S1	213	56	108 to 352	84	$p < 0.01$
S2	191	49	94 to 291	76	not sig.
S3	255	74	97 to 540	70	$p < 0.01$
S4	153	43	100 to 240	19	not sig.
S5	150	38	57 to 249	89	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	106048.2	48.94	$p < 0.01$
Within Subjects		779	2166.913		
Levene		5, 779		9.00	$p < 0.01$

Table 19. Distance Of Transitional Movements (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	0.951	0.539	0.06 to 4.01	441	
S1	1.322	0.386	0.47 to 2.04	89	$p < 0.01$
S2	0.492	0.260	0.10 to 1.36	94	$p < 0.01$
S3	1.567	0.547	0.61 to 3.87	70	$p < 0.01$
S4	0.992	0.175	0.70 to 1.33	19	not sig.
S5	0.861	0.437	0.19 to 1.71	91	not sig.
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	11.708	20.35	$p < 0.01$
Within Subjects		798	0.233		
Levene		5, 798		8.22	$p < 0.01$

Table 20. Distance Of Vowel-Related Movements (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	1.572	0.490	0.53 to 4.48	447	
S1	1.811	0.417	1.02 to 2.76	84	$p < 0.01$
S2	0.811	0.281	0.24 to 1.46	76	$p < 0.01$
S3	2.332	0.652	1.36 to 4.40	70	$p < 0.01$
S4	1.137	0.137	0.92 to 1.39	19	$p < 0.01$
S5	1.086	0.390	0.15 to 1.87	89	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	22.452	108.44	$p < 0.01$
Within Subjects		779	0.219		
Levene		5, 779		9.85	$p < 0.01$

Table 21. **Peak Velocity Of Transitional Movements (Centimeters Per Second) Under The Control Condition**

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	10.7	6.4	1.3 to 52.3	441	
S1	14.3	6.9	4.9 to 34.5	89	$p < 0.01$
S2	4.7	1.9	1.1 to 10.4	94	$p < 0.01$
S3	13.6	4.2	6.6 to 25.6	70	$p < 0.01$
S4	12.9	4.8	7.1 to 21.6	19	not sig.
S5	11.5	7.0	4.3 to 34.6	91	not sig.
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	1048.948	29.09	$p < 0.01$
Within Subjects		798	36.059		
Levene		5, 798		10.46	$p < 0.01$

Table 22. **Peak Velocity Of Vowel-Related Movements (Centimeters Per Second) Under The Control Condition**

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	18.1	6.6	6.1 to 48.4	447	
S1	20.5	8.5	9.2 to 44.1	84	not sig.
S2	8.3	1.9	4.1 to 13.6	76	$p < 0.01$
S3	21.0	7.0	11.5 to 37.6	70	$p < 0.05$
S4	16.1	5.0	8.5 to 25.4	19	not sig.
S5	13.1	5.9	2.1 to 30.9	89	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		5	1357.404	46.65	$p < 0.01$
Within Subjects		779	41.958		
Levene		5, 779		11.01	$p < 0.01$

Table 23. Vertical Position Of /s, ʃ, tʃ/ (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	0.594	0.210	-0.088 to 1.080	245	
S1	0.404	0.189	-0.026 to 0.678	49	$p < 0.01$
S2	0.287	0.162	-0.031 to 0.701	48	$p < 0.01$
S3	0.847	0.459	-0.189 to 1.715	34	$p < 0.05$
S5	0.310	0.259	-0.157 to 0.742	50	$p < 0.01$
One Way ANOVA		*df*	M.S.	*F*	*p*
Between Subjects		4	2.61	45.83	$p < 0.01$
Within Subjects		421	0.057		
Levene		4, 421		21.47	$p < 0.01$

Table 24. Vertical Position Of /æ, ɑ/ (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	-0.590	0.267	-1.425 to 0.541	247	
S1	-0.403	0.196	-0.831 to 0.126	49	$p < 0.01$
S2	-0.288	0.107	-0.514 to -0.026	48	$p < 0.01$
S3	-0.719	0.406	-1.464 to 0.001	40	not sig.
S5	-0.309	0.219	-0.806 to 0.346	50	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		4	2.062	30.84	$p < 0.01$
Within Subjects		429	0.067		
Levene		4, 429		15.95	$p < 0.01$

Table 25. Vertical Position Of /k/ (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	1.819	0.683	0.839 to 3.202	100	
S1	0.967	0.379	0.458 to 1.845	19	$p < 0.01$
S2	1.333	0.097	1.204 to 1.546	19	$p < 0.01$
S3	1.940	0.243	1.535 to 2.228	17	not sig.
S5	0.866	0.081	0.707 to 1.000	20	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		4	6.6	22.42	$p < 0.01$
Within Subjects		170	0.294		
Levene		4, 170		62.64	$p < 0.01$

Table 26. Horizontal Position Of /s, ʃ, tʃ/ (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	-0.201	0.439	-2.335 to 1.044	245	
S1	-0.232	0.169	-0.502 to 0.119	49	not sig.
S2	-0.117	0.156	-0.403 to 0.520	48	not sig.
S3	-0.655	0.324	-1.299 to 0.059	34	$p < 0.01$
S5	-0.172	0.167	-0.486 to 0.134	50	not sig.
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		4	1.782	13.79	$p < 0.01$
Within Subjects		421	0.129		
Levene		4, 421		10.44	$p < 0.01$

Table 27. Horizontal Position Of /æ, ɑ/ (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	0.200	0.266	-0.302 to 1.113	247	
S1	0.231	0.148	0.062 to 0.499	49	not sig.
S2	0.118	0.118	0.168 to 0.428	48	$p < 0.01$
S3	0.557	1.041	0.942 to 2.715	40	not sig.
S5	0.171	0.103	0.062 to 0.412	50	not sig.
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		4	1.313	9.1	$p < 0.01$
Within Subjects		429	0.144		
Levene		4, 429		93.05	$p < 0.01$

Table 28. Horizontal Position Of /k/ (Centimeters) Under The Control Condition

	Mean	*SD*	Range	Cases	*p*
Normal Speakers	3.462	1.299	1.900 to 6.132	100	
S1	4.478	0.078	4.313 to 4.601	19	$p < 0.01$
S2	1.472	0.156	1.184 to 1.936	19	$p < 0.01$
S3	2.370	0.220	2.129 to 2.769	17	$p < 0.01$
S5	1.495	0.174	1.267 to 1.848	20	$p < 0.01$
One Way ANOVA		*df*	*MS*	*F*	*p*
Between Subjects		4	39.78	40.02	$p < 0.01$
Within Subjects		170	0.994		
Levene		4, 170		18.89	$p < 0.01$

Table 29. Duration Of Voiced Segments (Milliseconds) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	816	866	823	839	953	899
SD	108	152	122	109	144	164
Cases	185	185	185	185	185	185
Speakers Who Stutter						
Mean	853	916	908	907	967	1015
SD	172	135	149	143	138	220
Cases	214	214	214	214	214	214

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	2259883.614	23.33	**
Condition	5	1035752.158	134.36	**
Interaction	5	132260.325	17.16	**
Error	1985	7708.890		

Table 30. Duration Of Unvoiced Segments (Milliseconds) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	402	425	432	458	425	466
SD	48	66	51	61	59	78
Cases	179	179	179	179	179	179
Speakers Who Stutter						
Mean	466	466	466	492	441	486
SD	139	113	141	125	138	122
Cases	201	201	201	201	201	201

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	679961.537	13.78	**
Condition	5	142857.403	47.57	**
Interaction	5	28030.678	9.33	.**
Error	1890	3002.930		

Key ** $p < 0.01$
* $p < 0.05$
n.s. not significant

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Table 31. Duration Of Transitional Movements (Milliseconds) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	150	156	153	159	161	163
SD	47	50	52	51	54	54
Cases	336	336	336	336	336	336
Speakers Who Stutter						
Mean	201	215	223	213	213	213
SD	74	74	82	71	86	77
Cases	271	271	271	271	271	271

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	2803581.409	182.41	**
Condition	5	13882.028	7.37	**
Interaction	5	8256.967	4.38	**
Error	3025	1883.394		

Table 32. Duration Of Vowel-Related Movements (Milliseconds) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	175	193	189	194	193	196
SD	43	47	46	55	48	52
Cases	340	340	340	340	340	340
Speakers Who Stutter						
Mean	205	212	212	216	216	218
SD	66	57	67	58	64	68
Cases	261	261	261	261	261	261

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	455498.079	33.58	**
Condition	5	21048.201	21.16	**
Interaction	5	1971.199	1.98	n.s.
Error	2995	994.540		

Key
** $p < 0.01$
* $p < 0.05$
n.s. not significant

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Table 33. Distance Of Transitional Movements (Centimeters) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	0.917	0.900	0.840	0.837	0.985	0.719
SD	0.547	0.484	0.419	0.424	0.546	0.379
Cases	338	338	338	338	338	338
Speakers Who Stutter						
Mean	1.142	1.043	1.105	1.035	1.201	0.990
SD	0.565	0.458	0.526	0.465	0.514	0.494
Cases	269	269	269	269	269	269
Repeated Measures ANOVA	*df*	*MS*		*F*		*p*
Group	1	43.393		41.38		**
Condition	5	3.955		53.51		**
Interaction	5	.328		4.44		**
Error	3025	0.07391				

Table 34. Distance Of Vowel-Related Movements (Centimeters) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	1.595	1.637	1.550	1.524	1.719	1.261
SD	0.518	0.486	0.467	0.438	0.447	0.405
Cases	338	338	338	338	338	338
Speakers Who Stutter						
Mean	1.617	1.511	1.537	1.481	1.715	1.440
SD	0.823	0.632	0.771	0.669	0.794	0.738
Cases	263	263	263	263	263	263
Repeated Measures ANOVA	*df*	*MS*		*F*		*p*
Group	1	0.05162		0.00		n.s.
Condition	5	8.707		93.79		**
Interaction	5	1.494		16.09		**
Error	2995	0.09284				

Key
** $p < 0.01$
* $p < 0.05$
n.s. not significant

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Table 35. Peak Velocity Of Transitional Movements (Centimeters Per Second) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	10.9	10.0	9.6	9.2	10.9	7.7
SD	6.7	5.5	5.2	4.8	6.1	4.4
Cases	338	338	338	338	338	338
Speakers Who Stutter						
Mean	11.8	10.1	10.4	10.1	12.5	9.8
SD	7.0	5.1	5.8	5.6	6.8	5.9
Cases	269	269	269	269	269	269
Repeated Measures ANOVA	*df*	*MS*		*F*		*p*
Group	1	1044.232		6.68		*
Condition	5	712.339		85.41		**
Interaction	5	70.283		8.43		**
Error	3025	8.340				

Table 36. Peak Velocity Of Vowel-Related Movements (Centimeters Per Second) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	18.6	16.8	16.3	15.9	18.5	12.4
SD	6.7	6.5	6.2	5.7	7.5	4.3
Cases	338	338	338	338	338	338
Speakers Who Stutter						
Mean	18.0	15.5	16.2	15.4	17.9	14.9
SD	10.2	6.7	8.5	7.6	8.8	7.9
Cases	263	263	263	263	263	263
Repeated Measures ANOVA	*df*	*MS*		*F*		*p*
Group	1	4.868		0.02		n.s.
Condition	5	1802.583		125.52		**
Interaction	5	245.005		17.06		**
Error	2995	14.361				

Key
** $p < 0.01$
* $p < 0.05$
n.s. not significant

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Table 37. Vertical Position Of /s, ʃ, tʃ/ (Centimeters) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	0.664	0.745	0.790	0.678	0.679	0.782
SD	0.197	0.237	0.173	0.231	0.215	0.184
Cases	136	136	136	136	136	136
Speakers Who Stutter						
Mean	0.354	0.389	0.403	0.429	0.378	0.508
SD	0.186	0.277	0.214	0.252	0.257	0.365
Cases	92	92	92	92	92	92

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	32.197	153.01	**
Condition	5	0.527	23.36	**
Interaction	5	0.145	6.43	**
Error	1130	0.02254		

Table 38. Vertical Position Of /æ, ɑ/ (Centimeters) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	-0.653	-0.555	-0.501	-0.625	-0.680	-0.228
SD	0.270	0.313	0.327	0.238	0.312	0.286
Cases	135	135	135	135	135	135
Speakers Who Stutter						
Mean	-0.349	-0.297	-0.226	-0.209	-0.434	-0.139
SD	0.170	0.245	0.183	0.195	0.180	0.298
Cases	91	91	91	91	91	91

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	22.844	96.73	**
Condition	5	3.635	98.85	**
Interaction	5	0.605	16.45	**
Error	1120	0.03677		

Key
** $p < 0.01$
* $p < 0.05$
n.s. not significant

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Table 39. Horizontal Position Of /s, ʃ, tʃ/ (Centimeters) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	-0.148	-0.054	-0.049	-0.127	-0.067	-0.109
SD	0.258	0.416	0.389	0.282	0.321	0.407
Cases	136	136	136	136	136	136
Speakers Who Stutter						
Mean	-0.173	-0.211	-0.159	-0.118	-0.168	-0.263
SD	0.175	0.222	0.181	0.178	0.233	0.149
Cases	92	92	92	92	92	92

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	23.315	57.67	**
Condition	5	0.236	9.35	**
Interaction	5	0.350	13.86	**
Error	1130	0.02524		

Table 40. Horizontal Position Of /æ, ɑ/ (Centimeters) Under All Conditions

Normal Speakers	Con	LAF	HAF	DAF	Noise	Mon
Mean	0.147	0.266	0.217	0.153	0.242	0.106
SD	0.253	0.301	0.288	0.258	0.280	0.283
Cases	135	135	135	135	135	135
Speakers Who Stutter						
Mean	0.174	0.284	0.210	0.254	0.299	0.142
SD	0.147	0.213	0.189	0.243	0.184	0.196
Cases	91	91	91	91	91	91

Repeated Measures ANOVA	*df*	*MS*	*F*	*p*
Group	1	0.479	2.24	n.s.
Condition	5	0.772	24.62	**
Interaction	5	0.07479	2.39	*
Error	1120	0.03134		

Key
** $p < 0.01$
* $p < 0.05$
n.s. not significant

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Mon = Self-Monitoring Under Noise

Table 41. Voicing Duration (Milliseconds) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	876	995	844	856	1036	926	*df*	5	289
Cases	50	49	49	50	49	48	*MS*	302251	3301.06
SD	53	64	52	57	45	72	*F*	91.56	
p		H**	L*	n.s.	H**	H**	*p*	**	
N2									
Mean	644	615	641	679	746	678	*df*	5	291
Cases	50	50	50	50	50	47	*MS*	103795	2624.82
SD	39	44	51	28	53	79	*F*	39.54	
p		L*	n.s.	H**	H**	n.s.	*p*	**	
N3									
Mean	835	930	917	854	909	860	*df*	5	289
Cases	50	50	49	49	48	49	*MS*	76651.3	4471.85
SD	55	55	98	66	69	47	*F*	17.14	
p		H**	H**	n.s.	H**	n.s.	*p*	**	
N4									
Mean	843	832		822	881	861	*df*	4	241
Cases	49	49		50	50	48	*MS*	27930.1	3024.4
SD	48	48		46	74	54	*F*	9.23	
p		n.s.		n.s.	H*	n.s.	*p*	**	
N5									
Mean	888	896	872	948	1094	1106	*df*	5	289
Cases	49	50	49	50	49	48	*MS*	548986	3291.07
SD	58	50	47	53	64	69	*F*	166.81	
p		n.s.	n.s.	H**	H**	H**	*p*	**	

Key

** $p < 0.01$

* $p < 0.05$

n.s. not significant

N1 to N5 Normal Speakers

S1 to S5 Speakers Who Stutter

Con = Control Condition

LAF = Low Frequency Altered Feedback

HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

Nois = Noise

Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 42. Voicing Duration (Milliseconds) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Noise	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	843	877	942	862	911	834	*df*	5	288
Cases	48	49	49	50	49	49	*MS*	84376.19	2644.35
SD	70	40	53	46	47	48	*F*	31.90	
p		n.s.	H**	n.s.	H**	n.s.	*p*	**	
S2									
Mean	899	969	971	918	1106	1335	*df*	5	288
Cases	48	50	50	50	47	49	*MS*	1328415	9530.31
SD	69	81	96	117	59	138	*F*	139.39	
p		H**	H**	n.s.	H**	H**	*p*	**	
S3									
Mean	1173	1152	1129	1153	1156	1149	*df*	5	253
Cases	40	41	44	48	38	48	*MS*	8511.76	7604.75
SD	86	86	78	92	91	90	*F*	1.12	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S4									
Mean	710	822	813	852	853	863	*df*	5	290
Cases	48	50	50	50	50	48	*MS*	156573.5	3968.54
SD	63	61	59	72	51	70	*F*	39.45	
p		H**	H**	H**	H**	H**	*p*	**	
S5									
Mean	713	816	723	795	855	907	*df*	5	289
Cases	50	50	50	50	49	46	*MS*	273031.5	4276.47
SD	52	53	47	61	67	101	*F*	63.85	
p		H**	n.s.	H**	H**	H**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 43. Duration Of Unvoiced Segments (Milliseconds) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	416	499	460	473	426	452	*df*	5	289
Cases	50	49	49	50	49	48	*MS*	46821.7	2079.74
SD	37	48	44	58	47	35	*F*	22.51	
p		H**	H**	H**	n.s.	H**	*p*	**	
N2									
Mean	372	355	380	402	372	346	*df*	5	291
Cases	50	50	50	50	50	47	*MS*	18942.8	2792.02
SD	37	31	46	31	33	104	*F*	6.78	
p		n.s.	n.s.	H**	n.s.	n.s.	*p*	**	
N3									
Mean	393	410	441	444	417	498	*df*	5	289
Cases	50	50	49	49	48	49	*MS*	67145.5	4090.95
SD	58	39	42	59	42	113	*F*	16.41	
p		n.s.	H**	H**	n.s.	H**	*p*	**	
N4									
Mean	526	501		494	497	522	*df*	4	241
Cases	49	49		50	50	48	*MS*	10788.1	1556.44
SD	34	44		37	41	40	*F*	6.93	
p		L*		L**	L**	n.s.	*p*	**	
N5									
Mean	422	433	441	503	483	532	*df*	5	289
Cases	49	50	49	50	49	48	*MS*	93625.4	2266.35
SD	41	42	30	42	52	69	*F*	41.31	
p		n.s.	n.s.	H**	H**	H**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 44. Duration Of Unvoiced Segments (Millisecond) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	556	556	581	581	554	575	*df*	5	288
Cases	48	49	49	50	49	49	*MS*	8669.5	20355.4
SD	191	109	192	161	85	65	*F*	0.43	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S2									
Mean	487	496	449	531	494	568	*df*	5	288
Cases	48	50	50	50	47	49	*MS*	81462.7	10925.3
SD	65	73	127	95	150	94	*F*	7.46	
p		n.s.	n.s.	n.s.	n.s.	H**	*p*	**	
S3									
Mean	605	565	577	570	511	540	*df*	5	253
Cases	40	41	44	48	38	48	*MS*	42157.1	17255.4
SD	115	87	88	80	216	159	*F*	2.44	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	*	
S4									
Mean	384	371	368	397	341	365	*df*	5	290
Cases	48	50	50	50	50	48	*MS*	17616.1	3457.03
SD	59	42	47	55	48	91	*F*	5.10	
p		n.s.	n.s.	n.s.	L**	n.s.	*p*	**	
S5									
Mean	291	354	316	362	268	327	*df*	5	289
Cases	50	50	50	50	49	46	*MS*	65279.9	4959.07
SD	50	52	51	76	73	107	*F*	13.16	
p		H**	n.s.	H**	n.s.	n.s.	*p*	**	

Key ** $p < 0.01$ — Con = Control Condition

* $p < 0.05$ — LAF = Low Frequency Altered Feedback

n.s. not significant — HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers — Nois = Noise

S1 to S5 Speakers Who Stutter — Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 45. Duration of Transitional Movements (Milliseconds) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	175	194	162	168	193	176	*df*	5	514
Cases	97	98	80	81	87	77	*MS*	15449.5	3072.84
SD	58	55	56	52	56	55	*F*	5.03	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	**	
N2									
Mean	144	132	144	145	140	140	*df*	5	584
Cases	98	99	100	103	97	93	*MS*	2309.87	2767.88
SD	57	49	54	54	52	50	*F*	0.83	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
N3									
Mean	137	137	153	141	136	147	*df*	5	586
Cases	101	101	98	97	98	97	*MS*	4815.96	2784.21
SD	52	45	61	54	42	60	*F*	1.73	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
N4									
Mean	204	194		198	197	196	*df*	4	485
Cases	97	100		97	100	96	*MS*	1238.62	4743.39
SD	71	71		62	68	72	*F*	0.26	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	147	157	147	174	177	181	*df*	5	582
Cases	98	99	103	100	96	92	*MS*	23950.1	1271.1
SD	30	32	28	38	46	38	*F*	18.84	
p		n.s.	n.s.	H**	H**	H**	*p*	**	

Key ** $p < 0.01$
* $p < 0.05$
n.s. not significant

N1 to N5 Normal Speakers
S1 to S5 Speakers Who Stutter

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Nois = Noise
Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition
L Value Significantly Lower Than Control Condition

Table 46. Duration Of Transitional Movements (Milliseconds) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	208	218	243	229	204	208	*df*	5	590
Cases	99	99	97	100	101	100	*MS*	22472.5	5180.64
SD	67	58	83	67	83	70	*F*	4.34	
p		n.s.	H*	n.s.	n.s.	n.s.	*p*	**	
S2									
Mean	192	211	204	202	225	238	*df*	5	527
Cases	104	79	97	99	75	79	*MS*	24296.4	7273.22
SD	77	82	86	78	93	98	*F*	3.34	
p		n.s.	n.s.	n.s.	n.s.	H*	*p*	**	
S3									
Mean	222	217	239	218	218	218	*df*	5	516
Cases	80	82	87	98	76	99	*MS*	6447.24	5513.73
SD	81	68	89	69	65	71	*F*	1.17	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S4									
Mean	165	154	168	164	158	162	*df*	5	114
Cases	19	21	20	20	20	20	*MS*	545.78	5374.13
SD	71	65	77	78	78	70	*F*	0.10	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S5									
Mean	140	179	145	169	180	162	*df*	5	443
Cases	98	90	73	75	39	74	*MS*	21506.5	5386.22
SD	73	81	63	65	101	66	*F*	3.99	
p		H*	n.s.	n.s.	n.s.	n.s.	*p*	**	

Key ** $p < 0.01$
* $p < 0.05$
n.s. not significant
N1 to N5 Normal Speakers
S1 to S5 Speakers Who Stutter

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Nois = Noise
Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition
L Value Significantly Lower Than Control Condition

Table 47. Duration Of Vowel-Related Movements (Milliseconds) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	177	207	189	188	181	189	*df*	5	512
Cases	99	96	78	79	89	77	*MS*	10195	1918.12
SD	39	42	49	47	43	44	*F*	5.32	
p		H**	n.s.	n.s.	n.s.	n.s.	*p*	**	
N2									
Mean	154	159	166	166	169	167	*df*	5	586
Cases	102	98	100	97	100	95	*MS*	3323.35	975.804
SD	28	30	34	28	31	37	*F*	3.41	
p		n.s.	n.s.	H*	H**	n.s.	*p*	**	
N3									
Mean	182	216	212	198	191	204	*df*	5	582
Cases	99	99	98	99	94	99	*MS*	16433.5	1712.05
SD	38	37	38	56	36	39	*F*	9.60	
p		H**	H**	n.s.	n.s.	H**	*p*	**	
N4									
Mean	191	185		183	193	194	*df*	4	488
Cases	99	96		103	100	95	*MS*	2329.71	1114.33
SD	34	30		40	34	28	*F*	2.09	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	203	211	209	236	233	239	*df*	5	575
Cases	98	100	93	100	96	94	*MS*	24452.2	1750.83
SD	40	40	36	46	46	41	*F*	13.97	
p		n.s.	n.s.	H**	H**	H**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 48. Duration Of Vowel-Related Movements (Milliseconds) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	211	223	241	231	221	211	*df*	5	573
Cases	94	94	98	99	98	96	*MS*	12806.3	2904.41
SD	53	47	60	54	56	53	*F*	4.41	
p		n.s.	H**	n.s.	n.s.	n.s.	*p*	**	
S2									
Mean	185	207	193	205	200	235	*df*	5	508
Cases	86	81	100	99	72	76	*MS*	23469.7	2939.97
SD	51	53	50	46	54	72	*F*	7.98	
p		n.s.	n.s.	n.s.	n.s.	H**	*p*	**	
S3									
Mean	246	239	247	250	258	242	*df*	5	512
Cases	80	82	89	94	76	97	*MS*	3396.25	4164.63
SD	75	60	61	52	75	65	*F*	0.82	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S4									
Mean	153	151	140	164	161	149	*df*	5	114
Cases	19	19	22	20	20	20	*MS*	1460.22	862.05
SD	43	23	24	32	30	19	*F*	1.69	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S5									
Mean	149	167	152	155	172	173	*df*	5	466
Cases	99	100	79	82	39	73	*MS*	8120.09	1714.52
SD	38	44	35	35	53	48	*F*	4.74	
p		H*	H**	H**	H**	H*	*p*	**	

Key ** $p < 0.01$
* $p < 0.05$
n.s. not significant
N1 to N5 Normal Speakers
S1 to S5 Speakers Who Stutter

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Nois = Noise
Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition
L Value Significantly Lower Than Control Condition

Table 49. Distance of Transitional Movements (Centimeters) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	1.42	1.28	1.07	1.03	1.56	1.08	*df*	5	514
Cases	97	98	80	81	87	77	*MS*	4.11193	0.31372
SD	0.73	0.46	0.46	0.45	0.68	0.48	*F*	13.12	
p		n.s.	L**	L**	n.s.	L**	*p*	**	
N2									
Mean	0.76	0.74	0.75	0.79	0.80	0.58	*df*	5	584
Cases	98	99	100	103	97	93	*MS*	0.58412	0.16285
SD	0.39	0.41	0.42	0.45	0.43	0.31	*F*	3.59	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
N3									
Mean	0.62	0.53	0.57	0.57	0.73	0.42	*df*	5	586
Cases	101	101	98	97	98	97	*MS*	1.03672	0.09948
SD	0.34	0.28	0.30	0.32	0.41	0.21	*F*	10.42	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
N4									
Mean	0.92	0.92		0.92	0.92	0.87	*df*	4	485
Cases	97	100		97	100	96	*MS*	0.03688	0.18919
SD	0.38	0.49		0.43	0.43	0.44	*F*	0.19	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	0.97	1.10	1.08	1.04	0.98	0.91	*df*	5	582
Cases	98	99	103	100	96	92	*MS*	0.48747	0.08698
SD	0.23	0.32	0.40	0.30	0.25	0.22	*F*	5.60	
p		H*	n.s.	n.s.	n.s.	n.s.	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 50. Distance of Transitional Movements (Centimeters) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	1.31	1.26	1.26	1.30	1.36	1.14	*df*	5	590
Cases	99	99	97	100	101	100	*MS*	0.55852	0.14967
SD	0.37	0.39	0.42	0.38	0.44	0.30	*F*	3.73	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
S2									
Mean	0.53	0.66	0.60	0.51	0.73	0.56	*df*	5	527
Cases	104	79	97	99	75	79	*MS*	0.59961	0.07075
SD	0.28	0.23	0.31	0.25	0.23	0.27	*F*	8.48	
p		H**	n.s.	n.s.	H**	n.s.	*p*	**	
S3									
Mean	1.49	1.20	1.48	1.26	1.48	1.26	*df*	5	516
Cases	80	82	87	98	76	99	*MS*	1.56767	0.3155
SD	0.56	0.55	0.61	0.42	0.56	0.65	*F*	4.97	
p		L*	n.s.	L*	n.s.	n.s.	*p*	**	
S4									
Mean	0.99	0.68	0.77	0.91	0.98	0.71	*df*	5	114
Cases	19	21	20	20	20	20	*MS*	0.37624	0.0278
SD	0.18	0.13	0.15	0.16	0.22	0.16	*F*	13.53	
p		L**	L**	n.s.	n.s.	L**	*p*	**	
S5									
Mean	0.94	0.88	0.91	1.04	1.28	0.92	*df*	5	443
Cases	98	90	73	75	39	74	*MS*	1.06104	0.25506
SD	0.53	0.43	0.39	0.63	0.49	0.52	*F*	4.16	
p		n.s.	n.s.	n.s.	H*	n.s.	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 51. Distance Of Vowel-Related Movements (Centimeters) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	1.78	1.78	1.48	1.40	1.93	1.40	*df*	5	512
Cases	99	96	78	79	89	77	*MS*	4.47404	0.25812
SD	0.70	0.41	0.42	0.41	0.56	0.44	*F*	17.33	
p		n.s.	L**	L**	n.s.	L**	*p*	**	
N2									
Mean	1.29	1.29	1.24	1.34	1.33	0.96	*df*	5	586
Cases	102	98	100	97	100	95	*MS*	1.97705	0.06235
SD	0.24	0.26	0.26	0.28	0.26	0.19	*F*	31.71	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
N3									
Mean	1.45	1.42	1.47	1.42	1.73	1.14	*df*	5	582
Cases	99	99	98	99	94	99	*MS*	3.36445	0.19047
SD	0.39	0.45	0.43	0.49	0.48	0.36	*F*	17.66	
p		n.s.	n.s.	n.s.	H**	L**	*p*	**	
N4									
Mean	1.57	1.56		1.45	1.58	1.56	*df*	4	488
Cases	99	96		103	100	95	*MS*	0.30115	0.16907
SD	0.36	0.44		0.43	0.37	0.45	*F*	1.78	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	1.86	2.04	1.96	1.89	1.86	1.62	*df*	5	575
Cases	98	100	93	100	96	94	*MS*	1.93827	0.12726
SD	0.34	0.44	0.40	0.31	0.30	0.32	*F*	15.23	
p		H*	n.s.	n.s.	n.s.	L**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 52. Distance Of Vowel-Related Movements (Centimeters) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	1.86	1.71	1.73	1.76	1.85	1.54	*df*	5	573
Cases	94	94	98	99	98	96	*MS*	1.261	0.15181
SD	0.42	0.37	0.40	0.43	0.36	0.34	*F*	8.31	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
S2									
Mean	0.81	0.96	0.81	0.75	0.97	0.81	*df*	5	508
Cases	86	81	100	99	72	76	*MS*	0.66716	0.07571
SD	0.27	0.29	0.26	0.27	0.29	0.28	*F*	8.81	
p		H*	n.s.	n.s.	H*	n.s.	*p*	**	
S3									
Mean	2.50	2.06	2.39	2.16	2.49	2.10	*df*	5	512
Cases	80	82	89	94	76	97	*MS*	3.32031	0.63692
SD	0.84	0.73	0.80	0.59	0.90	0.90	*F*	5.21	
p		L**	n.s.	L*	n.s.	L*	*p*	**	
S4									
Mean	1.14	0.83	0.94	1.09	1.20	0.86	*df*	5	114
Cases	19	19	22	20	20	20	*MS*	0.47216	0.01545
SD	0.14	0.14	0.13	0.11	0.11	0.12	*F*	30.56	
p		L**	L**	n.s.	n.s.	L**	*p*	**	
S5									
Mean	1.21	1.23	1.36	1.24	1.61	1.18	*df*	5	466
Cases	99	100	79	82	39	73	*MS*	1.23867	0.30479
SD	0.58	0.66	0.58	0.44	0.46	0.48	*F*	4.06	
p		n.s.	n.s.	n.s.	H**	n.s.	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 53. Peak Velocity Of Transitional Movements In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	15.4	12.2	11.2	10.4	15.9	10.9	*df*	5	514
Cases	97	98	80	81	87	77	*MS*	497.06	41.47
SD	8.7	5.0	5.3	4.7	8.3	4.8	*F*	11.98	
p		L*	L**	L**	n.s.	L**	*p*	**	
N2									
Mean	9.0	9.0	8.9	9.0	9.8	7.0	*df*	5	584
Cases	98	99	100	103	97	93	*MS*	84.79	26.44
SD	4.9	5.3	5.2	5.3	5.7	4.2	*F*	3.21	
p		n.s.	n.s.	n.s.	n.s.	L*	*p*	**	
N3									
Mean	7.9	6.1	6.2	6.7	8.4	4.7	*df*	5	586
Cases	101	101	98	97	98	97	*MS*	176.20	10.55
SD	4.0	3.1	3.0	3.3	3.7	2.2	*F*	16.70	
p		L**	L**	n.s.	n.s.	L**	*p*	**	
N4									
Mean	9.1	9.2		9.0	9.3	8.9	*df*	4	485
Cases	97	100		97	100	96	*MS*	1.84	27.24
SD	4.4	5.7		5.5	5.4	5.0	*F*	0.07	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	11.8	12.6	13.2	11.1	10.4	9.3	*df*	5	582
Cases	98	99	103	100	96	92	*MS*	201.33	23.83
SD	4.4	4.9	6.9	4.4	3.9	3.8	*F*	8.45	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 54. Peak Velocity Of Transitional Movements In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	13.7	11.4	10.9	11.7	14.8	11.7	*df*	5	590
Cases	99	99	97	100	101	100	*MS*	224.44	39.01
SD	6.8	5.4	6.0	5.6	7.5	5.9	*F*	5.75	
p		n.s.	L*	n.s.	n.s.	n.s.	*p*	**	
S2									
Mean	5.1	6.7	5.5	4.8	7.0	4.7	*df*	5	527
Cases	104	79	97	99	75	79	*MS*	76.75	7.22
SD	2.2	3.4	2.9	2.1	3.0	2.4	*F*	10.62	
p		H**	n.s.	n.s.	H**	n.s.	*p*	**	
S3									
Mean	13.0	10.5	12.7	11.2	13.7	10.4	*df*	5	516
Cases	80	82	87	98	76	99	*MS*	170.07	18.11
SD	4.3	3.7	4.7	4.2	5.1	3.6	*F*	9.39	
p		L**	n.s.	n.s.	n.s.	L**	*p*	**	
S4									
Mean	12.9	10.6	10.6	13.0	14.1	10.2	*df*	5	114
Cases	19	21	20	20	20	20	*MS*	53.02	17.90
SD	4.8	3.4	3.8	4.9	4.8	3.6	*F*	2.96	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	*	
S5									
Mean	12.4	9.1	12.6	11.9	14.6	10.6	*df*	5	443
Cases	98	90	73	75	39	74	*MS*	222.95	48.50
SD	7.9	5.5	6.5	7.4	7.3	7.0	*F*	4.60	
p		L*	n.s.	n.s.	n.s.	n.s.	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 55. Peak Velocity Of Vowel-Related Movements (Centimeters/Second) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	21.2	19.1	15.6	15.2	23.8	15.0	*df*	5	512
Cases	99	96	78	79	89	77	*MS*	1149.9	70.34
SD	9.4	7.5	6.6	7.2	11.2	7.0	*F*	16.35	
p		n.s.	L**	L**	n.s.	L**	*p*	**	
N2									
Mean	16.1	15.4	14.7	15.8	15.2	11.0	*df*	5	586
Cases	102	98	100	97	100	95	*MS*	338.3	23.19
SD	4.8	5.2	5.0	5.2	5.0	3.3	*F*	14.59	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
N3									
Mean	17.1	13.3	14.6	15.1	18.6	11.0	*df*	5	582
Cases	99	99	98	99	94	99	*MS*	711.14	18.51
SD	4.3	3.9	4.7	5.1	4.5	3.0	*F*	38.42	
p		L**	L**	n.s.	n.s.	L**	*p*	**	
N4									
Mean	17.7	18.0		16.5	18.0	17.0	*df*	4	488
Cases	99	96		103	100	95	*MS*	46.35	45.27
SD	5.7	7.6		6.7	6.8	6.8	*F*	1.02	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	19.3	19.6	18.8	17.2	16.8	13.7	*df*	5	575
Cases	98	100	93	100	96	94	*MS*	464.46	31.18
SD	5.5	7.2	6.0	5.2	5.0	4.0	*F*	14.90	
p		n.s.	n.s.	n.s.	L*	L**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 56. Peak Velocity Of Vowel-Related Movements (Centimeters/Second) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between Conditions	Within Conditions
Mean	23.0	18.0	18.7	18.9	20.5	17.4	*df*	5	573
Cases	94	94	98	99	98	96	*MS*	392.73	71.21
SD	10.8	7.2	8.2	7.7	9.0	7.1	*F*	5.51	
p		L**	L*	n.s.	n.s.	L**	*p*	**	
S2									
Mean	8.5	9.8	8.1	7.2	10.3	7.4	*df*	5	508
Cases	86	81	100	99	72	76	*MS*	127.67	6.22
SD	2.0	2.7	2.4	2.2	3.0	2.7	*F*	20.52	
p		H**	n.s.	L**	H**	L*	*p*	**	
S3									
Mean	23.0	18.3	21.1	18.6	22.2	18.2	*df*	5	512
Cases	80	82	89	94	76	97	*MS*	3.32	0.6369
SD	9.0	6.0	8.0	5.8	8.5	7.9	*F*	5.21	
p		L**	n.s.	L*	n.s.	L*	*p*	**	
S4									
Mean	16.1	11.0	13.2	14.1	16.2	11.7	*df*	5	114
Cases	19	19	22	20	20	20	*MS*	91.76	15.69
SD	5.0	3.1	2.9	4.0	5.0	3.2	*F*	5.85	
p		L*	n.s.	n.s.	n.s.	L*	*p*	**	
S5									
Mean	14.4	13.9	16.9	15.0	18.0	13.6	*df*	5	466
Cases	99	100	79	82	39	73	*MS*	184.58	48.52
SD	7.2	8.0	6.8	5.5	5.0	7.5	*F*	3.80	
p		n.s.	n.s.	n.s.	H*	n.s.	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 57. Vertical Position of /s, ʃ, tʃ/ (Centimeters) In Individual Normal Speakers

							One Way ANOVA		
N1	Con	LAF	HAF	DAF	Nois	Mon		Between	Within
Mean	0.407						*df*		
Cases	47						*MS*		
SD	0.240						*F*		
p							*p*		
N2									
Mean	0.489	0.518	0.738	0.439	0.533	0.728	*df*	5	292
Cases	50	52	51	50	50	45	*MS*	0.78979	0.010
SD	0.118	0.093	0.075	0.131	0.098	0.070	*F*	78.79	
p		n.s.	H**	n.s.	n.s.	H**	*p*	**	
N3									
Mean	0.635			0.673	0.557		*df*	2	143
Cases	50			48	48		*MS*	0.16836	0.018
SD	0.135			0.131	0.135		*F*	9.42	
p				n.s.	L*		*p*	**	
N4									
Mean	0.585	0.618		0.583	0.585	0.550	*df*	4	239
Cases	49	46		50	50	49	*MS*	0.02753	0.005
SD	0.054	0.074		0.068	0.069	0.097	*F*	5.06	
p		n.s.		n.s.	n.s.	n.s.	*p*	**	
N5									
Mean	0.849	0.981	0.937	0.897	0.924	0.962	*df*	5	289
Cases	49	50	49	50	48	49	*MS*	0.10997	0.024
SD	0.140	0.165	0.167	0.147	0.122	0.186	*F*	4.53	
p		H**	n.s.	n.s.	n.s.	H*	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 58. Vertical Position of /s, ʃ, tʃ/ (Centimeters) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Noise	Mon	One Way ANOVA		
								Between	Within
Mean	0.404	0.575	0.488	0.539	0.41	0.765	*df*	5	294
Cases	49	50	51	50	50	50	*MS*	0.89352	0.071
SD	0.189	0.203	0.217	0.314	0.303	0.338	*F*	12.49	
p		H**	n.s.	n.s.	n.s.	H**	*p*	**	
S2									
Mean	0.287	0.203	0.317	0.33	0.347	0.258	*df*	5	288
Cases	48	50	50	50	46	50	*MS*	0.13895	0.029
SD	0.162	0.190	0.173	0.144	0.189	0.160	*F*	4.80	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	**	
S3									
Mean	0.847		1.177	0.533	1.226		*df*	3	155
Cases	34		42	45	38		*MS*	4.40041	0.232
SD	0.459		0.521	0.446	0.498		*F*	18.95	
p			H*	L*	H**		*p*	**	
S5									
Mean	0.310	0.235					*df*	1	98
Cases	50	50					*MS*	0.1404	0.088
SD	0.259	0.328					*F*	1.60	
p		n.s.					*p*	n.s.	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 59. Vertical Position of /æ, ɑ/ (Centimeters) In Individual Normal Speakers

							One Way ANOVA		
N1	Con	LAF	HAF	DAF	Nois	Mon		Between	Within
Mean	-0.391						*df*		
Cases	49						*MS*		
SD	0.222						*F*		
p							*p*		
N2									
Mean	-0.490	-0.402	-0.192	-0.542	-0.429	0.013	*df*	5	291
Cases	50	50	50	50	50	47	*MS*	2.13747	0.026
SD	0.152	0.175	0.144	0.156	0.167	0.165	*F*	83.27	
p	n.s.	H**	n.s.	n.s.	H**		*p*	**	
N3									
Mean	-0.635			-0.550	-0.922		*df*	2	144
Cases	50			49	48		*MS*	1.8418	0.048
SD	0.245			0.207	0.205		*F*	38.10	
p				n.s.	L**		*p*	**	
N4									
Mean	-0.584	-0.470		-0.509	-0.509	-0.521	*df*	4	241
Cases	49	49		50	50	48	*MS*	0.0825	0.052
SD	0.186	0.239		0.205	0.235	0.271	*F*	1.58	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	-0.850	-0.804	-0.767	-0.773	-0.711	-0.399	*df*	5	287
Cases	49	50	49	50	48	47	*MS*	1.25685	0.095
SD	0.272	0.317	0.344	0.263	0.335	0.314	*F*	13.17	
p		n.s.	n.s.	n.s.	n.s.	H**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 60. Vertical Position of /æ, ɑ/ (Centimeters) In Individual Speakers Who Stutter

							One Way ANOVA		
S1	Con	LAF	HAF	DAF	Nois	Mon		Between	Within
Mean	-0.403	-0.165	-0.203	-0.238	-0.380	0.087	*df*	5	290
Cases	49	49	49	50	50	49	*MS*	1.54428	0.049
SD	0.196	0.254	0.210	0.237	0.206	0.218	*F*	31.61	
p		H**	H**	H**	n.s.	H**	*p*	**	
S2									
Mean	-0.288	-0.445	-0.242	-0.174	-0.475	-0.384	*df*	5	288
Cases	48	50	50	50	47	49	*MS*	0.69502	0.018
SD	0.107	0.123	0.139	0.131	0.157	0.140	*F*	38.93	
p		L**	n.s.	H**	L**	L**	*p*	**	
S3									
Mean	-0.719		-0.241	-0.835	-0.202		*df*	3	166
Cases	40		44	48	38		*MS*	4.53279	0.225
SD	0.406		0.527	0.455	0.500		*F*	20.14	
p			H**	n.s.	H**		*p*	**	
S5									
Mean	-0.309	-0.3					*df*	1	96
Cases	50	48					*MS*	0.00202	0.044
SD	0.219	0.199					*F*	0.05	
p		n.s.					*p*	n.s.	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 61. Vertical Position of /k/ (Centimeters) In Individual Normal Speakers

							One Way ANOVA		
N1	Con	LAF	HAF	DAF	Nois	Mon		Between	Within
Mean	1.207	1.170					*df*	1	37
Cases	20	19					*MS*	0.01293	0.021
SD	0.138	0.153					*F*	0.61	
p		n.s.					*p*	n.s.	
N2									
Mean	1.263	1.323	1.455	1.209	1.333	1.433	*df*	5	113
Cases	20	19	20	20	20	20	*MS*	0.18128	0.006
SD	0.077	0.061	0.064	0.108	0.080	0.068	*F*	29.83	
p		n.s.	H**	n.s.	n.s.	H**	*p*	**	
N3									
Mean	2.806			2.784	2.778		*df*	2	57
Cases	20			20	20		*MS*	0.00441	0.134
SD	0.225			0.405	0.433		*F*	0.03	
p				n.s.	n.s.		*p*	n.s.	
N4									
Mean	2.417	2.562		2.482	2.447	2.493	*df*	4	94
Cases	20	20		20	20	19	*MS*	0.05931	0.026
SD	0.166	0.106		0.164	0.202	0.149	*F*	2.31	
p		H*		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	1.399	1.277	1.370	1.400	1.384	1.396	*df*	5	111
Cases	20	20	19	20	20	18	*MS*	0.04471	0.023
SD	0.147	0.212	0.156	0.135	0.113	0.117	*F*	1.96	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 64. Horizontal Position of /s, ʃ, tʃ/ (Centimeters) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between	Within
Mean	-0.232	-0.238	-0.217	-0.193	-0.294	-0.215	*df*	5	294
Cases	49	50	51	50	50	50	*MS*	0.06	0.035
SD	0.169	0.240	0.185	0.164	0.196	0.161	*F*	1.68	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	n.s.	
S2									
Mean	-0.117	-0.178	-0.096	-0.039	-0.049	-0.311	*df*	5	288
Cases	48	50	50	50	46	50	*MS*	0.50729	0.028
SD	0.156	0.192	0.176	0.145	0.204	0.109	*F*	18.38	
p		n.s.	n.s.	n.s.	n.s.	L**	*p*	**	
S3									
Mean	-0.655		-0.310	-0.855	-0.381		*df*	3	155
Cases	34		42	45	38		*MS*	2.68299	0.142
SD	0.324		0.418	0.330	0.421		*F*	18.92	
p			H**	n.s.	H*		*p*	**	
S5									
Mean	-0.172	-0.195					*df*	1	98
Cases	50	50					*MS*	0.01325	0.028
SD	0.167	0.167					*F*	0.47	
p		n.s.					*p*	n.s.	

Key ** $p < 0.01$

* $p < 0.05$

n.s. not significant

N1 to N5 Normal Speakers

S1 to S5 Speakers Who Stutter

Con = Control Condition

LAF = Low Frequency Altered Feedback

HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

Nois = Noise

Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 65. Horizontal Position of /æ, ɑ/ (Centimeters) In Individual Normal Speakers

							One Way ANOVA		
N1	Con	LAF	HAF	DAF	Nois	Mon		Between	Within
Mean	0.368						*df*		
Cases	49						*MS*		
SD	0.309						*F*		
p							*p*		
N2									
Mean	0.111	0.068	0.022	0.092	0.156	0.006	*df*	5	291
Cases	50	50	50	50	50	47	*MS*	0.15386	0.041
SD	0.189	0.230	0.202	0.203	0.199	0.181	*F*	3.79	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	**	
N3									
Mean	0.278			0.275	0.411		*df*	2	144
Cases	50			49	48		*MS*	0.29313	0.067
SD	0.255			0.239	0.280		*F*	4.39	
p				n.s.	H*		*p*	*	
N4									
Mean	0.192	0.350		0.291	0.324	0.200	*df*	4	241
Cases	49	49		50	50	48	*MS*	0.25307	0.065
SD	0.206	0.316		0.224	0.253	0.262	*F*	3.90	
p		H*		n.s.	n.s.	n.s.	*p*	**	
N5									
Mean	0.051	0.415	0.315	0.094	0.165	0.300	*df*	5	287
Cases	49	50	49	50	48	47	*MS*	0.99607	0.084
SD	0.236	0.292	0.317	0.275	0.270	0.340	*F*	11.85	
p		H**	H**	n.s.	n.s.	H**	*p*	**	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 66. Horizontal Position of /æ, ɑ/ (Centimeters) In Individual Speakers Who Stutter

S1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between	Within
Mean	0.231	0.364	0.229	0.329	0.266	0.271	*df*	5	290
Cases	49	49	49	50	50	49	*MS*	0.14412	0.046
SD	0.148	0.207	0.201	0.304	0.187	0.202	*F*	3.16	
p		H**	n.s.	n.s.	n.s.	n.s.	*p*	**	
S2									
Mean	0.118	0.221	0.197	0.210	0.344	0.023	*df*	5	288
Cases	48	50	50	50	47	49	*MS*	0.56013	0.024
SD	0.118	0.186	0.170	0.158	0.176	0.104	*F*	23.27	
p		H*	n.s.	H*	H**	L**	*p*	**	
S3									
Mean	0.557		0.902	0.236	0.747		*df*	3	166
Cases	40		44	48	38		*MS*	3.75429	0.879
SD	1.041		0.885	0.817	1.023		*F*	4.27	
p			n.s.	n.s.	n.s.		*p*	**	
S5									
Mean	0.171	0.131					*df*	1	96
Cases	50	48					*MS*	0.03957	0.014
SD	0.103	0.135					*F*	2.76	
p		n.s.					*p*	n.s.	

Key ** $p < 0.01$ Con = Control Condition

* $p < 0.05$ LAF = Low Frequency Altered Feedback

n.s. not significant HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

N1 to N5 Normal Speakers Nois = Noise

S1 to S5 Speakers Who Stutter Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 67. Horizontal Position of /k/ (Centimeters) In Individual Normal Speakers

N1	Con	LAF	HAF	DAF	Nois	Mon	One Way ANOVA	Between	Within
Mean	5.881	6.362					*df*	1	37
Cases	20	19					*MS*	2.25712	0.033
SD	0.175	0.188					*F*	68.29	
p		H**					*p*	**	
N2									
Mean	3.464	3.486	3.509	3.454	3.416	3.478	*df*	5	113
Cases	20	19	20	20	20	20	*MS*	0.02025	0.004
SD	0.053	0.076	0.056	0.062	0.069	0.064	*F*	5.00	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	**	
N3									
Mean	2.973			2.342	2.604		*df*	2	57
Cases	20			20	20		*MS*	2.00892	0.156
SD	0.420			0.405	0.358		*F*	12.85	
p				L**	L*		*p*	**	
N4									
Mean	2.324	2.456		2.429	2.593	2.435	*df*	4	94
Cases	20	20		20	20	19	*MS*	0.18604	0.130
SD	0.306	0.410		0.320	0.421	0.329	*F*	1.43	
p		n.s.		n.s.	n.s.	n.s.	*p*	n.s.	
N5									
Mean	2.667	2.949	2.768	2.669	2.649	2.882	*df*	5	111
Cases	20	20	19	20	20	18	*MS*	0.31427	0.102
SD	0.221	0.431	0.324	0.247	0.296	0.359	*F*	3.07	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	*	

Key ** $p < 0.01$

* $p < 0.05$

n.s. not significant

N1 to N5 Normal Speakers

S1 to S5 Speakers Who Stutter

Con = Control Condition

LAF = Low Frequency Altered Feedback

HAF = High Frequency Altered Feedback

DAF = Delayed Auditory Feedback

Nois = Noise

Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition

L Value Significantly Lower Than Control Condition

Table 68. Horizontal Position of /k/ (Centimeters) In Individual Speakers Who Stutter

							One Way ANOVA		
S1	Con	LAF	HAF	DAF	Nois	Mon		Between	Within
Mean	4.478	4.471	4.423	4.495	4.394	4.534	*df*	5	110
Cases	19	20	19	19	20	19	*MS*	0.04872	0.012
SD	0.078	0.093	0.071	0.113	0.148	0.131	*F*	4.07	
p		n.s.	n.s.	n.s.	n.s.	n.s.	*p*	**	
S2									
Mean	1.472		1.585	1.524			*df*	2	56
Cases	19		20	20			*MS*	0.06304	0.015
SD	0.156		0.078	0.126			*F*	4.13	
p			H*	n.s.			*p*	*	
S3									
Mean	2.370		2.468	2.440	2.445		*df*	3	66
Cases	17		18	22	13		*MS*	0.03036	0.046
SD	0.220		0.222	0.204	0.212		*F*	0.66	
p			n.s.	n.s.	n.s.		*p*	n.s.	
S5									
Mean	1.495	1.385			1.432		*df*	2	56
Cases	20	20			19		*MS*	0.061	0.038
SD	0.174	0.183			0.226		*F*	1.60	
p		n.s.			n.s.		*p*	n.s.	

Key ** $p < 0.01$
* $p < 0.05$
n.s. not significant
N1 to N5 Normal Speakers
S1 to S5 Speakers Who Stutter

Con = Control Condition
LAF = Low Frequency Altered Feedback
HAF = High Frequency Altered Feedback
DAF = Delayed Auditory Feedback
Nois = Noise
Mon = Self-Monitoring Under Noise

H Value Significantly Higher Than Control Condition
L Value Significantly Lower Than Control Condition

Table 69. Summary Of Individual Subject by Condition Comparisons Of Means

Duration	Subject by Condition Cells	Number Significant	Percent Significant	Percent Significant Higher	Percent Significant Lower
Voicing	49	29	59%	55%	4%
Unvoiced	49	18	37%	29%	8%
Transitional	49	6	12%	12%	0%
Vowel-related	49	16	33%	33%	0%
Total duration	**196**	**69**	**35%**	**32%**	**3%**
Distance					
Transitional	49	15	35%	8%	22%
Vowel-related	49	18	37%	10%	27%
Total distance	**98**	**33**	**34%**	**9%**	**24%**
Peak Velocity					
Transitional	49	15	31%	4%	27%
Vowel-related	49	22	45%	6%	39%
Total peak velocity	**98**	**37**	**38%**	**5%**	**33%**
Vertical /s, ʃ, t[1]/	30	10	33%	27%	7%
Vertical /ʉ, ɑ/	30	14	46%	33%	13%
Vertical /k/	29	4	14%	14%	0%
Total vertical	**89**	**28**	**31%**	**25%**	**6%**
Horizontal /s, ʃ, t[1]/	30	8	27%	23%	3%
Horizontal /ʉ, ɑ/	30	10	33%	30%	3%
Horizontal /k/	29	4	14%	7%	7%
Total horizontal	**89**	**22**	**25%**	**20%**	**5%**

Figure 1. Equipment Setup For Data Acquistion

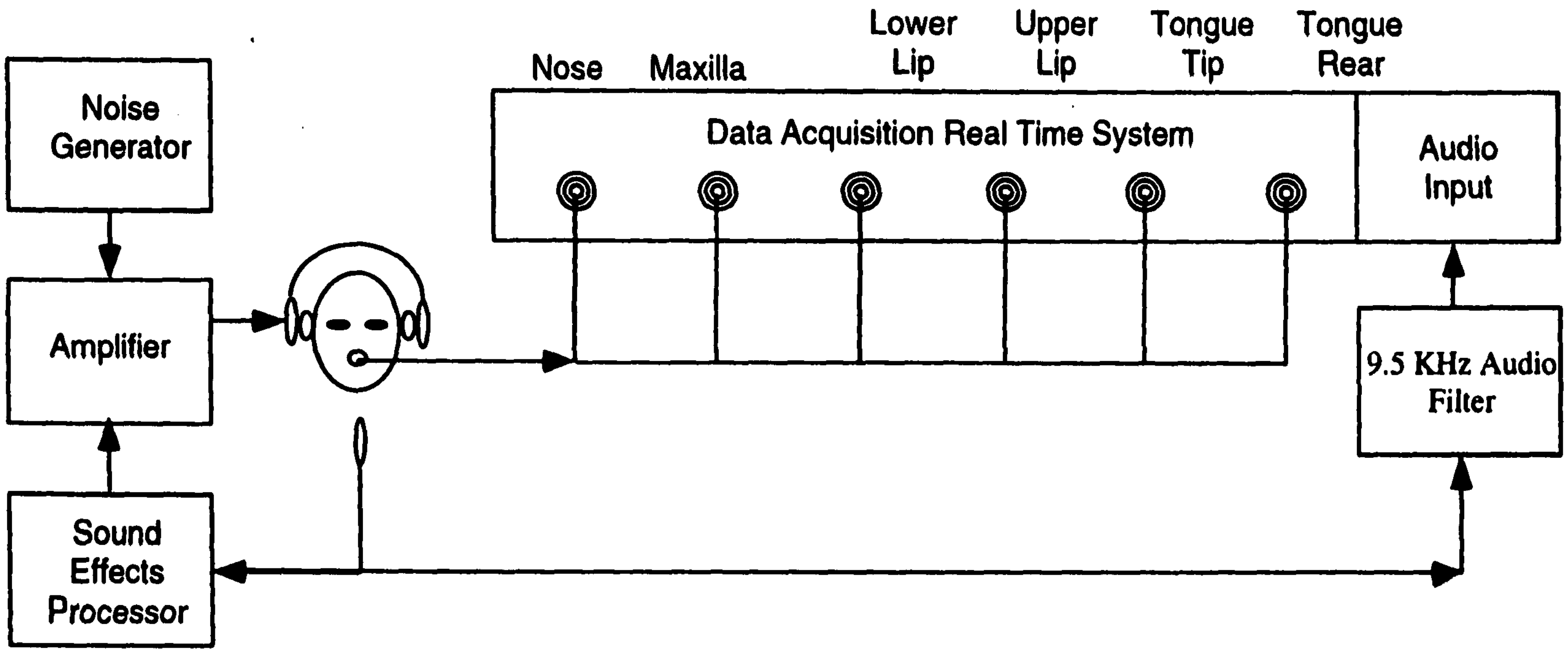


Figure 2. Signals for "Sash"

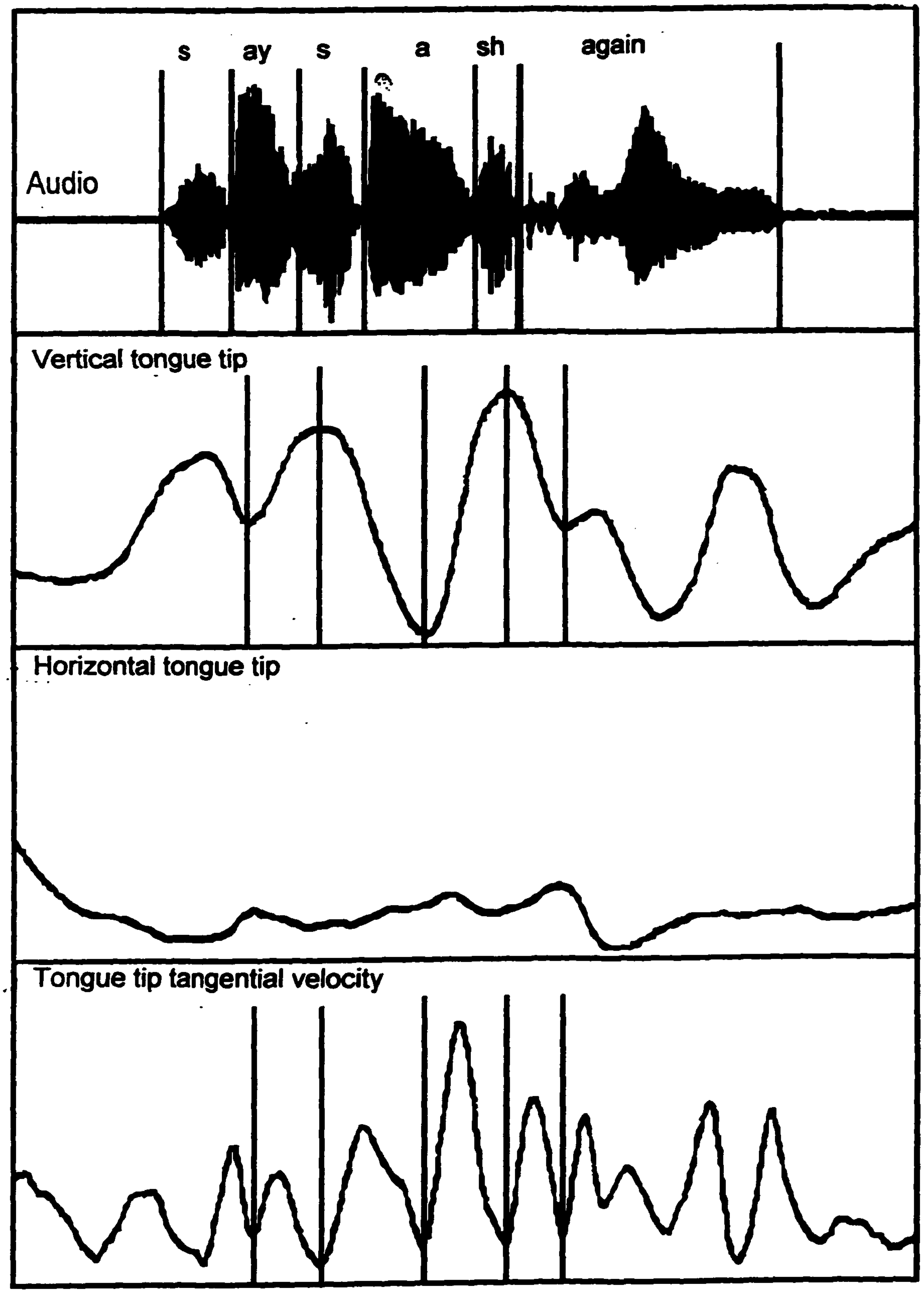


Figure 3. Signals For "Pass"

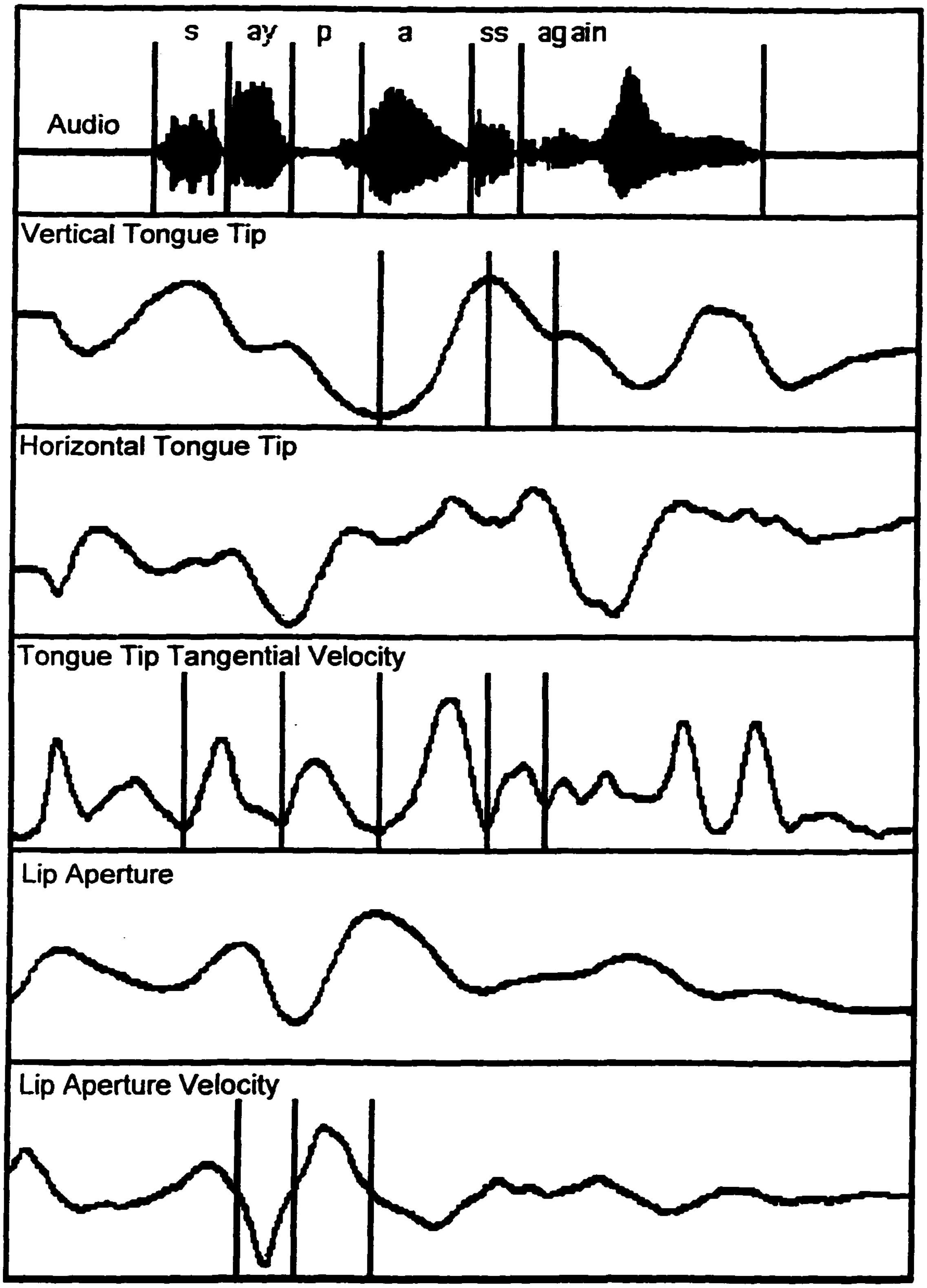


Figure 4. Signals For "Shop"

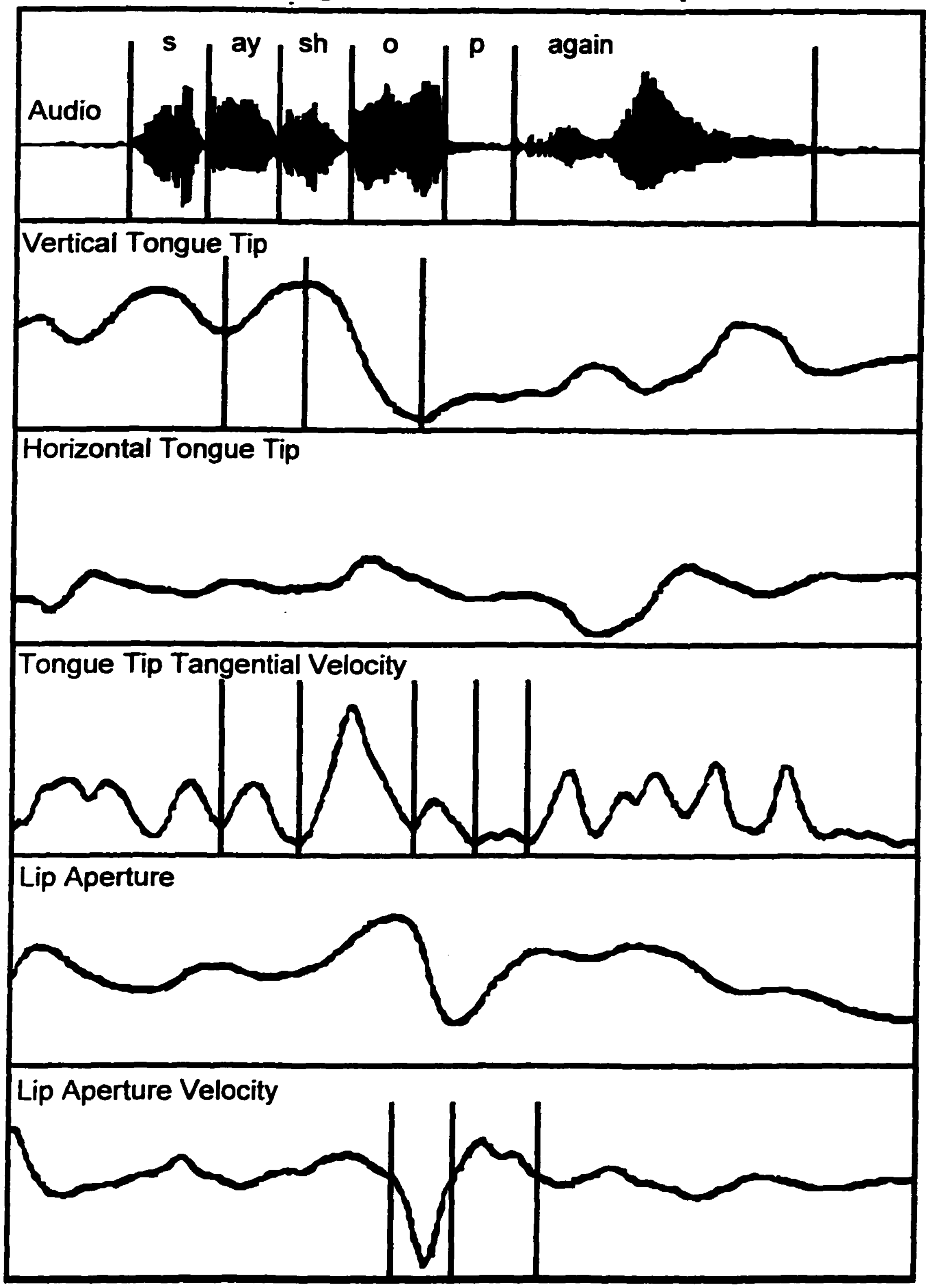


Figure 5. Signals For "Tack"

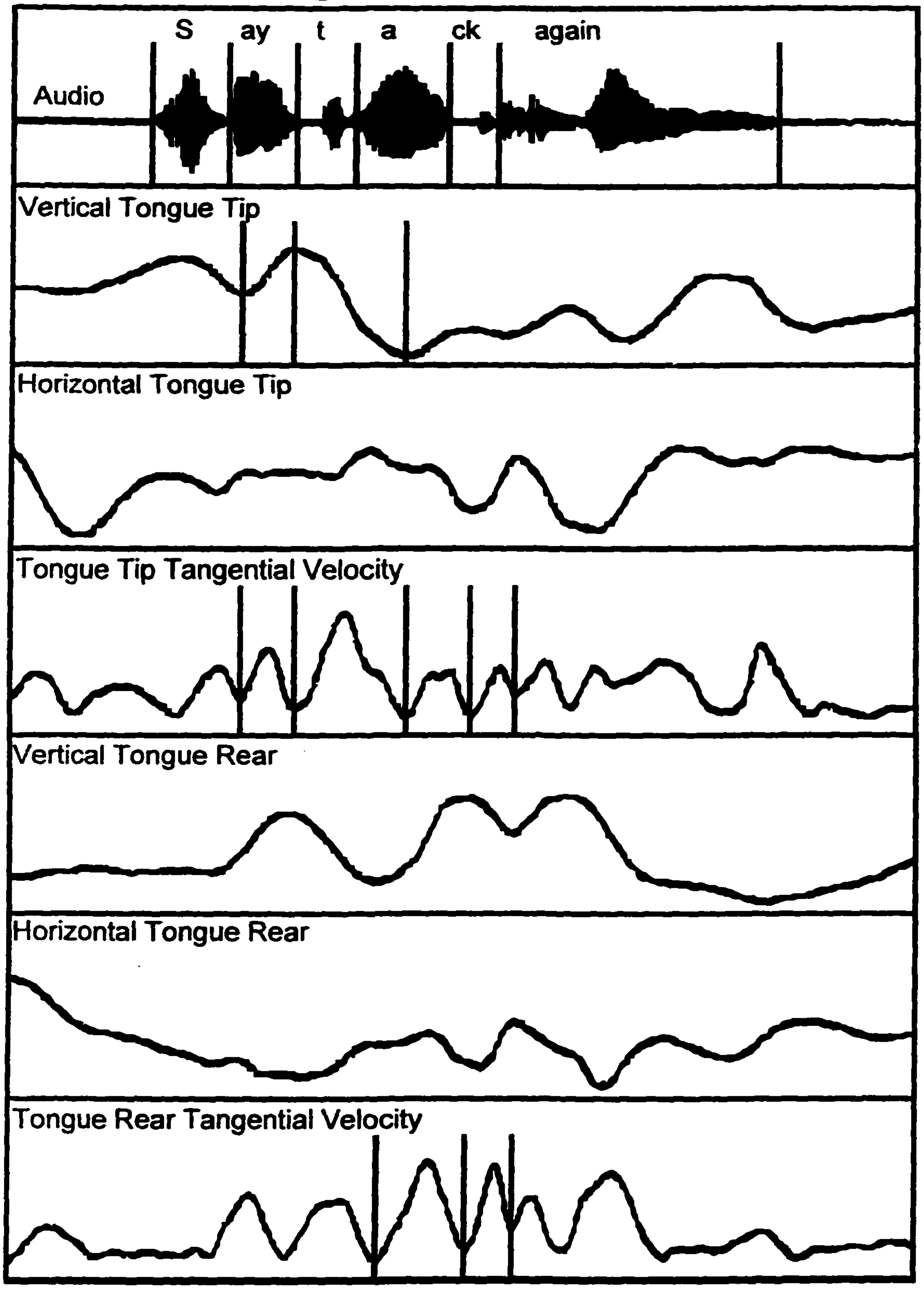


Figure 6. Signals For "Cot"

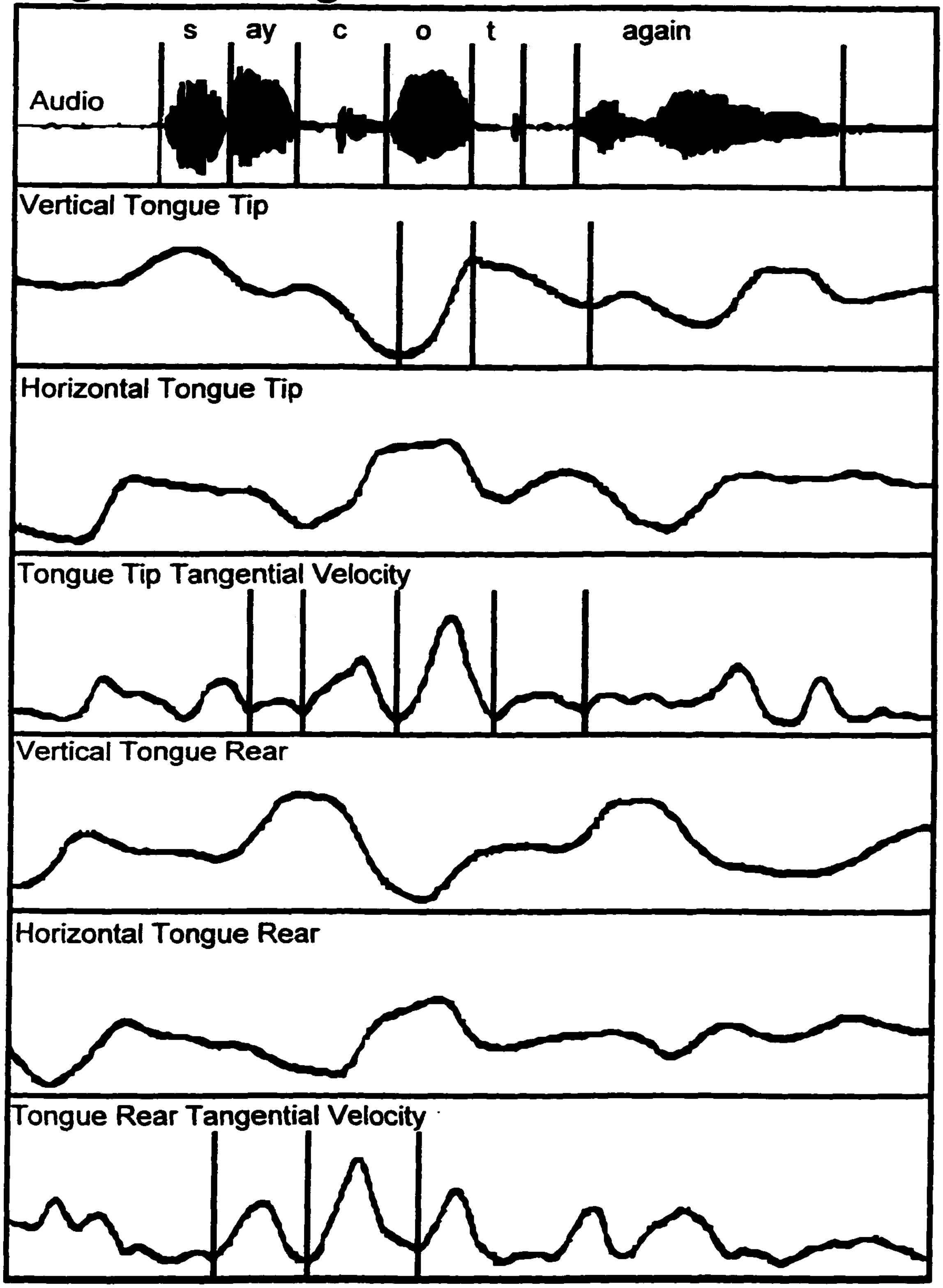


Figure 7. Movement Variables

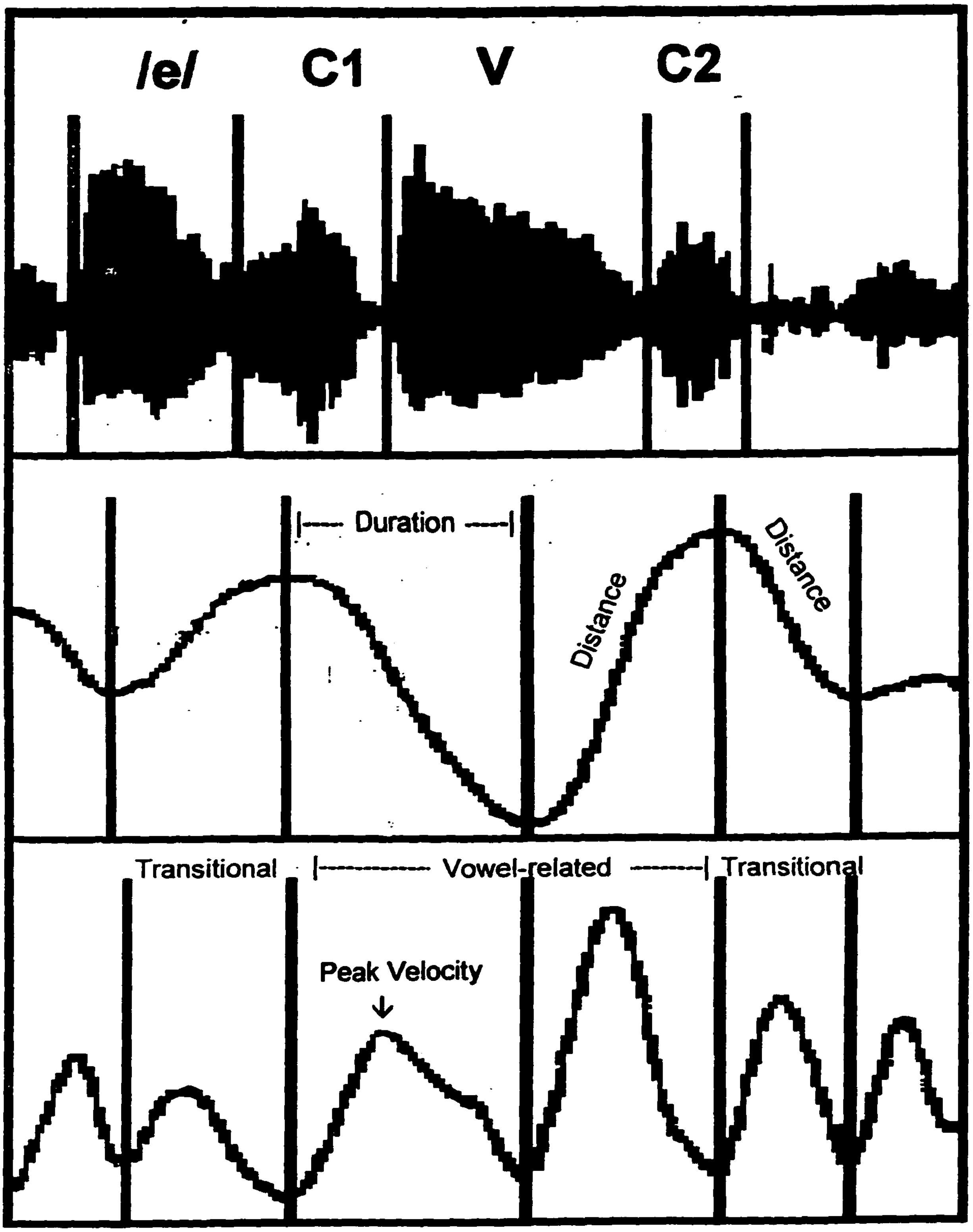


Figure 8. Mean Duration Under The Control Condition

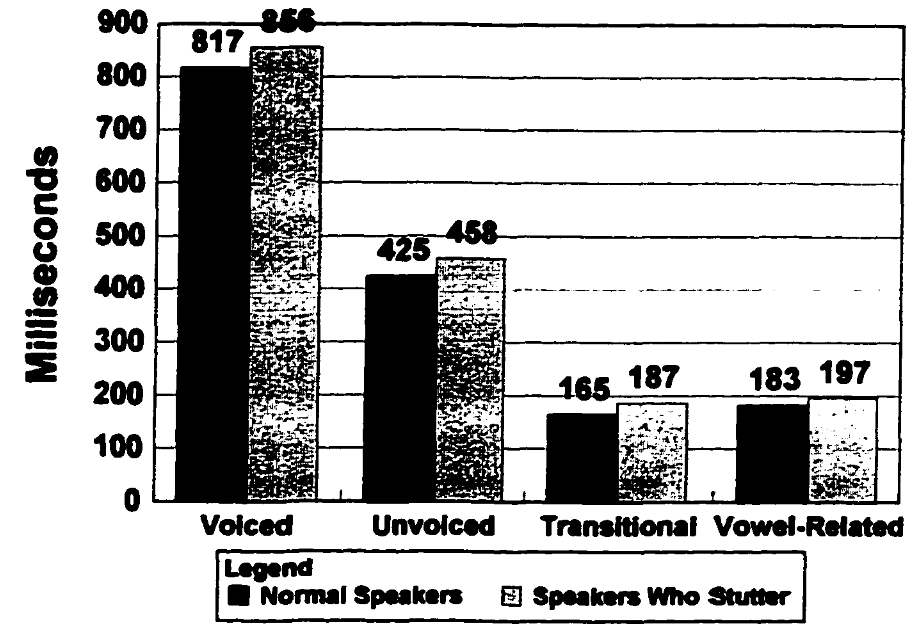


Figure 9. Standard Deviation Of Duration Under The Control Condition

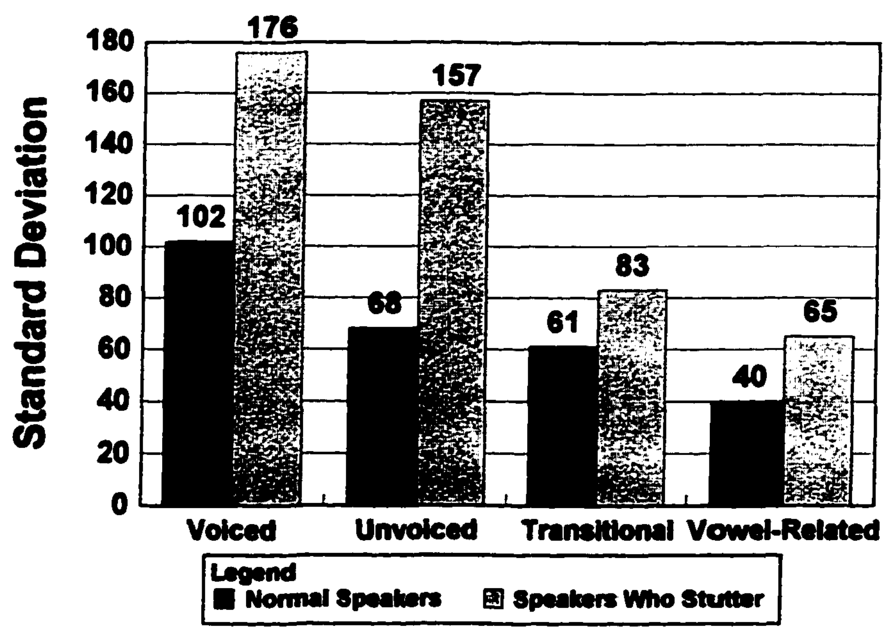


Figure 10. Distance Under The Control Condition

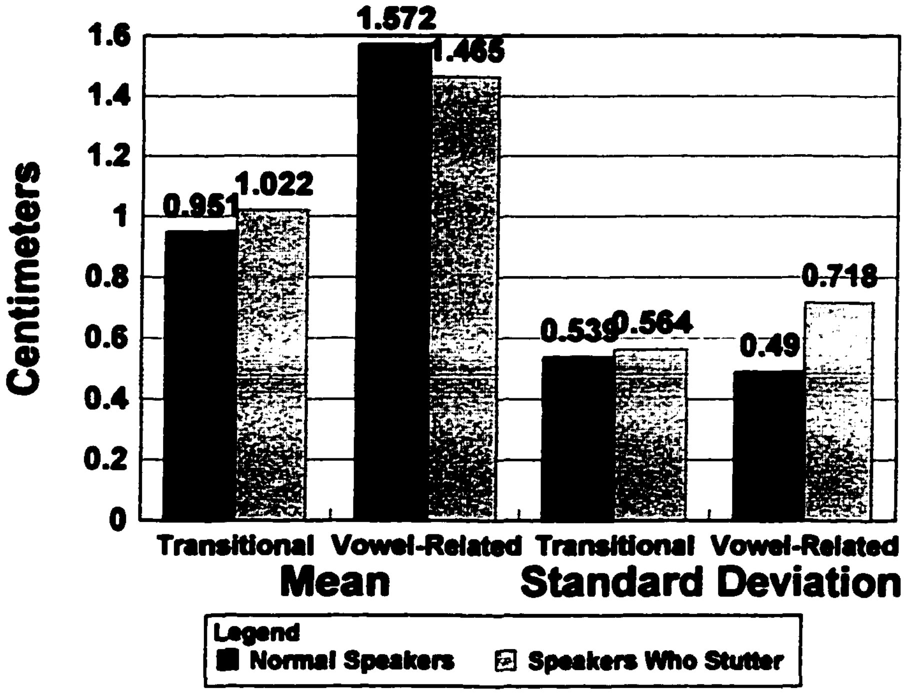


Figure 11. Peak Velocity Under The Control Condition

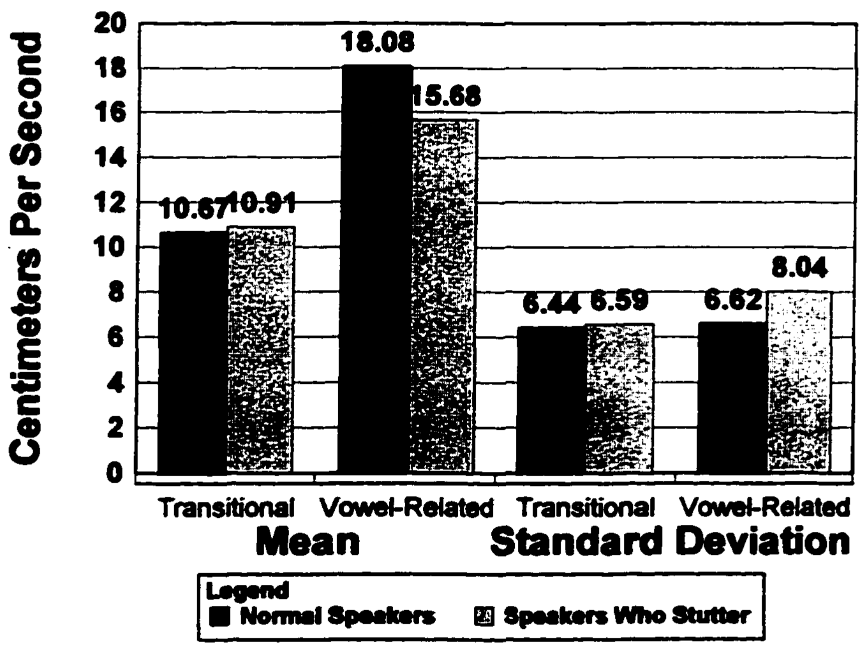


Figure 12. Position Under The Control Condition

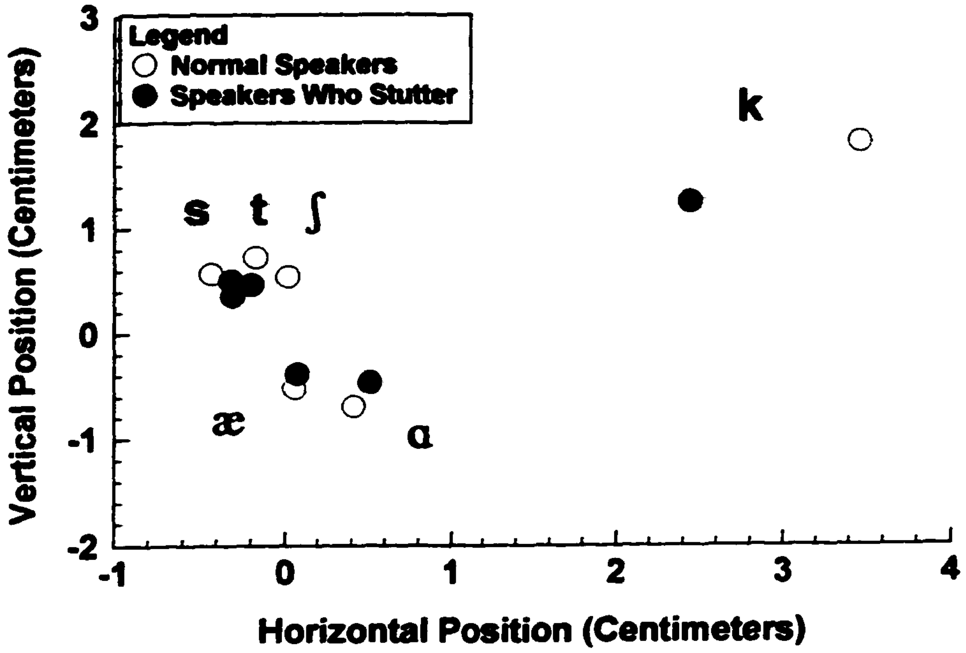


Figure 13. Mean Voicing Duration Of Individual Speakers Under The Control Condition

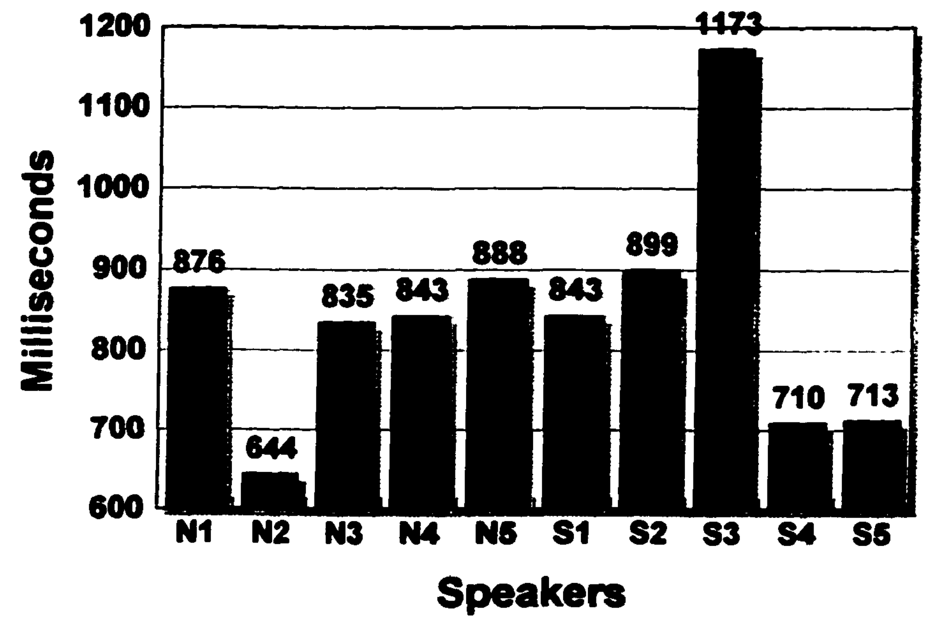


Figure 14. Standard Deviation Of Voicing Duration Of Individual Speakers Under The Control Condition

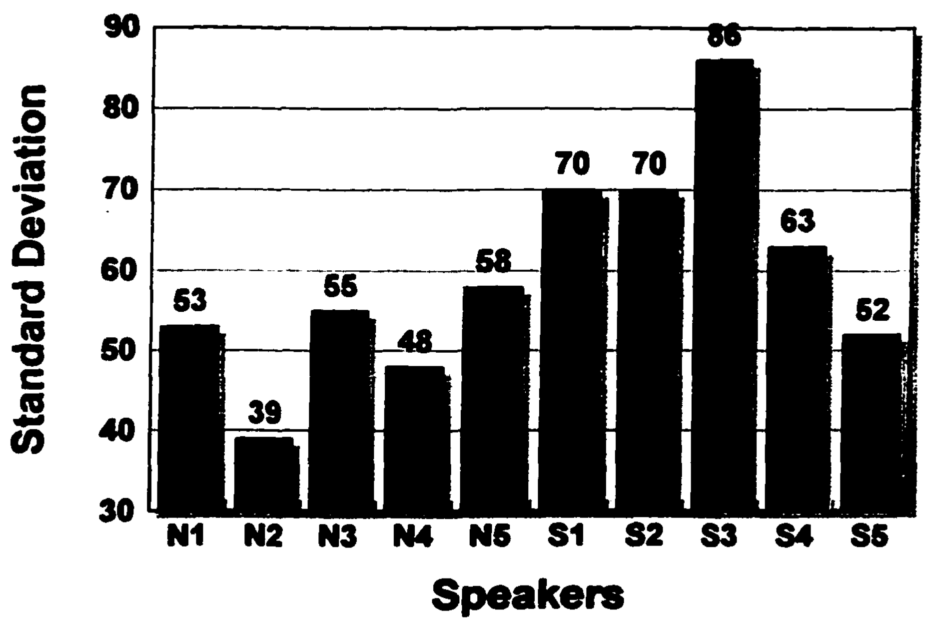


Figure 15. Mean Duration Of Unvoiced Segments Of Individual Speakers Under The Control Condition

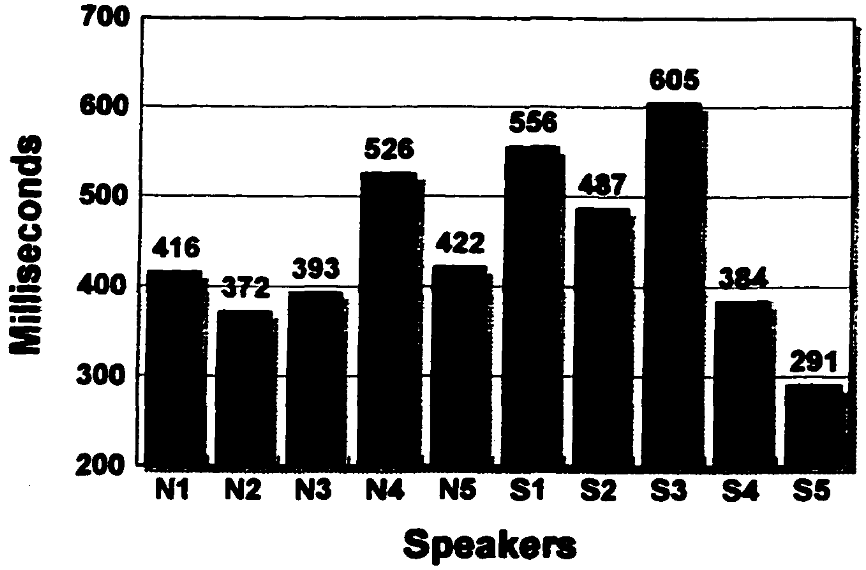


Figure 16. Standard Deviation Of Duration Of Unvoiced Segments Of Individual Speakers Under The Control Condition

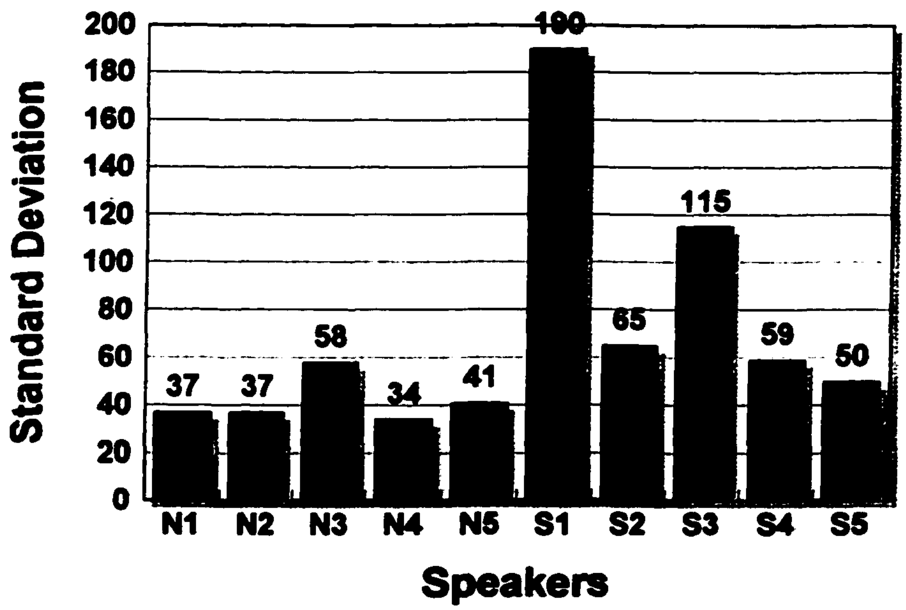


Figure 17. Mean Movement Duration Of Individual Speakers Under The Control Condition

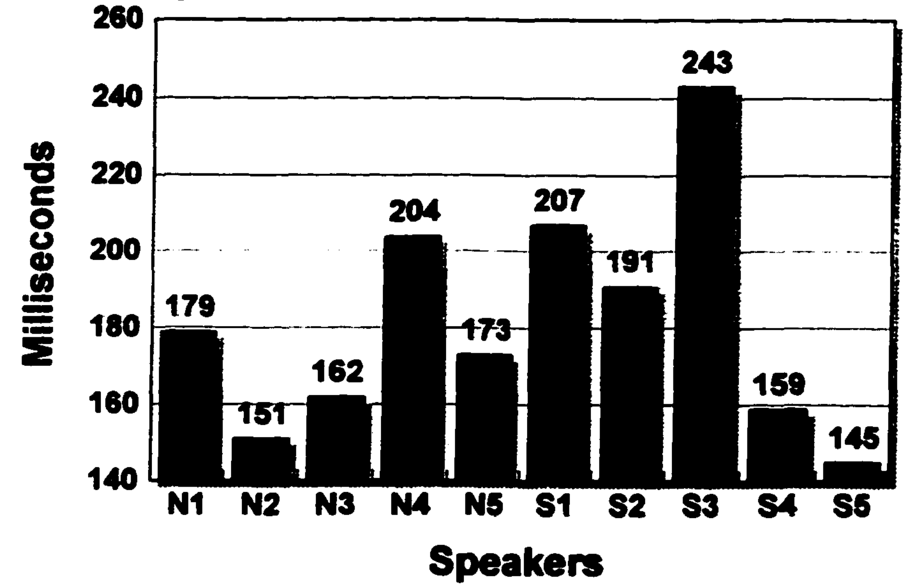


Figure 18. Standard Deviation Of Movement Duration Of Individual Speakers Under The Control Condition

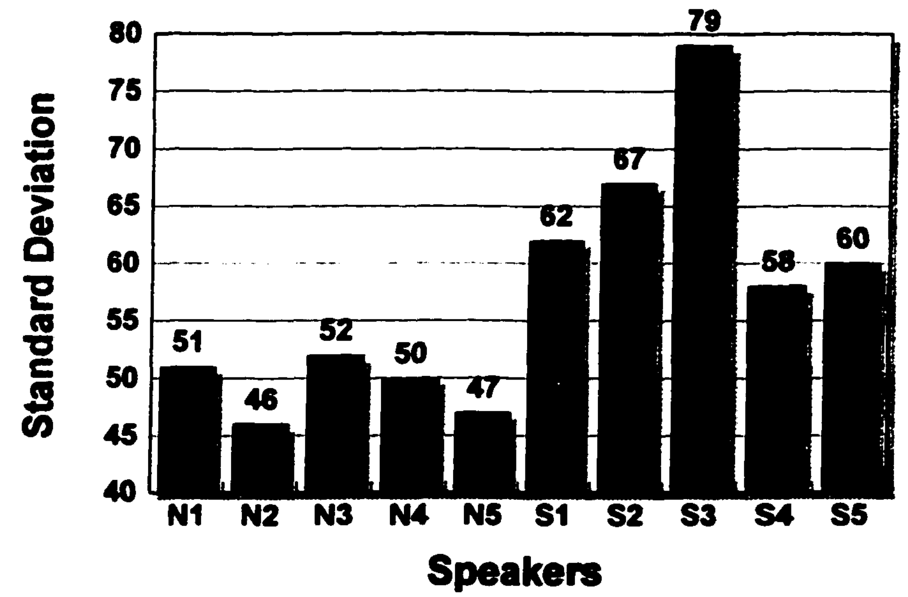


Figure 19. Mean Distance Of Individual Speakers Under The Control Condition

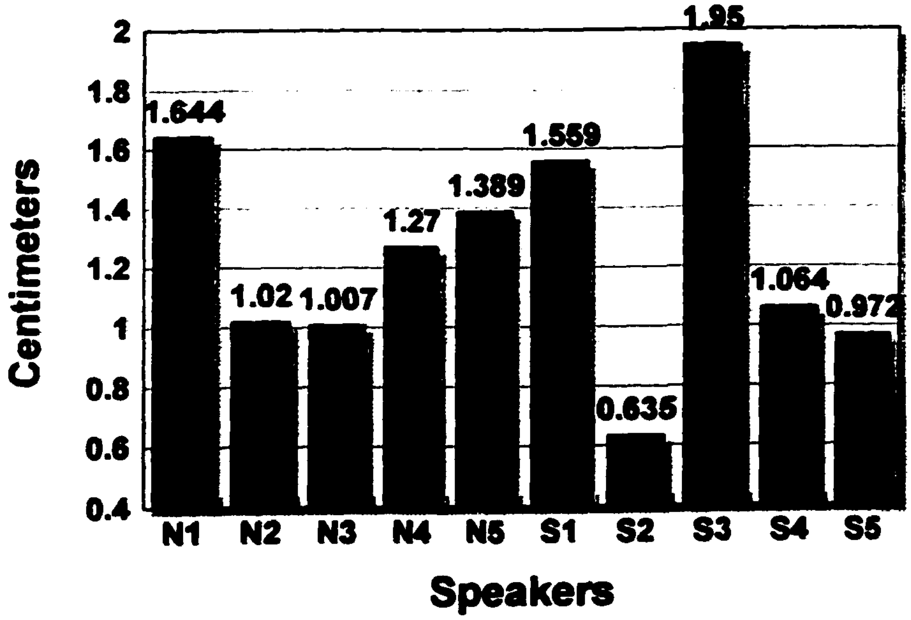


Figure 20. Standard Deviation Of Distance Of Individual Speakers Under The Control Condition

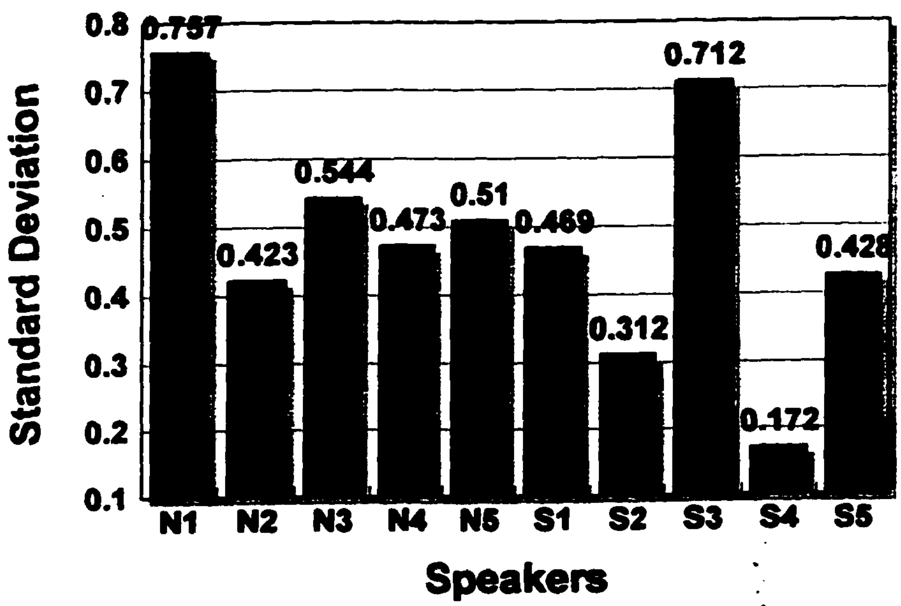


Figure 21. Mean Peak Velocity Of Individual Speakers Under The Control Condition

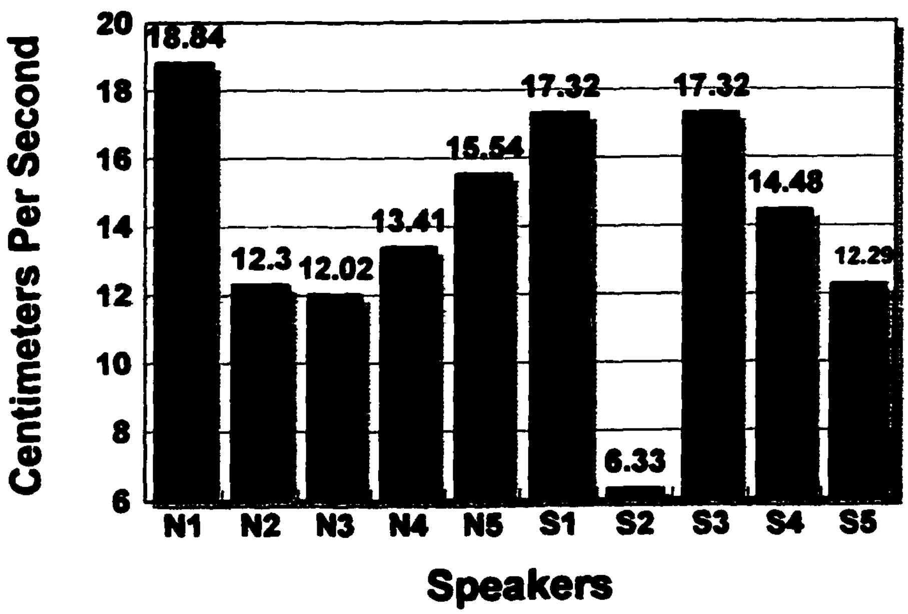


Figure 22. Standard Deviation Of Peak Velocity Of Individual Speakers Under The Control Condition

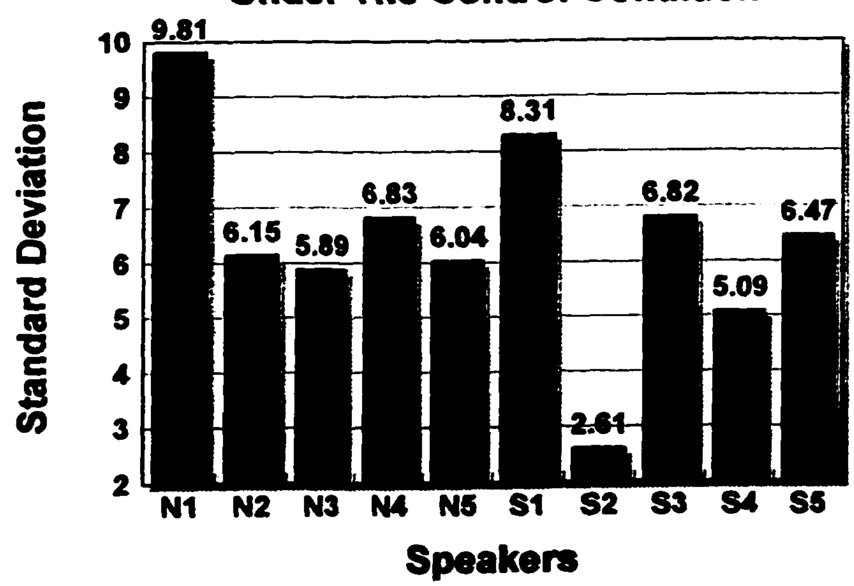


Figure 23. Transitional And Vowel-Related Duration In Individual Speakers Under The Control Condition

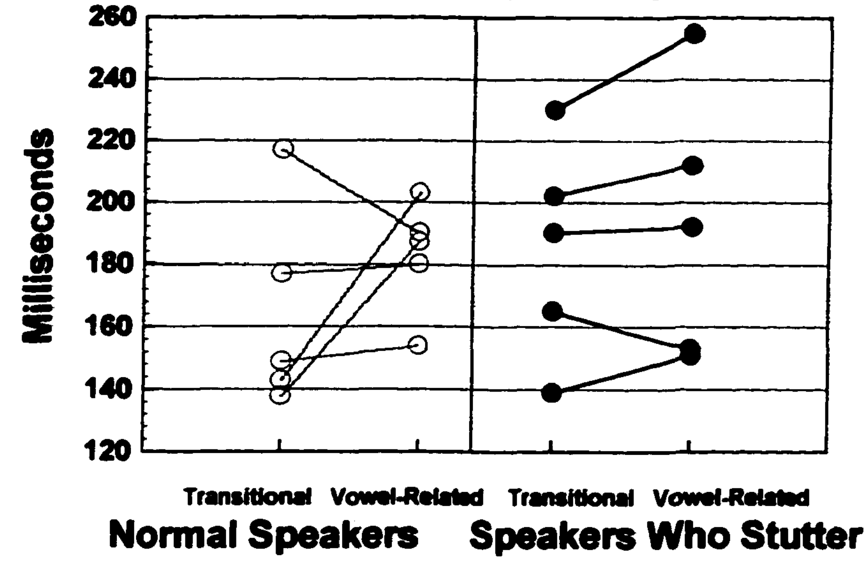


Figure 24. Transitional And Vowel-Related Distance In Individual Speakers Under The Control Condition

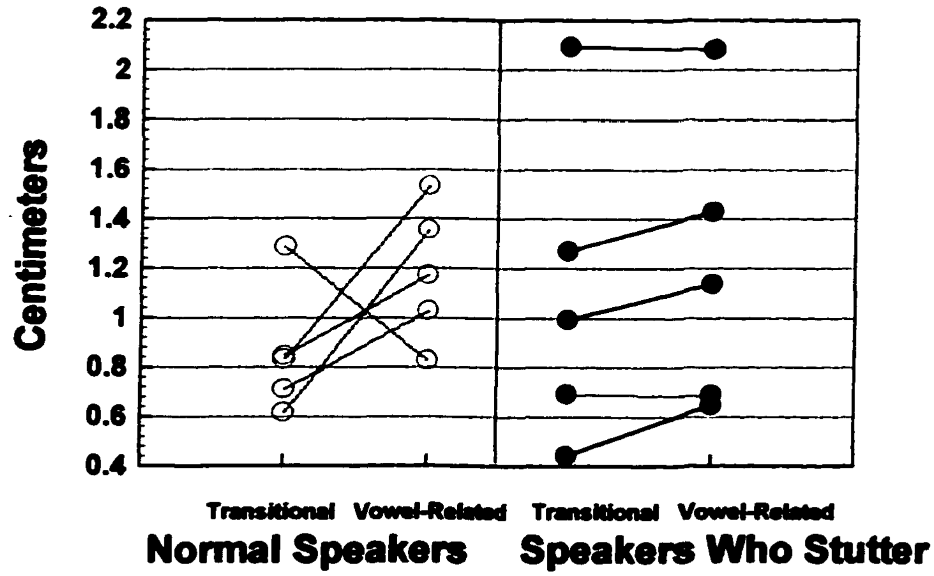


Figure 25. Mean Voicing Duration Under All Conditions

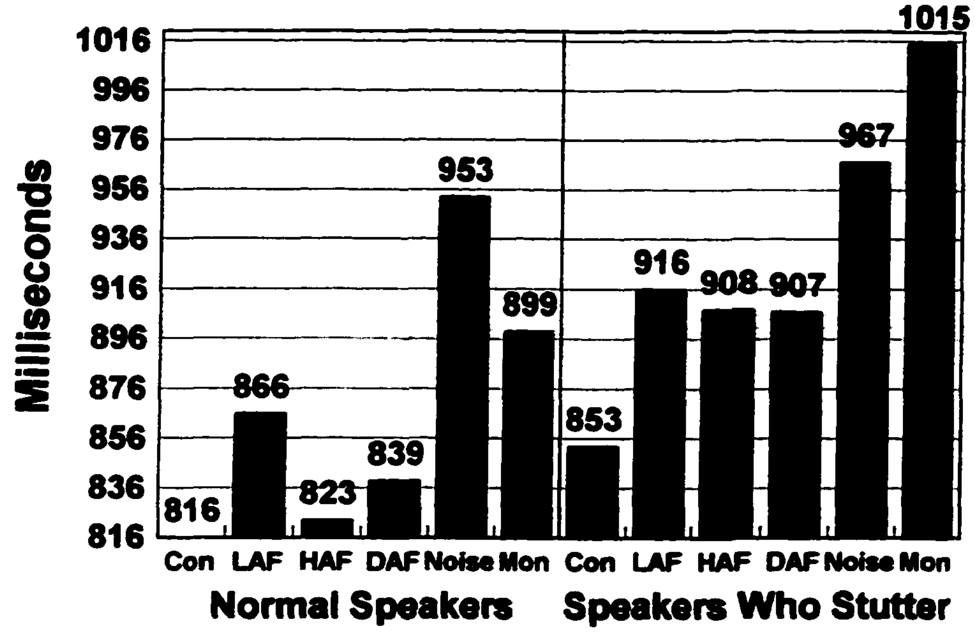


Figure 26. Standard Deviation Of Voicing Duration Under All Conditions

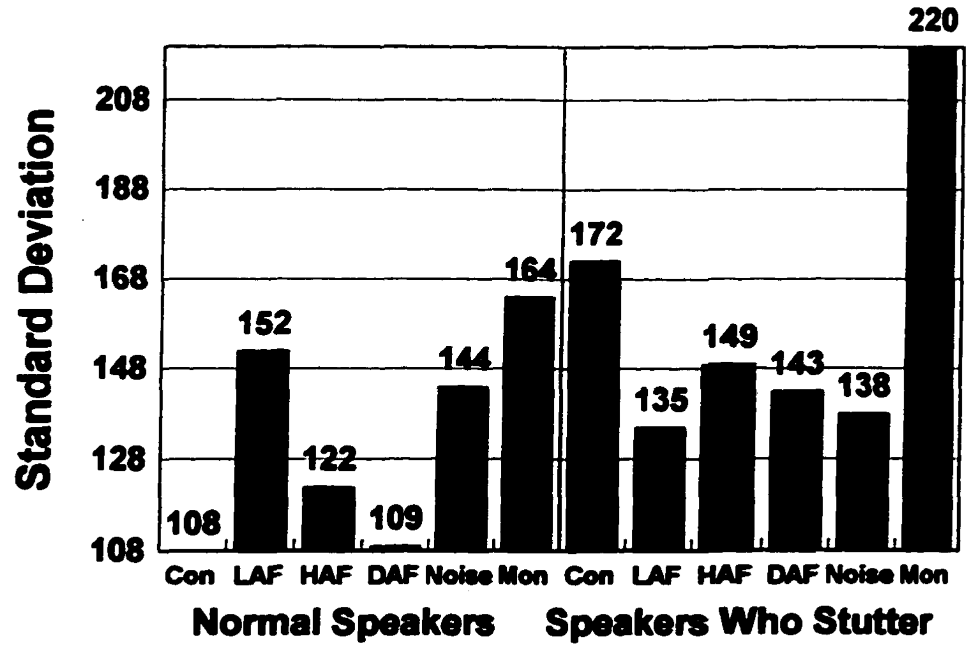


Figure 27. Mean Duration Of Unvoiced Segments Under All Conditions

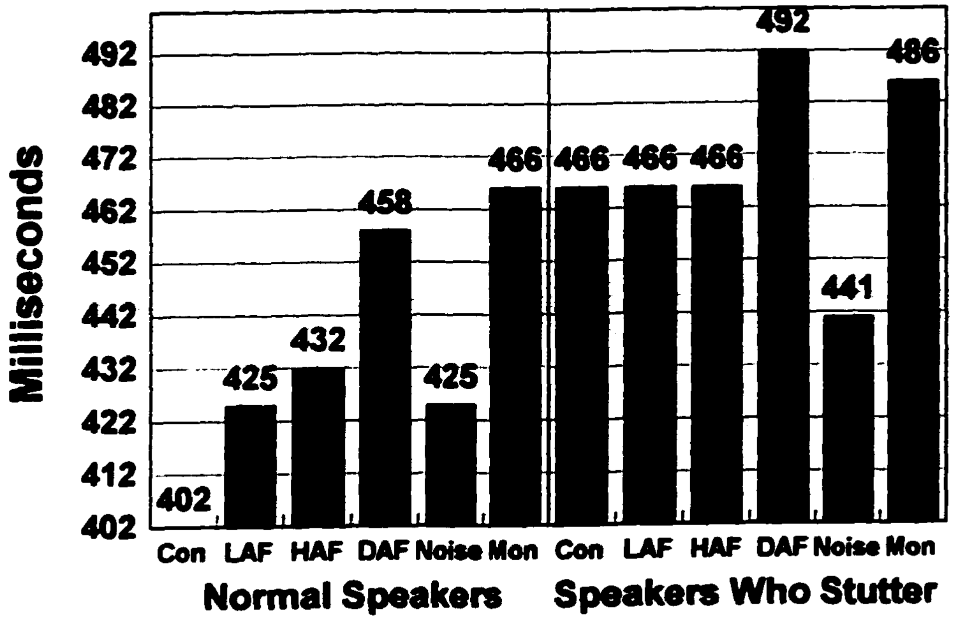


Figure 28. Standard Deviation Of Duration Of Unvoiced Segments Under All Conditions

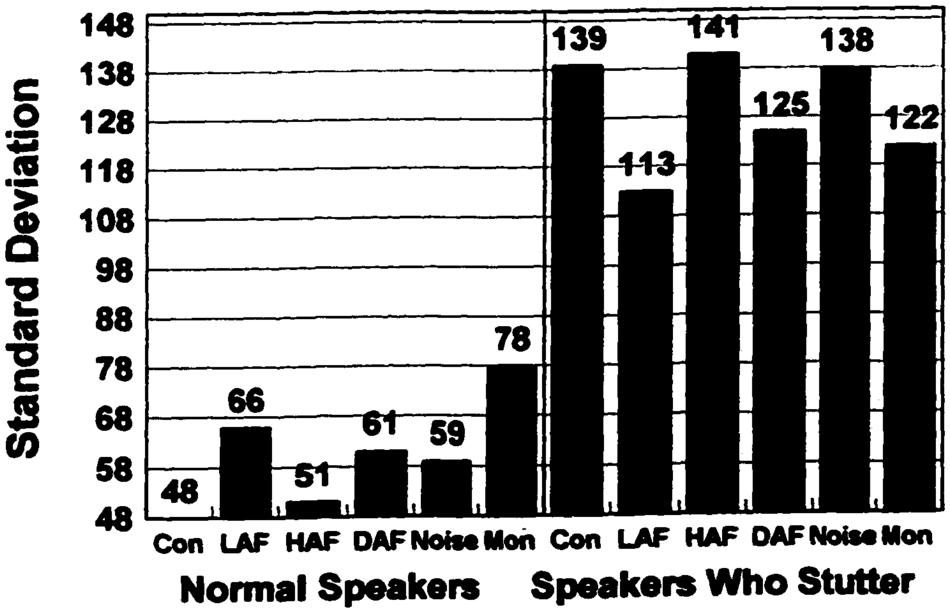


Figure 29. Mean Transitional Movement Duration Under All Conditions

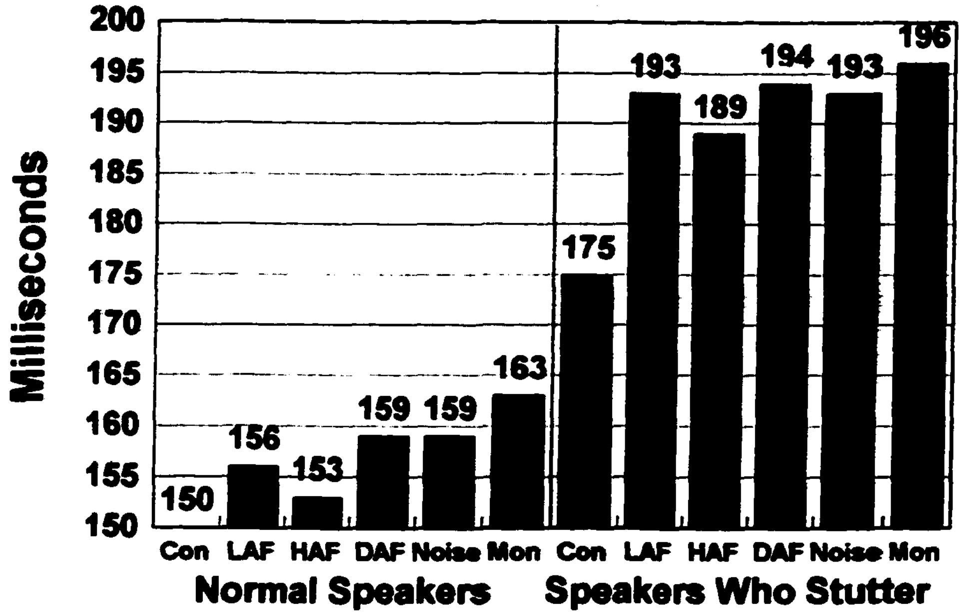


Figure 30. Standard Deviation Of Transitional Movement Duration Under All Conditions

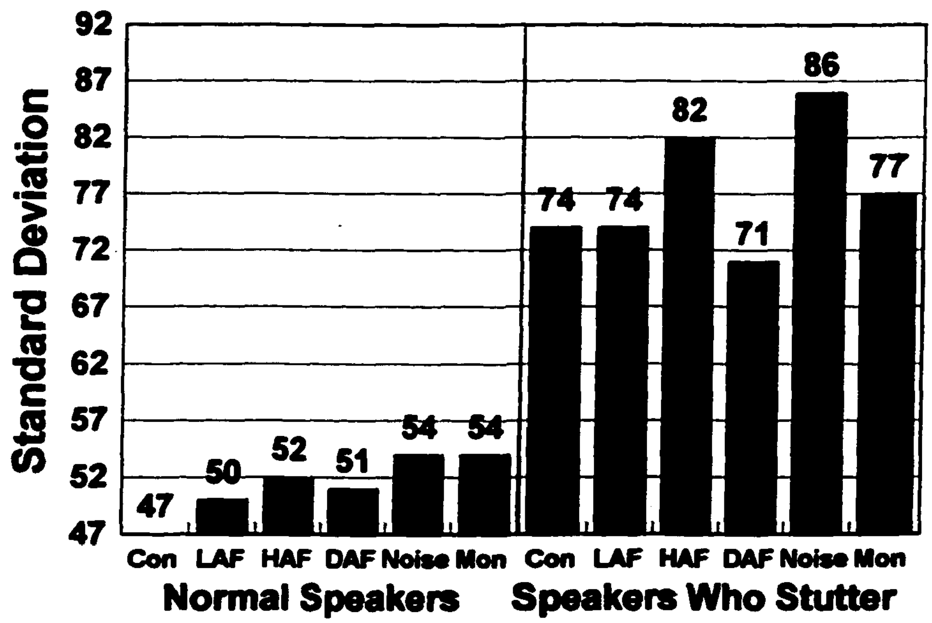


Figure 31. Mean Vowel-Related Movement Duration Under All Conditions

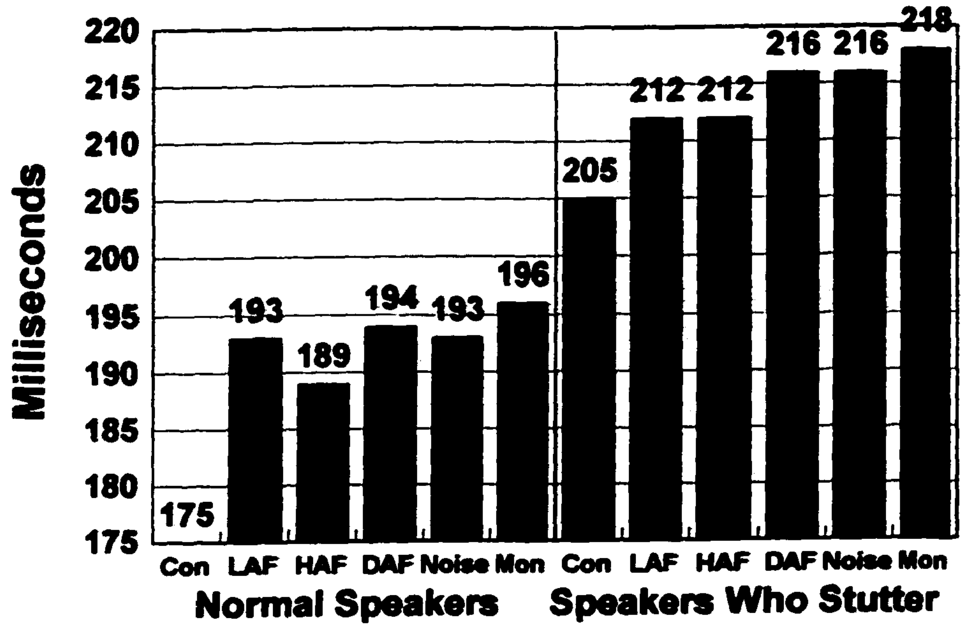


Figure 32. Standard Deviation Of Vowel-Related Movement Duration Under All Conditions

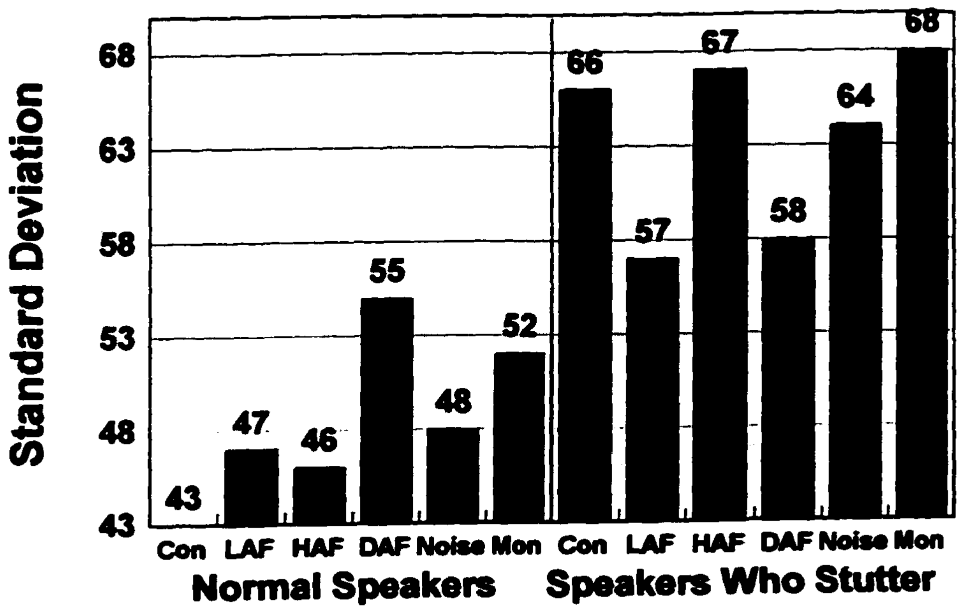


Figure 33. Mean Transitional Distance Under All Conditions

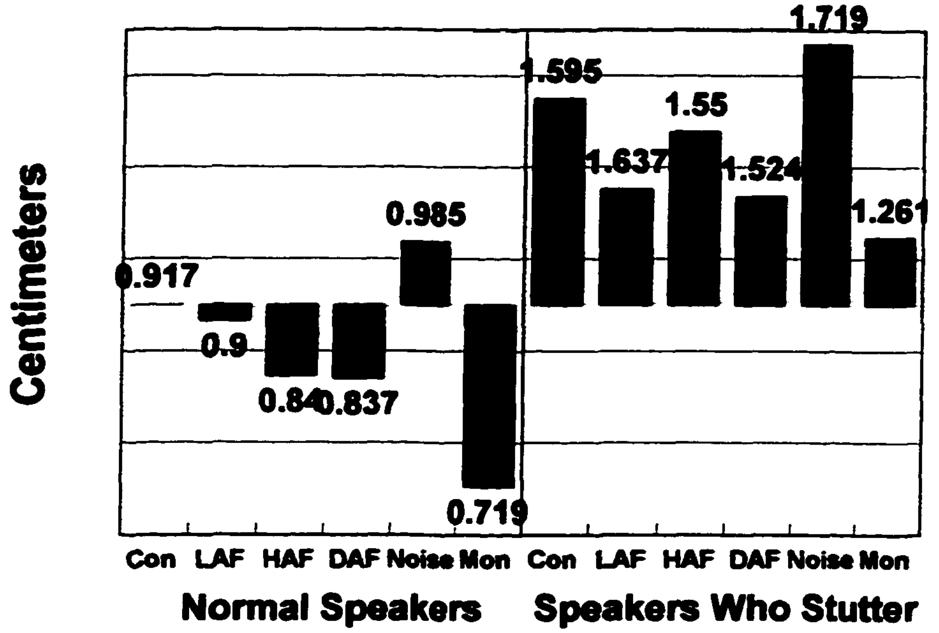


Figure 34. Standard Deviation Of Transitional Distance Under All Conditions

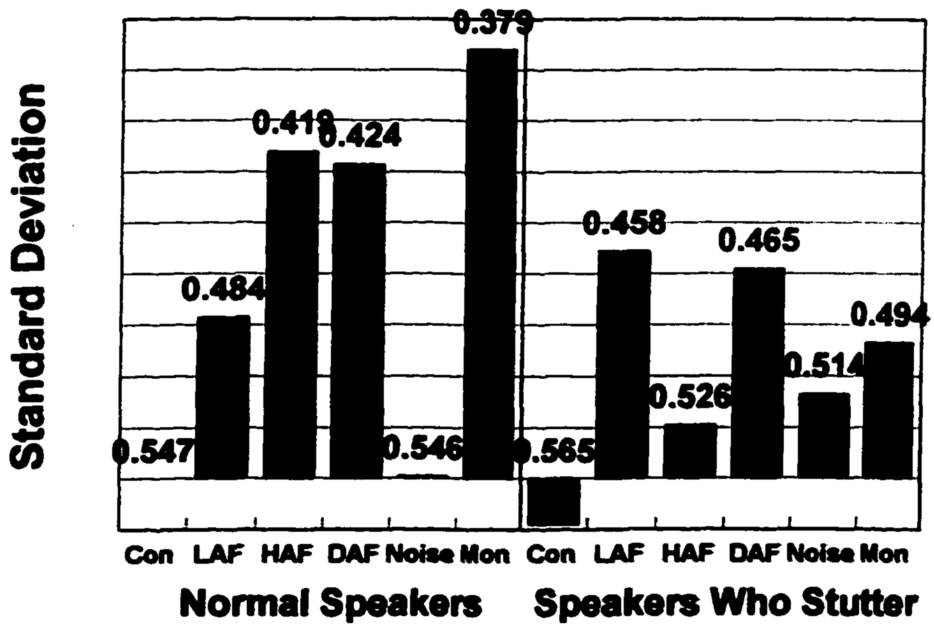


Figure 35. Mean Vowel-Related Distance Under All Conditions

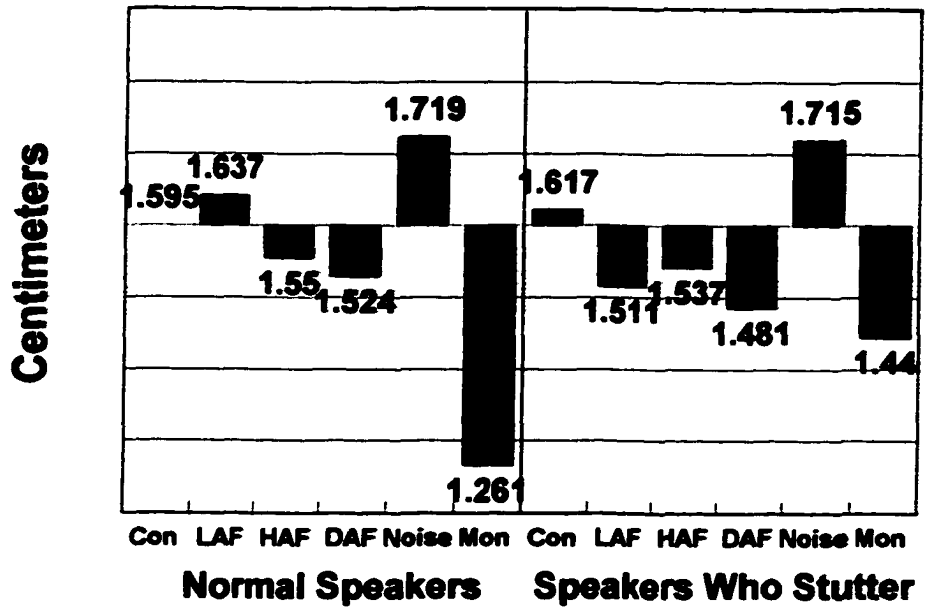


Figure 36. Standard Deviation Of Vowel-Related Distance Under All Conditions

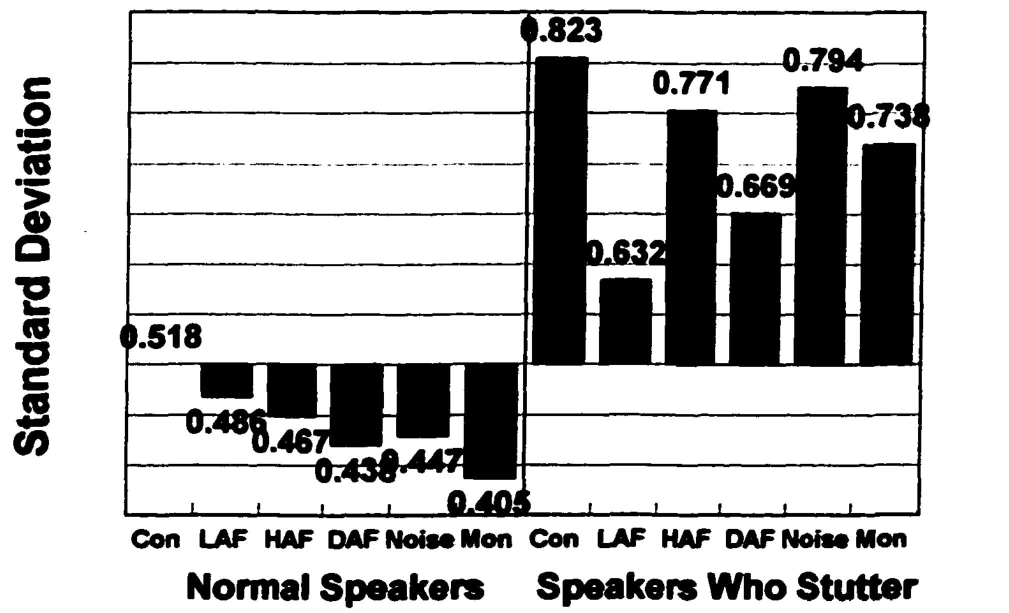


Figure 37. Mean Transitional Peak Velocity Under All Conditions

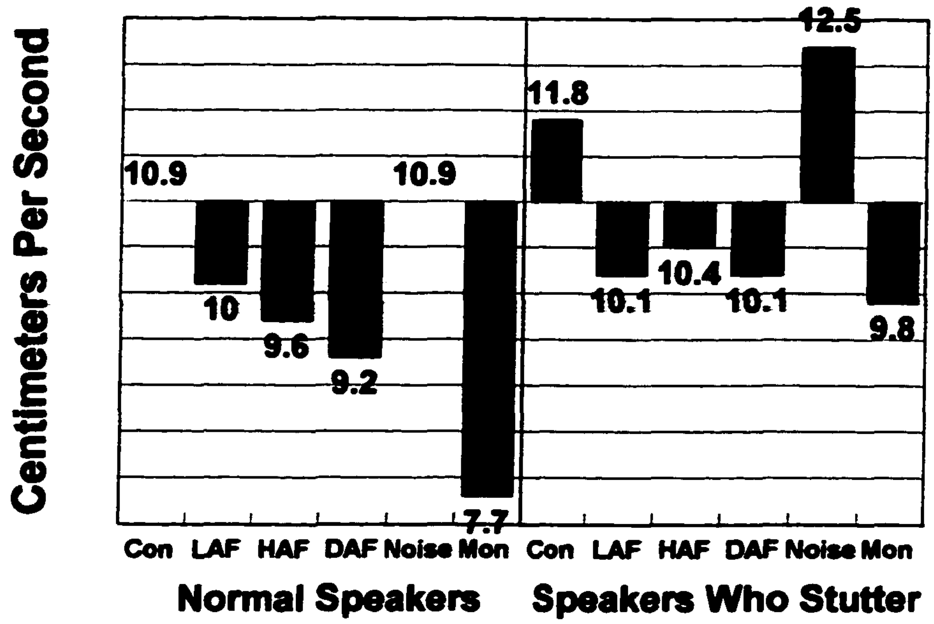


Figure 38. Standard Deviation Of Transitional Peak Velocity Under All Conditions

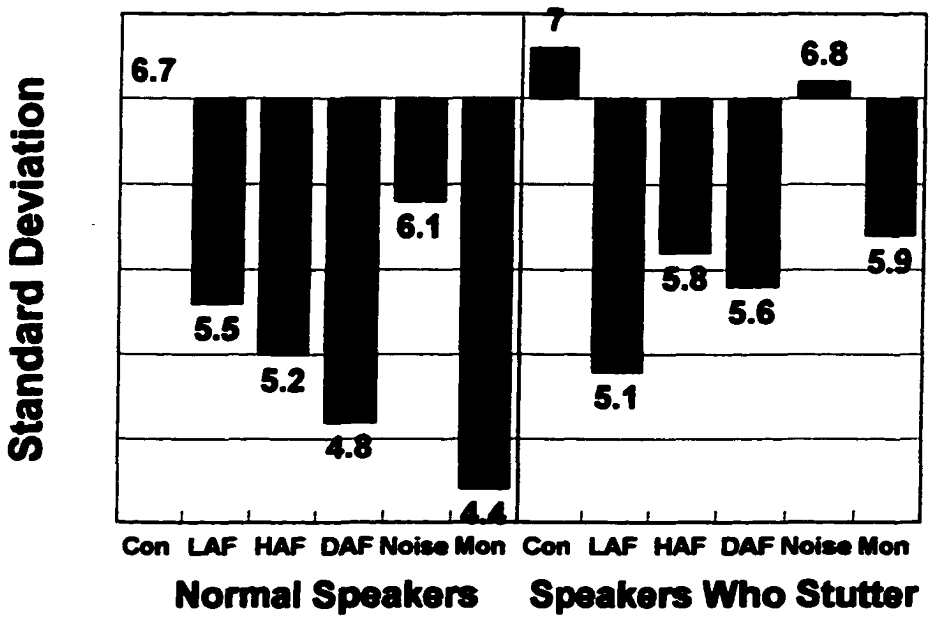


Figure 39. Mean Vowel-Related Peak Velocity Under All Conditions

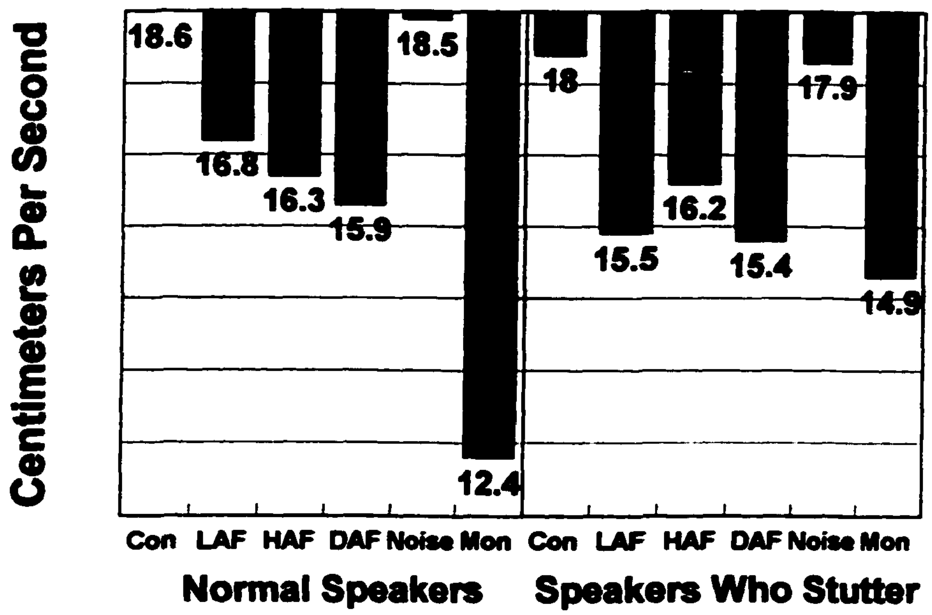


Figure 40. Standard Deviation Of Vowel-Related Peak Velocity Under All Conditions

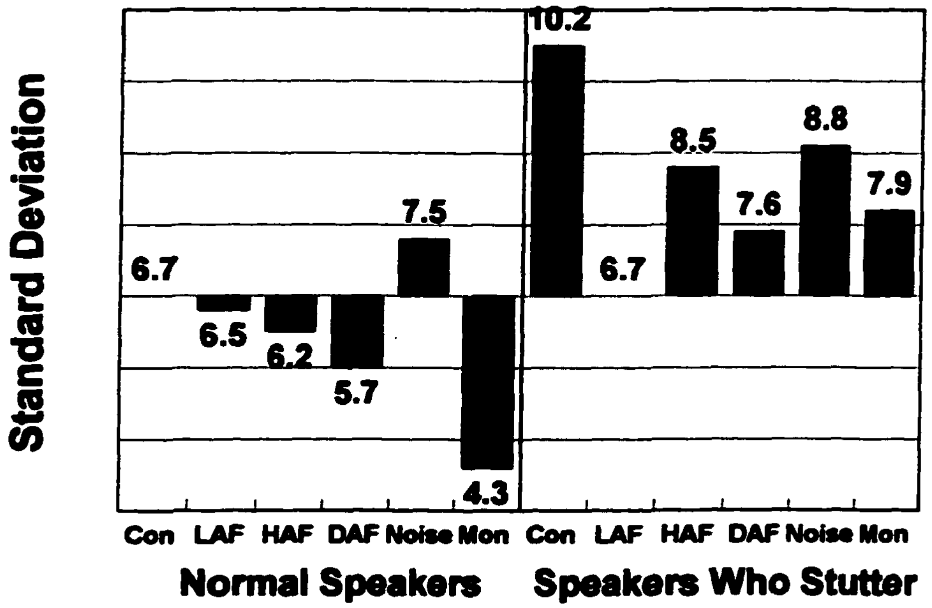


Figure 41. Mean Vertical Position Of /s, ʃ, t/ Under All Conditions

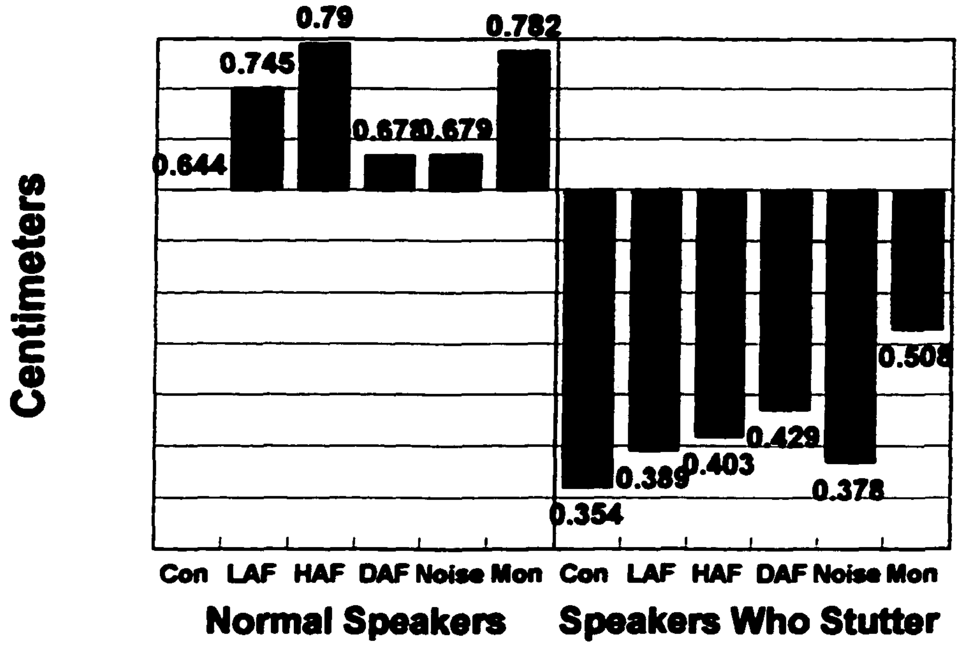


Figure 42. Standard Deviation Of Vertical Position Of /s, S, t/ Under All Conditions

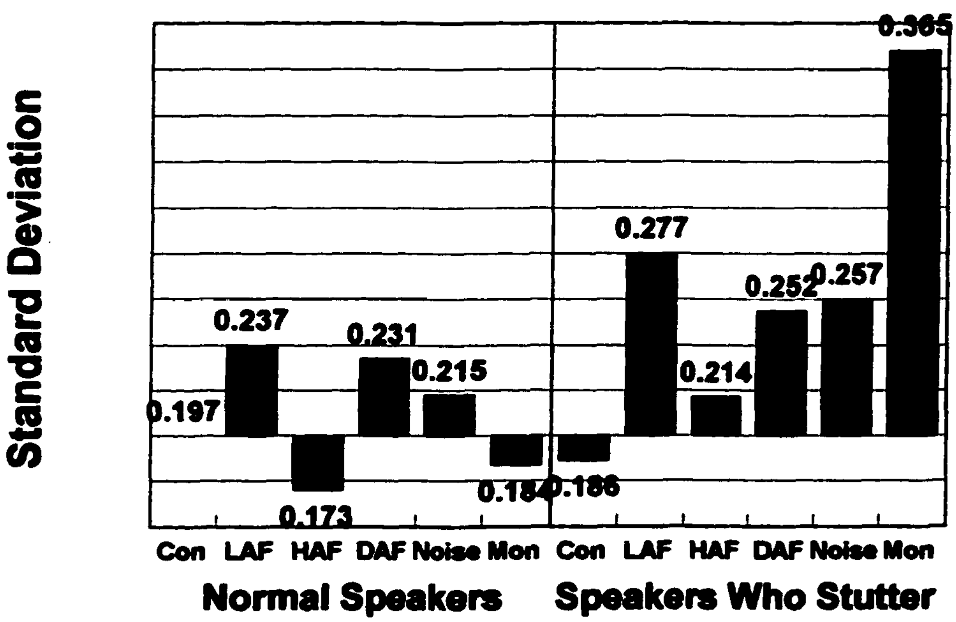


Figure 43. Mean Vertical Position Of /æ, ɑ/ Under All Conditions

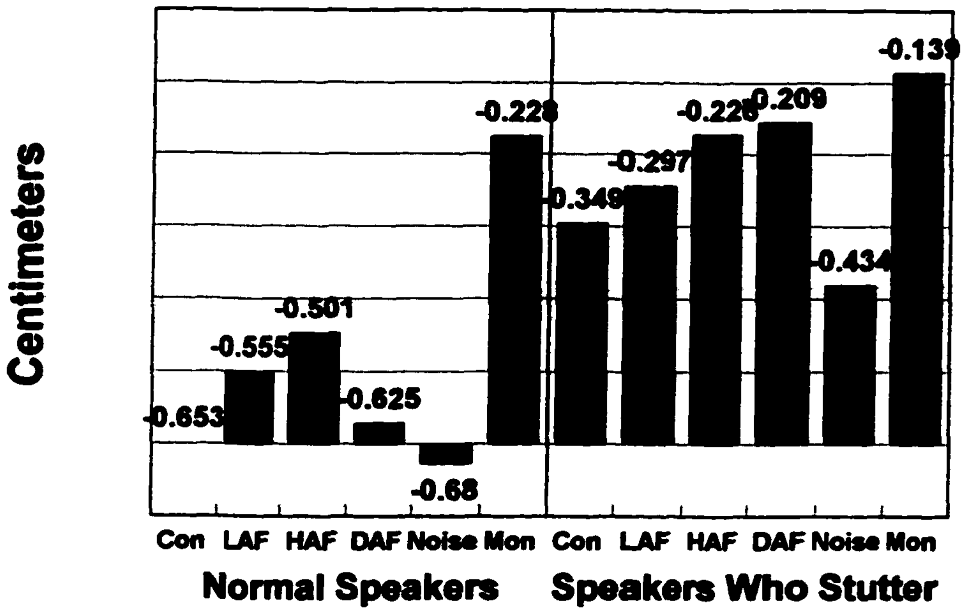


Figure 44. Standard Deviation Of Vertical Position Of /æ, ɑ/ Under All Conditions

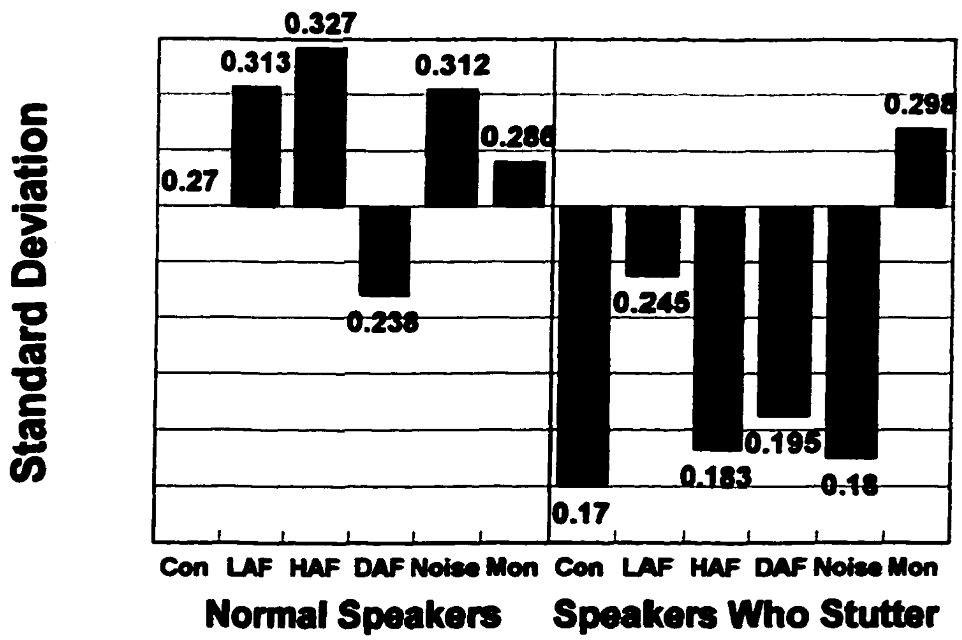


Figure 45. Mean Horizontal Position Of /s, ʃ, t/ Under All Conditions

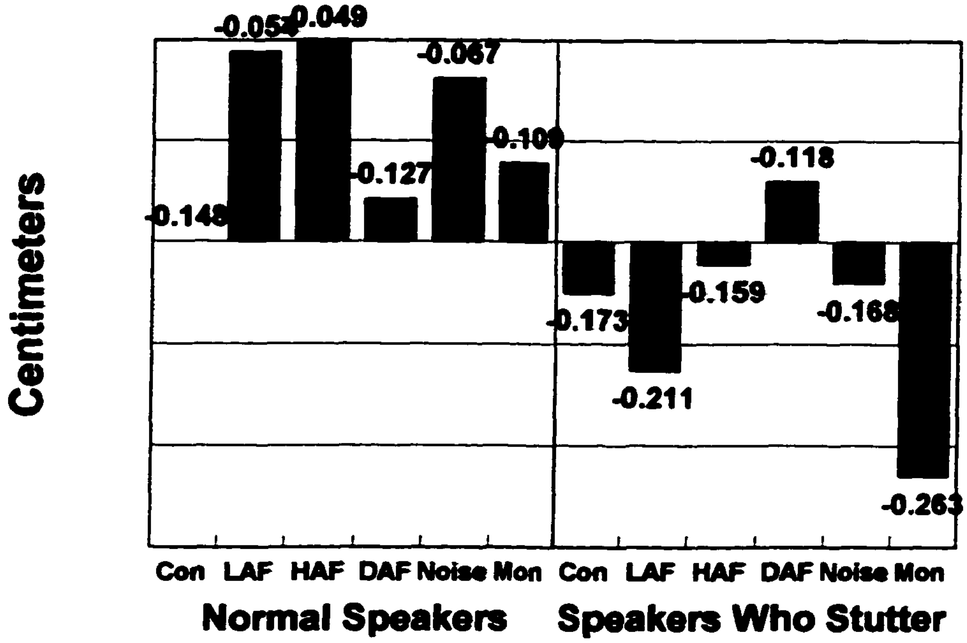


Figure 46. Standard Deviation Of Horizontal Position Of /s, ʃ, t/ Under All Conditions

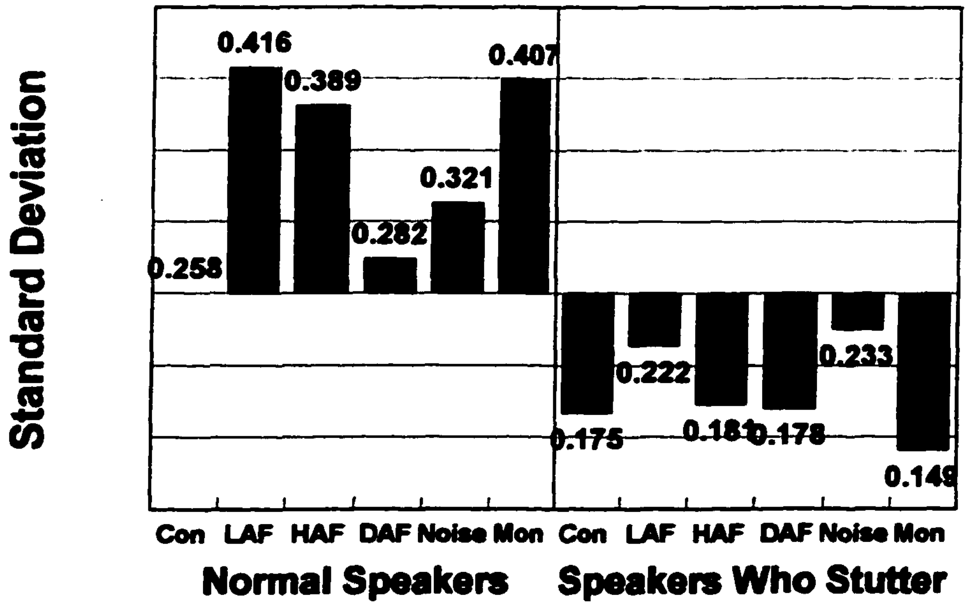


Figure 47. Mean Horizontal Position Of /æ, ɑ/ Under All Conditions

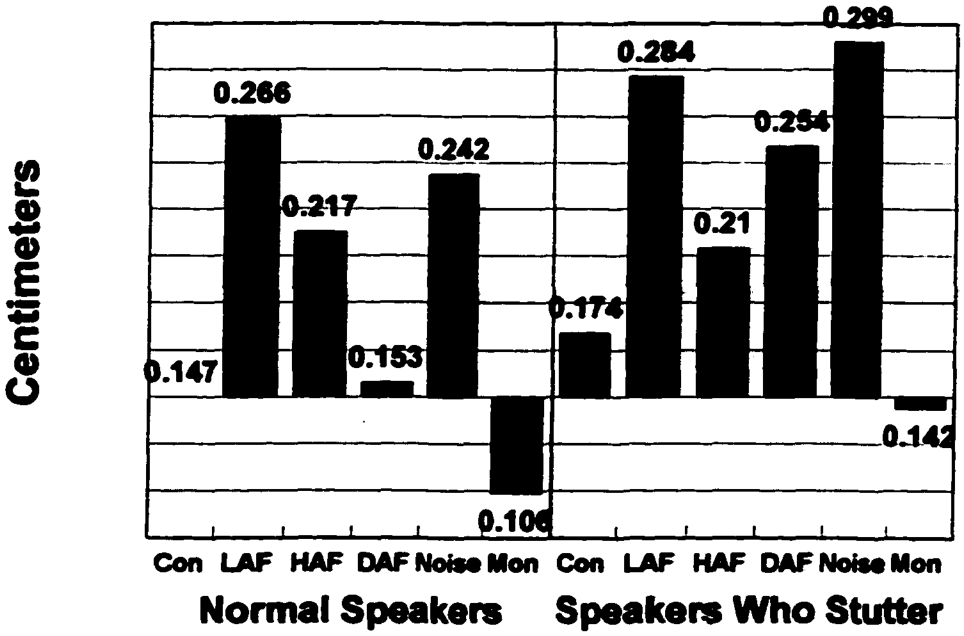


Figure 48. Standard Deviation Of Horizontal Position Of /æ, ɑ/ Under All Conditions

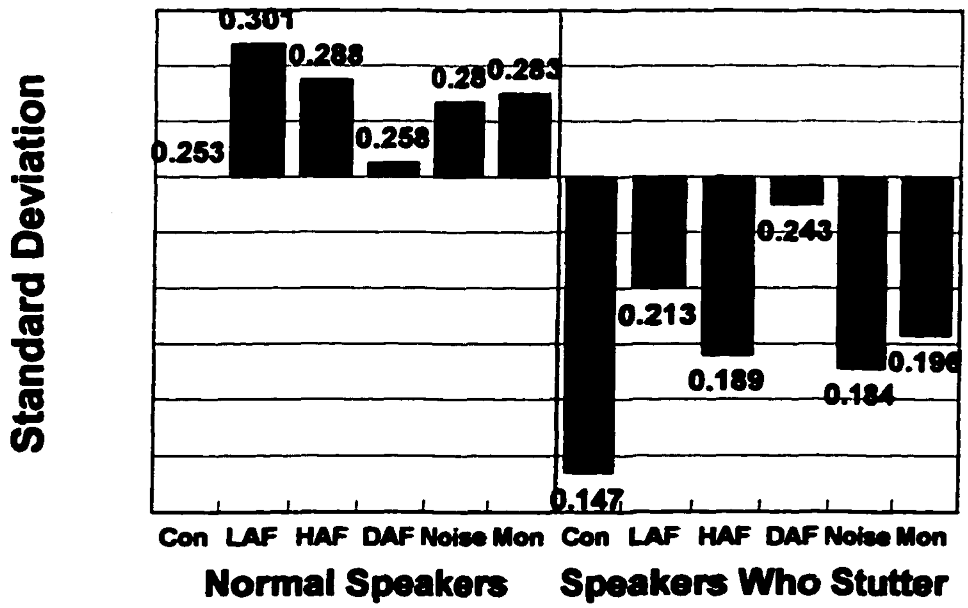


Figure 49. Change In Position From The Control Condition To The Experimental Conditions

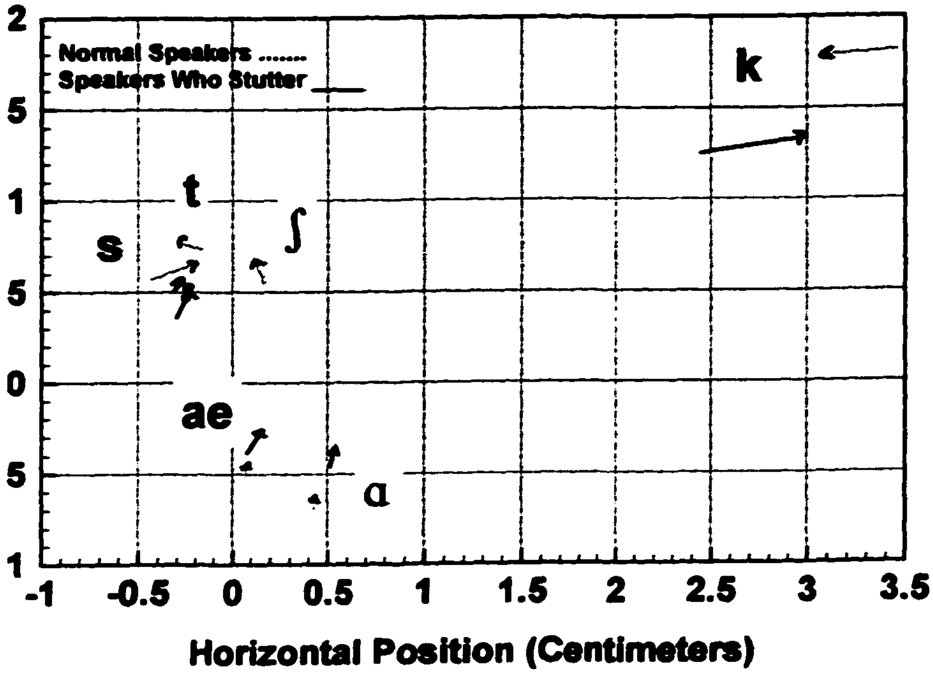


Figure 50. Mean Duration Under The Control Condition

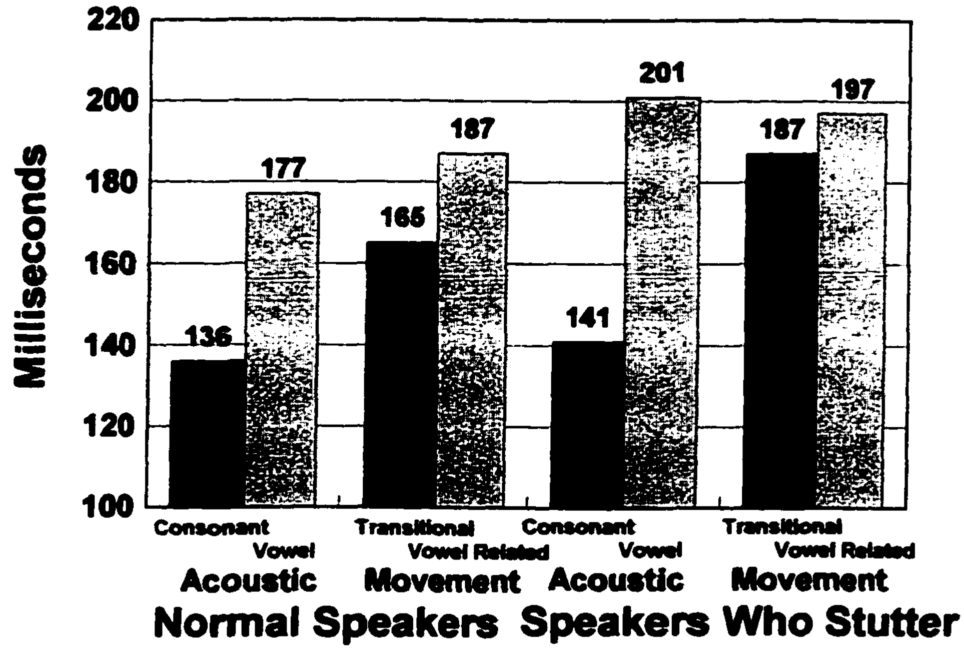


Figure 51. Movement Duration Under The Control Condition: Percent Difference Between Transitional And Vowel Related Movements

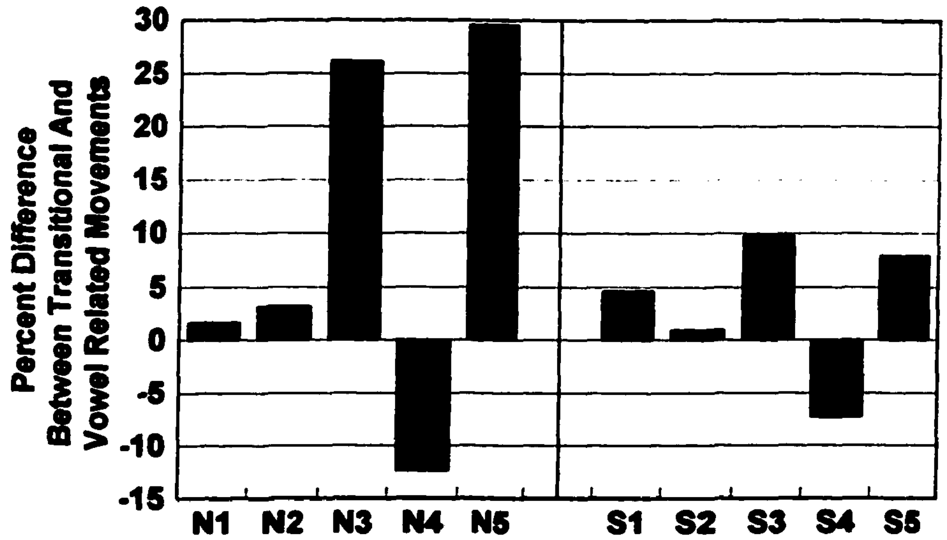


Figure 52. Movement Distance Under The Control Condition: Percent Difference Between Transitional And Vowel Related Movements

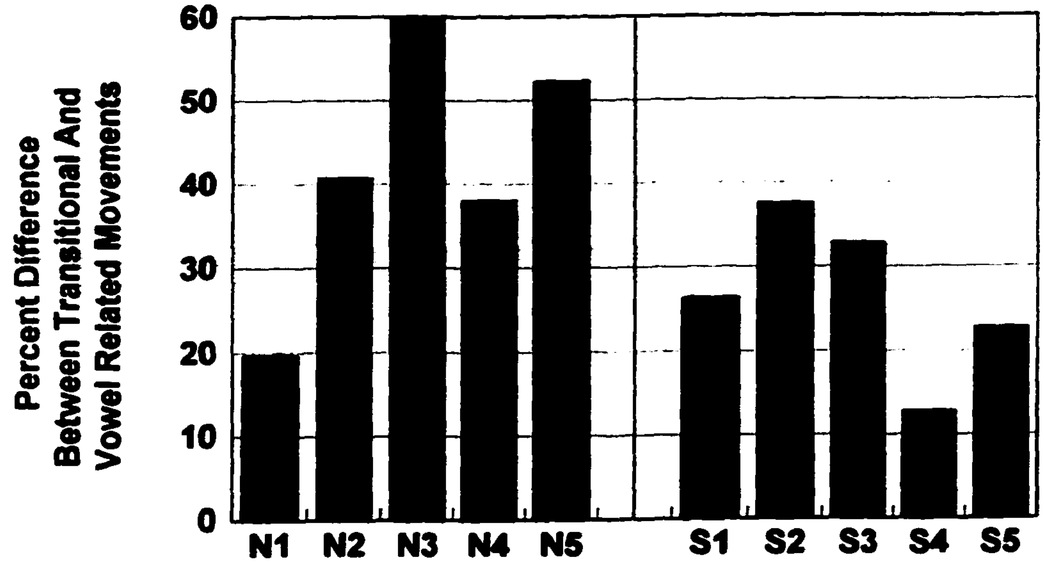
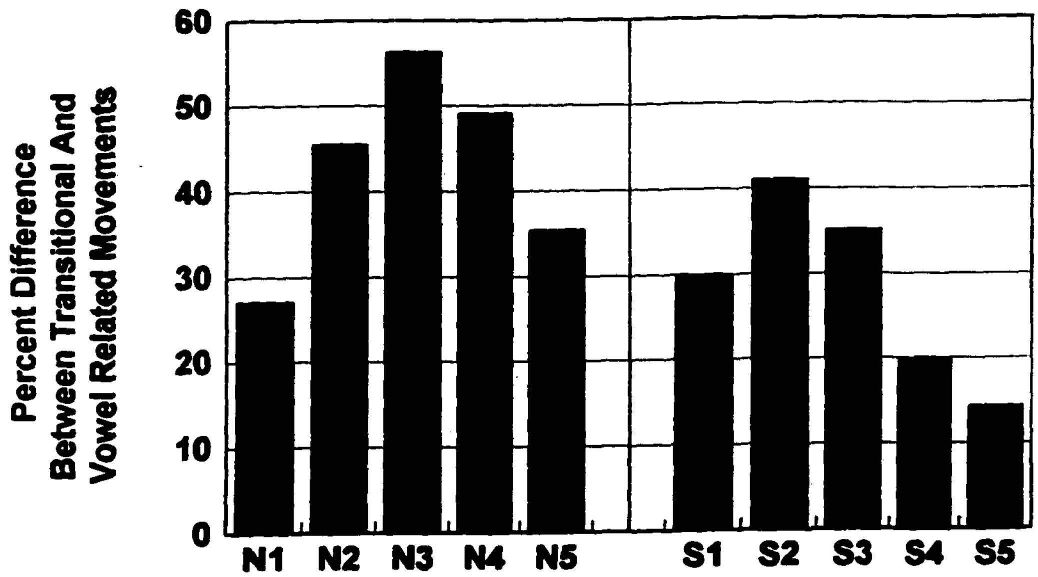


Figure 53. Movement Peak Velocity Under The Control Condition: Percent Difference Between Transitional And Vowel Related Movements



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