THE EFFECTS OF METRONOME PACING ON THE AERODYNAMIC PATTERNS OF STUTTERED SPEECH

Thesis for the Degree of M. A.

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ABSTRACT

THE EFFECTS OF METRONOME PACING ON THE AERODYNAMIC PATTERNS OF STUTTERED SPEECH

By

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It was the purpose of this study to investigate changes in aerodynamic events for normals and stutterers while reading with metronome stimulation. Subjects were five adult secondary stutterers and five normal adult speakers matched for sex. To determine the effects of metronome pacing on aerodynamic events each subject was requested to read under two conditions. The first condition involved reading with the beat of a metronome. Under the second condition the subject was requested to read without using any devices to reduce stuttering. Aerodynamic analysis was used to evaluate physiological changes associated with the experimental condition. Four experimental questions were asked: (1) How is peak intraoral air pressure affected by metronome stimulation? (2) What changes occur in duration as a result of metronome stimulation? (3) How does air flow rate change during metronome stimulation? (4) What qualitative differences occur when comparing metronome-induced fluency and dysfluent production of the same phoneme?

The results of this investigation revealed that both stutterers and normals exhibited lower peak intraoral air pressure during conditions of rhythmic stimulation. Both stutterers and normals also exhibited longer peak pressure onsets, offsets, and total durations during metronome pacing. Air flow values increased for normal speakers but decreased for stutterers during metronome pacing. Finally, qualitative inspection of fluent productions of words stuttered in the no-metronome condition indicated that pressure onset slopes were much more gradual with the metronome. The results of this investigation were interpreted in light of Wingate's [1969] "modified vocalization" hypothesis which accounts for the effects of rhythmic stimulation with references to consistent, routine and predictable changes in physiological function. Implications for further research are also presented.

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Brenda Mae Navarre

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INTRODUCTION

Historical Review

Historically, it has been well documented that rhythmic pacing produces fluent speech among dysfluent speakers. In his historical account of the use of pacing, Van Riper [1971] noted the increased therapeutic emphasis on timing procedures in the several stammering schools which were popular during the 1800's in the United States. However, controversy over the clinical use of rhythmic stimulation arose in the early Twentieth Century and these procedures were largely discontinued. Undoubtedly, several reasons may be offered for this decline in popularity: (1) the growing disrepute of stammering schools, (2) the rather transient effects of the metronome, and (3) an inability to explain the ameliorative effects of rhythmic pacing [Hutchinson, 1974].

Despite the disuse of these procedures from a clinical standpoint, researchers continued to investigate the effects of rhythmic stimulation on stuttered speech. One of the first empirical confirmations of the pacing effect was provided by Johnson and Rosen [1937] who attempted to ascertain whether specific changes in stutterers' speech rate would affect changes in frequency of dysfluencies. It was noted that the greatest reduction in stuttering occurred by alteration of the speech pattern in accordance with some imposed and very definite rhythm, (singing, metronome, arm-swing, sing-song, and reading in chorus). Barber [1940] added considerably more information to our understanding of the rhythm affect by documenting a variety of rhythmic stimuli associated with a reduction in stuttering (bodily activities, speech rhythms, sensory rhythms, etc.). Moreover, the salutary effects of rhythm are recognized by stutterers as seen in the questionnaire data of Bloodstein [1950] concerning conditions during which stuttering is reduced or absent.

In recent times, there has been a rekindling of interest in the use of pacing procedures for clinical management of dysfluency. Hutchinson [1974] attributes part of this revived interest to refutation of the first two reasons cited previously for the early decline in pacing therapy. The problem of misuse of rhythmic stimulation by disreputable therapists has been overshadowed by growing application of behavior therapy principles to stuttering therapy and a more rigorous, scientific accounting of the effects of metronome conditioning. The second problem of minimal carry-over of the pacing effects has been eliminated by the technoligcal development of a miniature behind-the-ear metronome [Meyer and Mair, 1963].

Perhaps the most complete clinical data regarding the use of pacing has been provided by Brady [1969] who designed four experiments to study the metronome effect on stuttering. The results of the first study suggested that the mere slowing of speech rate is not the basis of the metronome effect, since the speed of the metronome was equal to each subject's reading rate during the control condition. In his second experiment the subjects read in synchrony with the metronome and read while performing subsidiary tasks to produce a distraction effect. Since fluency was much higher for the metronome condition it was concluded that "distraction" is not the basis of the metronome effect. A third experiment resulted in the conclusion that auditory, tactile and visual pacing had equal effect on reducing dysfluencies. The final experiment required the subjects to read to a rhythmic beat and an arrythmic beat. Although the subjects were able to perform better with the rhythmic pace, a similar decrease in stuttering occurred for the arrythmic beat, suggesting that metronome effect may not be entirely a function of the rhythmical pattern. These last results are in disagreement with Fransella and Beech [1967] who observed no notable fluency changes with arrhythmic stimulation.

Brady [1971] was also responsible for developing one of the first complete therapy programs for use of the miniaturized metronome. The treatment involved a behavioral analysis of the disorder of stuttering since rather strong applications of learning theory principles are required to observe the behavioral changes exhibited with metronome pacing, as well as experimental studies on the effects of metronome pacing on stuttered speech. His clinical data revealed considerable treatment success. A group of 26 severe stutterers received metronome conditioning therapy, and of the 23 who completed the program, over 90 percent showed an increase in fluency which persisted for a period of six months to three years.

Despite the general alleviation of the problems of disreputable therapeutic use and clinical carry-over, the third concern expressed earlier, that of a reasonable theoretical explanation, remains unresolved. However, several attempts to account for the pacing phenomenon have been offered and warrant brief examination.

Theoretical Accounts

Perhaps the first major theoretical explanation of reduced stuttering during pacing was the distraction hypothesis. Johnson and Rosen [1937] and Barber [1940] first applied the distraction construct to explain the effects of syllable-timed speech. They suggested that a rhythmical pace draws the stutterer's attention away from anticipatory dysfluencies and reduces anxiety associated with speaking. Bloodstein [1950, 1972] further amplified the "distraction" hypothesis by suggesting that unusual stimulation absorbs the stutterer's attention thereby reducing speech anxiety and associated dysfluency. He concluded:

> The power of such a concept (as distraction) is that it vastly simplifies our perception of stuttering phenomena by reducing a great number of apparently unrelated observation to a single common denominator. In so doing, it performs a characteristic function of science, which strives to find more general explanations within which to encompass existing ones as special instances [1972, p. 490].

Unfortunately distraction is a weak theoretical construct because it was not an operational definition. Accordingly, assuming distraction by observing improved fluency places the theoretician in a difficult tautology.

The second explanation of the positive effects of rhythmic stimulation may be termed the auditory-perceptual deficit hypothesis. This hypothesis was derived from the observation that delayed auditory feedback produced stuttering behaviors in normal speakers. In view of this observation some suggested that stuttering is a result of a distorted auditory feedback system. For example, Webster and Lubker [1968] proposed that the delay in auditory feedback is due to a difference in middle ear muscle reflex patterns between stutterers and normals.

The auditory-perceptual deficit hypothesis lacks internal consistency because it does not account for several well known phenomena associated with stuttering. First, the adaptation effect is not well-explained by this theory since according to it, the improved fluency can only be the function of a sudden remission of the auditory-perceptual problem upon conclusion of the first reading of a passage. Second, the reasons for improved fluency during such conditions as high intensity masking noise or singing are not obvious. Finally, efforts to document the physiological substrate for an auditory-perceptual deficit have not been conclusive.

The final theoretical position has been termed the "modified vocalization" hypothesis and was first stated by

Wingate [1969]. He summarized this change of vocalization by stating:

> Imposed rhythm can thus be said to induce a simplification, routinization, and predictability of "melody" all of which could be powerful factors in producing this "artificial" fluency. . . .In short, the process is organized around the production of a melody which is actualized through emphasis on vocalization [p. 679].

Wingate thus brings forth the notion that rhythmic stimulation results in adjustment of peripheral speech events which become controlled so as to produce fluent vocalizations.

Adams, et al. [1973] have provided further data to support the modified vocalization hypothesis. Stutterers were required to read a passage first under normal conditions and secondly seeing and reading one word per second. Great increases in fluency were found to be associated with the pacing condition. These findings suggested that the slower reading rate allowed sufficient time to coordinate respiration, phonation and articulation and reduce the motoric complexity involved in contextual speech.

At the present time, the modified vocalization hypothesis, though unproven, still stands as the only theoretical account which may be a valid explanation of rhythmic stimulation. To date, most of the literature cited in support of this position involved relatively crude molar frequency count of stuttering behavior based upon subjective impressions [Adams and Reis, 1971; Adams and Moore, 1971; Conture, 1972]. This is a serious problem inasmuch as it is difficult to develop sound theoretical explanations about cortical function and peripheral adjustments, without data concerning physiological events associated with the changes encountered during metronome stimulation. Abbs and Netsell [1973] have corroborated this view by stating that it is "hazardous to investigate the nature of central nervous system events, muscle activity patterns, or movement of speech structure without a consideration of peripheral mechanics" [p. 421]. Therefore, before any credibility can be lent to a modified vocalization explanation of metronome stimulation, it is imperative that the peripheral physiological events associated with "modified vocalization" be properly investigated.

Some preliminary research [Hutchinson, 1974] has documented that there may be no one-to-one relationship between a perceptual judgment of stuttering and its physiological correlate. This casts further doubt on the development of theoretical systems which do not involve physiological data. Therefore, it seems clear that before further speculation regarding the effects of metronome condition are offered, some peripheral physiological data should be obtained.

Aerodynamic Analysis

The experimental literature concerning application of physiological investigation strategies during stuttering is relatively sparse. However, one experimental procedure has emerged as a sensitive index of the physiological concomitants of stuttering--aerodynamic analysis. The major investigation of aerodynamic changes during the moment of stuttering was reported by Hutchinson [1974]. This study involved an analysis of intraoral air pressure and air flow rate events operative during stuttering. One-hundred and fifty-five dysfluencies were recorded on optical osciollograms and six aerodynamically distinct stuttering patterns were described. Type I was characterized by multiple peak intraoral air pressure which released at the onset of subsequent phonemes. Perceptually this was perceived as a syllable repetition. Type II consisted of a prolonged intraoral air pressure rise time and was auditorily perceived as a prolonged phoneme. The most common pattern, Type III, was characterized by multiple peak intraoral air pressures without air flow or voicing and no release of constriction until termination of the block. These patterns were auditorily identified as prolonged silent blocks. Type IV was comprised of a prolonged rate of air flow associated with the onset of an attempted phoneme and an excessive peak air flow rate during the actual moment of stuttering. Type V patterns consisted of an abrupt decrement in intraoral air pressure, air flow rate and the acoustic component. Type VI was characterized by swift build-up of intraoral air pressure with sustained pressure following for a relatively long period of time. Data of this nature provide greatly increased precision in our description of stuttering and they provide more substantive evidence for explanations of the physiological commands operative during stuttering.

Statement of Problem

The conclusions drawn to support a modified vocalization hypothesis have in fact been based on subjective impressions from perceptual data. Given the availability of sensitive aerodynamic measures to obtain such information, it is logical that the nature of any hypothesized vocalization change accompanying rhythmic stimulation be studied using an aerodynamic analysis strategy. Accordingly, the purpose of this study was to investigate the effects of rhythmic stimulation on selected aerodynamic parameters of speech for stutterers and nonstutterers. Specifically, four experimental questions were asked:

1. How is peak intraoral air pressure affected by metronome stimulation?
2. What changes occur in duration as a result of metronome stimulation?
3. How does air flow rate change during metronome stimulation?
4. What qualitative differences occur when comparing metronome-induced fluency and dysfluent production of the same phoneme?

METHOD

Subjects

The subjects of the present study were five adult stutterers, (four males, 1 female) and five normal speakers, (four males, 1 female). The stutterers were all classed as secondary stutterers (phoneme, word, and situation fears; anticipatory avoidance and embarrassment of stuttering) by qualified speech pathologists as determined by inspection of clinical records. The stuttering subjects had a mean age of 25 years and a history of previous therapy ranging from approximately 60 to 350 hours. Three of the experimental subjects had previous metronome pacing experiences in therapy, ranging from 5 to 60 hours. Individual profiles for each stuttering subject were provided in Appendix A. All subjects included in the normal group exhibited normal speech behaviors and had no history of previous dysfluency problems. The mean age for this group was 26 years of age.

Speech Material

Each subject read a 121-syllable passage constructed such that 12 English consonants / p, t, k, b, g, f, θ, s, v, ð, z/, representing four consonant classes (voiceless stops, voiced stops, voiceless fricatives, voiced fricatives) appeared in a syllable-initial stressed position three times. (The phoneme /d/ was only represented twice.) The context was further constrained such that each consonant to be studied (hereafter referred to as a target consonant) was preceded by a linguistic pause, vowel, nasal, or semivowel and followed by a vowel. These contextual constraints facilitated identification of the target consonants on the oscillographic traces and reduced the coarticulatory effects of abutting consonants, which have high pressure and high volume velocity values. The passage and associated target consonants appear in Appendix B.

Experimental Conditions

All subjects read the 121-syllable passage in two conditions, control and experimental. In the control condition (no metronome) the talkers received no rhythmic stimulation and were instructed not to use any devices to reduce their stuttering. In the experimental condition (metronome) the talkers received a beat through headphones at a rate of 60 beats per minute. They were instructed to pace their reading of the passage such that each word was synchronized with a beat of the metronome. This metronome rate was chosen from the clinical observation by Brady [1969] that most stutterers are able to successfully synchronize their speech during oral reading at 60 beats per minute. The experimental and control conditions were presented in a randomized order, to control for potential order effects. The order in which each subject was tested can be seen in Appendix C.

<u>Instrumentation</u>

The instrumentation used in the present study was similar to that described by Hutchinson [1973]. A catheter (#12, French) was utilized to obtain measurements of intraoral air pressure. The catheter was inserted through the nasal passage until it was visible in the oropharynx. The opening of the catheter was perpendicular to the eggressive air flow to prevent spuriously high air pressure readings that can occur when air flow directly impinges on the orifice of the tube [Hardy,1965]. The catheter was attached to a pressure transducer (Stathamm, 131 TC). The signal from the transducer was amplified (Accudata 113 Bridge Amplifier) and recorded on one channel of an optical oscillograph (Visicorder 1508B). Prior to the initiation of each experimental session, a static calibration was accomplished using a U-tube water manometer. This procedure enabled the experimenter to establish specific galvonometer deflections on the optical oscillograph with known input pressures.

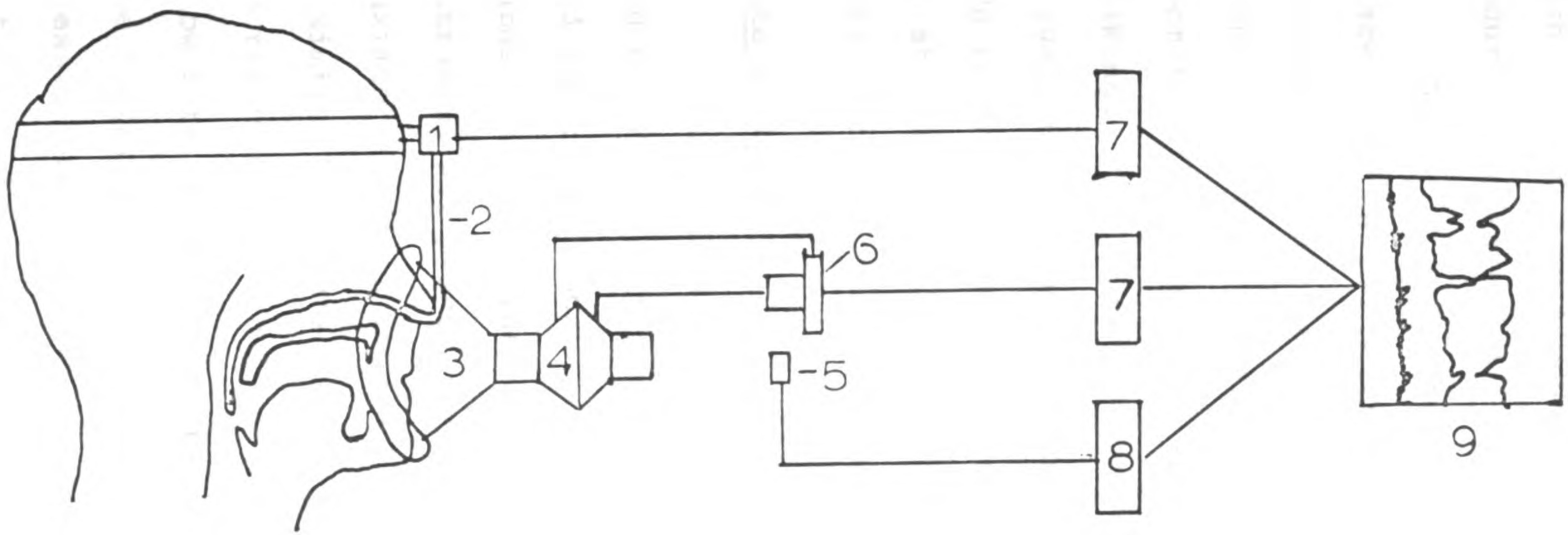
The air flow rate data were obtained by using a large tightly fitting face mask coupled to a pneumotachograph (Hewlett-Packard, custom made). The pneumotachograph houses a screen that provides a resistance to air flow. As stated by Isshiki and Ringel [1964], "the principle of measuring a flow rate is based on the fact that the pressure drop across a resistance (mesh screen), which is caused by an air stream varies linearly with flow rate." In the present investigation the pressure drop was sensed by a differential pressure transducer (Statham, PM 15), amplified (Honeywell Accudata 113 Bridge Amplifier) and recorded on a second channel of the optical oscillograph. Calibration of the flow rate was accomplished using a flowrater meter (Fisher and Porter, 10A1027A) in a fashion similar to that described for intraoral air pressure.

To obtain an audio signal a high quality microphone (Electrovoice 635 A) was placed near the end of the pneumotachograph. The signal was amplified (Ampex 601, tape recorder) and simultaneously recorded on a third channel of the optical oscillograph and the tape recorder. A schematic representation of the instrumental array is presented in Figure 1.

The metronome beat for the experimental condition was obtained from an electronic metronome (RCA Technical Series, HM 91) which was set to produce a high amplitude pulse occurring 60 beats per minute. This pulse was then directly recorded (Ampex AG 440) onto a tape to be presented via headphones.

Procedure

Prior to each experimental session, the subject practiced pacing his speech during oral reading until he and the experimenter were confident that mastery of the task had been achieved. The subject was then seated in the testing room where the catheter was inserted and the face mask positioned.



1. PRESSURE TRANSDUCER
2. CATHETER
3. FACE MASK
4. PNEUMOTACHOGRAPH
5. MICROPHONE
6. PRESSURE TRANSDUCER
7. BRIDGE AMPLIFIER
8. GALVONOMETER AMPLIFIER
9. OPTICAL OSCILLOGRAPH

Figure 1. Schematic array of instrumentation used for recording the aerodynamic data.

Instructions for the appropriate condition were then read to each subject (see Appendix D) and any questions about procedures were answered.

At the experimenter's signal, the subject was asked to place his nose and mouth tightly into the face mask and read the passage placed at eye level before him. At the conclusion of the first reading, the subject was taken to another room for thirty minutes where he was asked to refrain from talking. This time interval was introduced to minimize situational and passage adaptation. Further, some spontaneous recovery of stuttering can be expected with a rest period of at least thirty minutes [Jamison, 1955]. After the rest period, the second experimental condition was completed.

Data Analysis

The oscillographic traces obtained from the experimental and control conditions were transcribed by the experimenter and the target consonants were identified using both audio tapes and visual inspection of the aerodynamic data. Peak intraoral air pressure measurements were made by calculating maximum deviation from a baseline representing no pressure. A similar procedure was employed for peak air flow rates. In the case of voiceless fricative productions where two flow rate peaks may be observed [Warren, and Wood, 1969] the larger was selected for measurement. Intraoral air pressure duration was determined by measuring along the established baseline from the point where the pressure curve was observed to deviate from base pressure to the point where the curve shifted slope on the offset excursion into the steady state of the following vowel. This duration factor was further divided into: (1) Intraoral air pressure onset from the onset of the pressure curve to the peak of maximum excursion, (2) Intraoral air pressure offset from the peak of maximum excursion to the point of offset. These measurement procedures are similar to those reported by Subtelny et al. [1966], Malecot [1968], Schwartz [1974] and Prosek and House [1974]. Phonemes on which dysfluencies occurred were not included in their respective consonant classes for analysis, but were extracted for qualitative comparison with their fluent counterparts. They were excluded because of the extremely high pressures, flow rates, and exaggerated durations.

RESULTS

Peak Intraoral Air Pressure

The results for peak intraoral air pressure are presented in Figure 2 (the raw data are available in Appendix E). Inspection of this figure reveals that peak intraoral air pressure values obtained by the stuttering group were below the values recorded for the normal subjects for both experimental conditions. A consistent decrease in pressure resulted for both stutterers and normals during the metronome condition. The differences associated with the metronome condition were greater for the normal group except in the case of voiced fricatives where no significant change was noted between experimental conditions. The greatest differences for both groups were voiceless productions. This pattern was relatively consistent among subjects with two notable exceptions. Four of the stutterers exhibited decreased pressures, while one stutterer evidenced increased pressures for all consonant classes. The individual values obtained by the normal sample demonstrated a similar pattern. Four subjects had lower presures and one subject had elevated pressures during metronome pacing, for all consonant classes.

Although the central tendency data reflect a relatively consistent decrease in pressure during metronome pacing, the standard deviations seen in Figure 2 are also of interest.

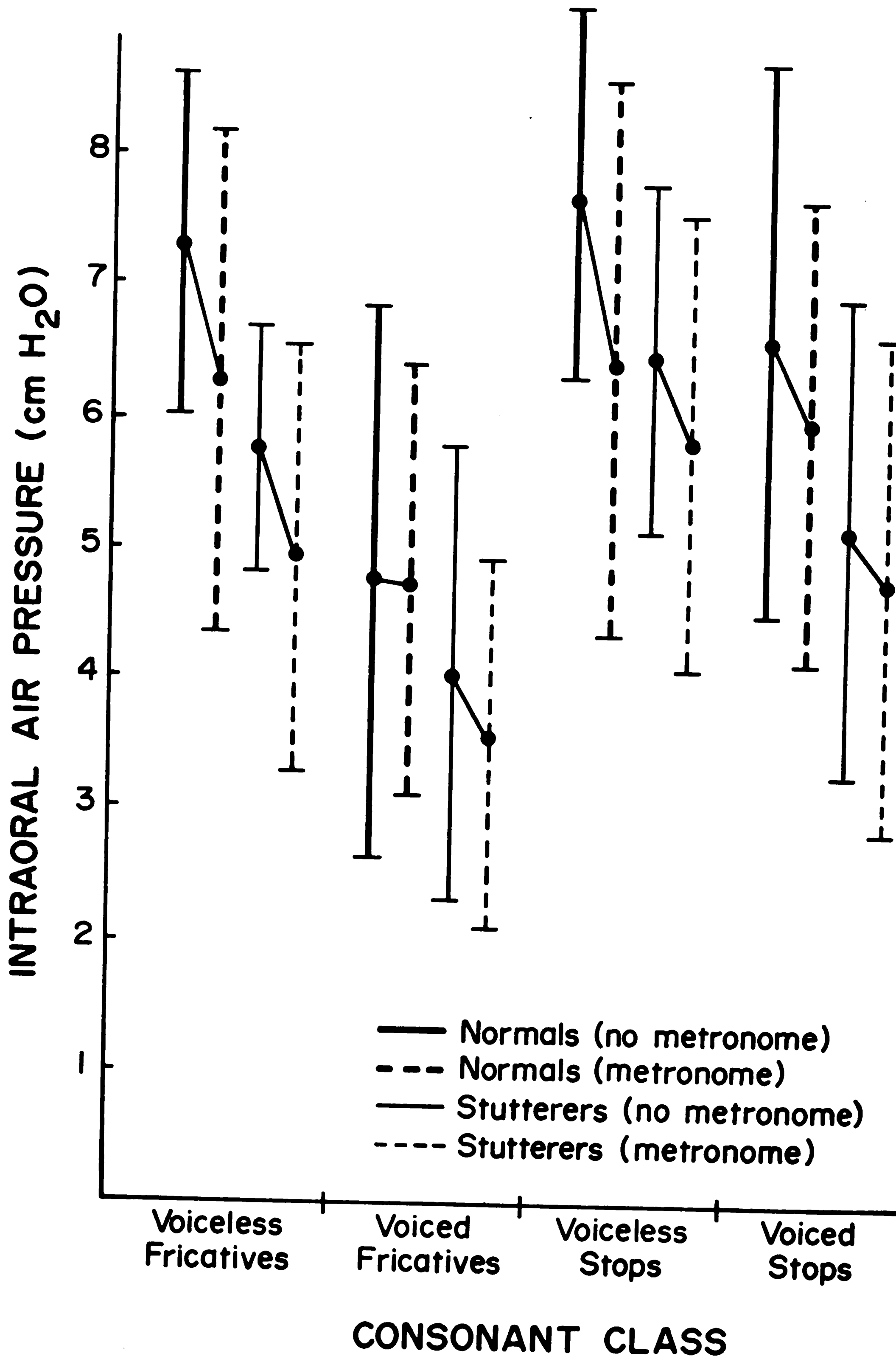


Figure 2. Summary of mean intraoral air pressure and standard deviations.

It was observed that the standard deviations were generally higher in the metronome condition. In three instances, (voiceless stops and voiceless fricatives produced by stutterers as well as voiced fricatives for normals) the standard deviations for the metronome condition were sufficiently large to encompass the corresponding range of standard deviation for the control condition. This finding requires some caution in interpreting the mean data even though a decrease in pressure accompanied metronome conditioning for seven of the eight sets of consonant class data reported.

Duration

Onset Duration: The results for onset duration are presented in Figure 3 (the raw data are available in Appendix E). Examination of this figure reveals both normal and stuttering groups consistently exhibited longer onset values during metronome pacing. This pattern was characteristic for all individual subjects. Further inspection of these data revealed that the normal group showed the greater difference between the metronome and no metronome conditions. The voiceless consonant classes revealed the greatest differences for both groups. Finally, the metronome condition was associated with greater standard deviations than the control condition for groups of subjects.

Offset Duration: The results for offset duration are presented in Figure 4 (the raw data are available in

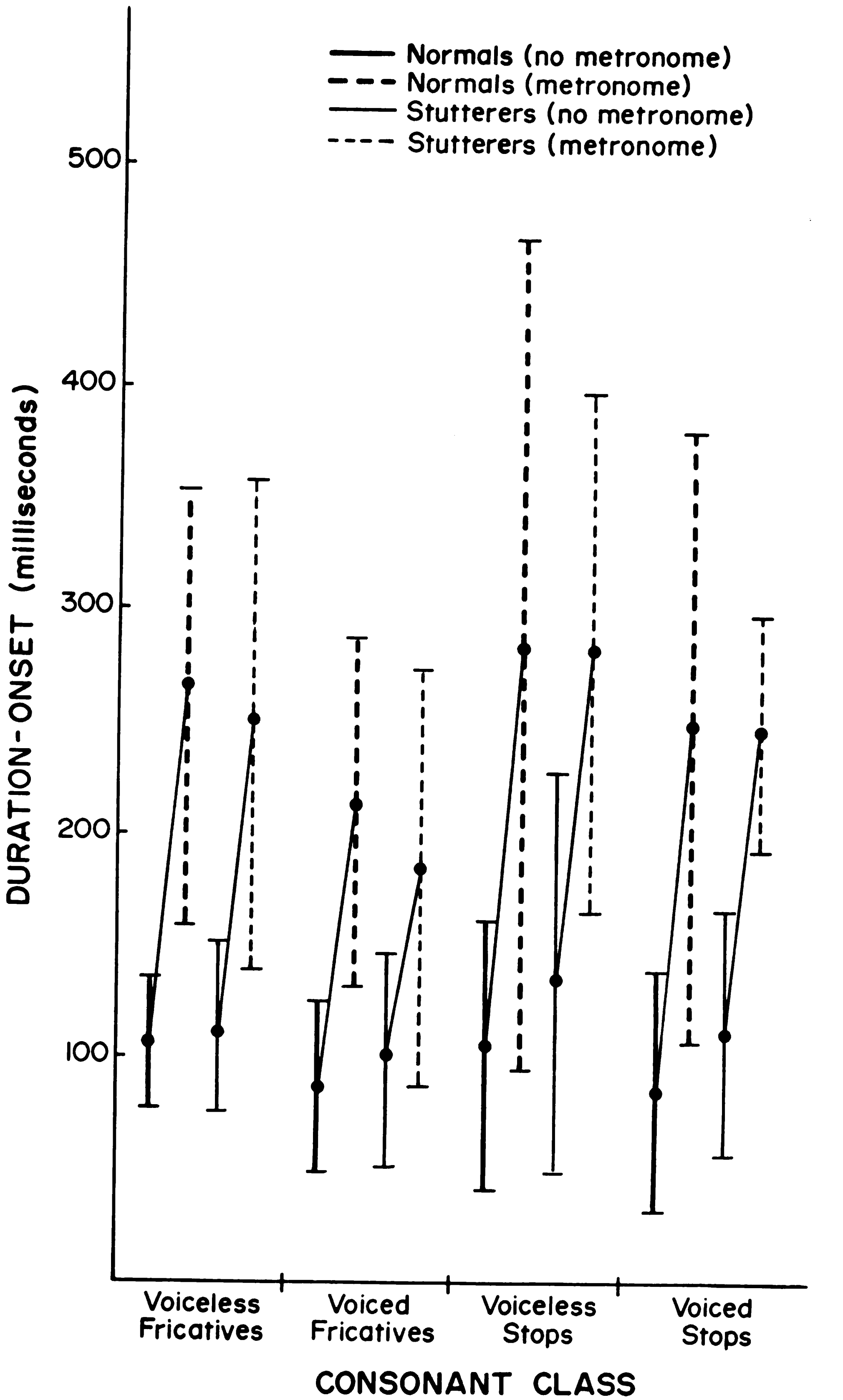


Figure 3. Summary of mean onset durations and standard deviations.

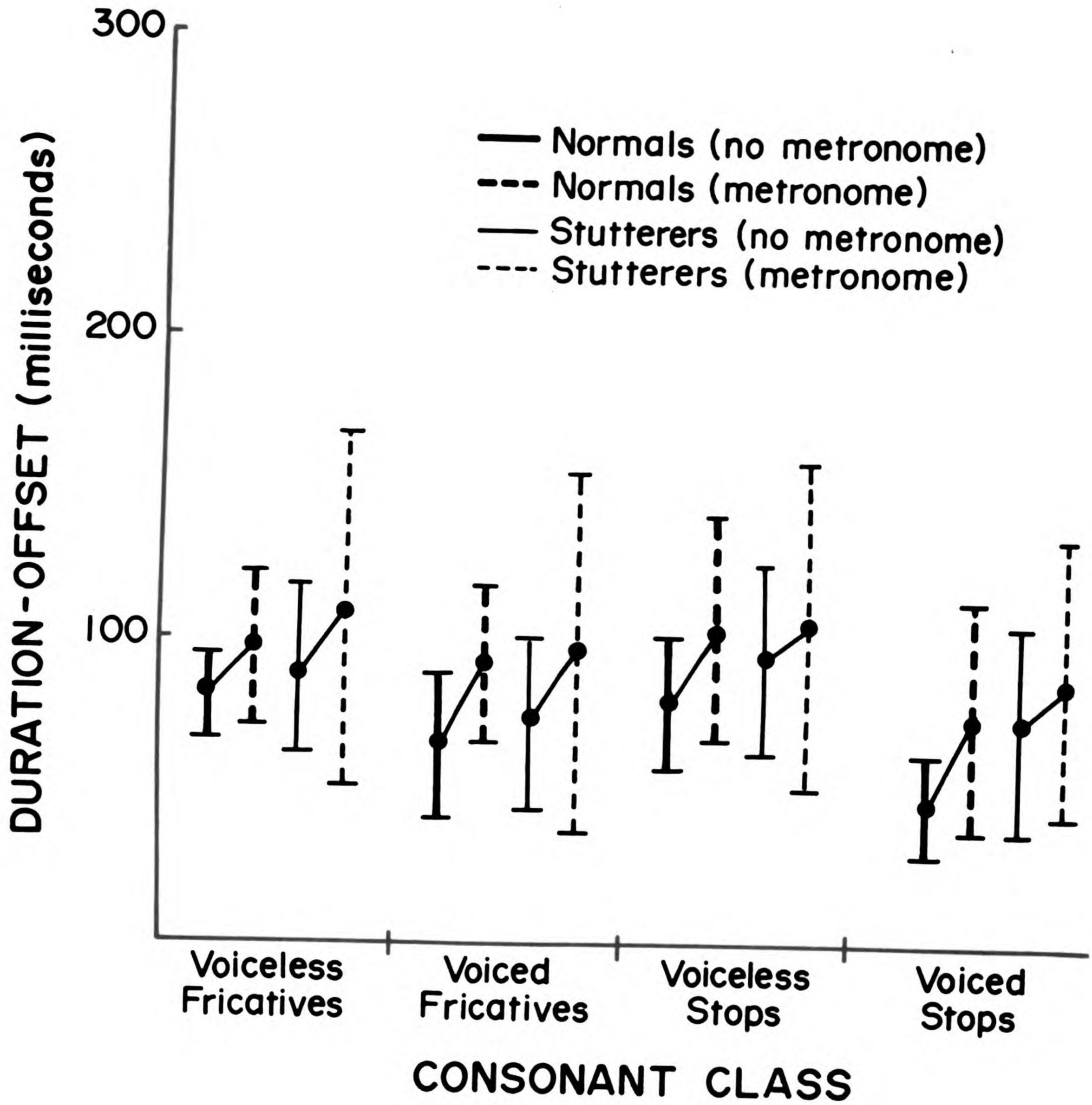


Figure 4. Summary of mean offset durations and standard deviations.

Appendix E). Figure 4 reveals that the stuttering group produced longer offset durations regardless of experimental condition, but during metronome pacing both experimental groups exhibited increased offset times. The differences associated with metronome pacing were greater for the normal group, with the exception of voiceless fricatives. For both groups, the greatest difference in offset duration between the experimental conditions occurred for voiced fricatives.

Total Duration: The results for the total duration are presented in Figure 5 (the raw data are available in Appendix E). This figure reveals longer total duration during metronome pacing for normals and stutterers. The differences associated with the metronome condition were greater for the normal group. Voiceless stops revealed the greatest difference for both groups.

Air Flow Rate

The results for air flow rate are presented in Figure 6 (the raw data are available in Appendix E). Figure 6 reveals that the stuttering group produced smaller air flow rates for both conditions. Although the magnitude of change in air flow rate values for the stutterers was not large, the metronome condition was associated with a relatively consistent decrease in volume velocity. Conversely, air flow rate values increased during the metronome condition for the control group. The differences in volume velocity

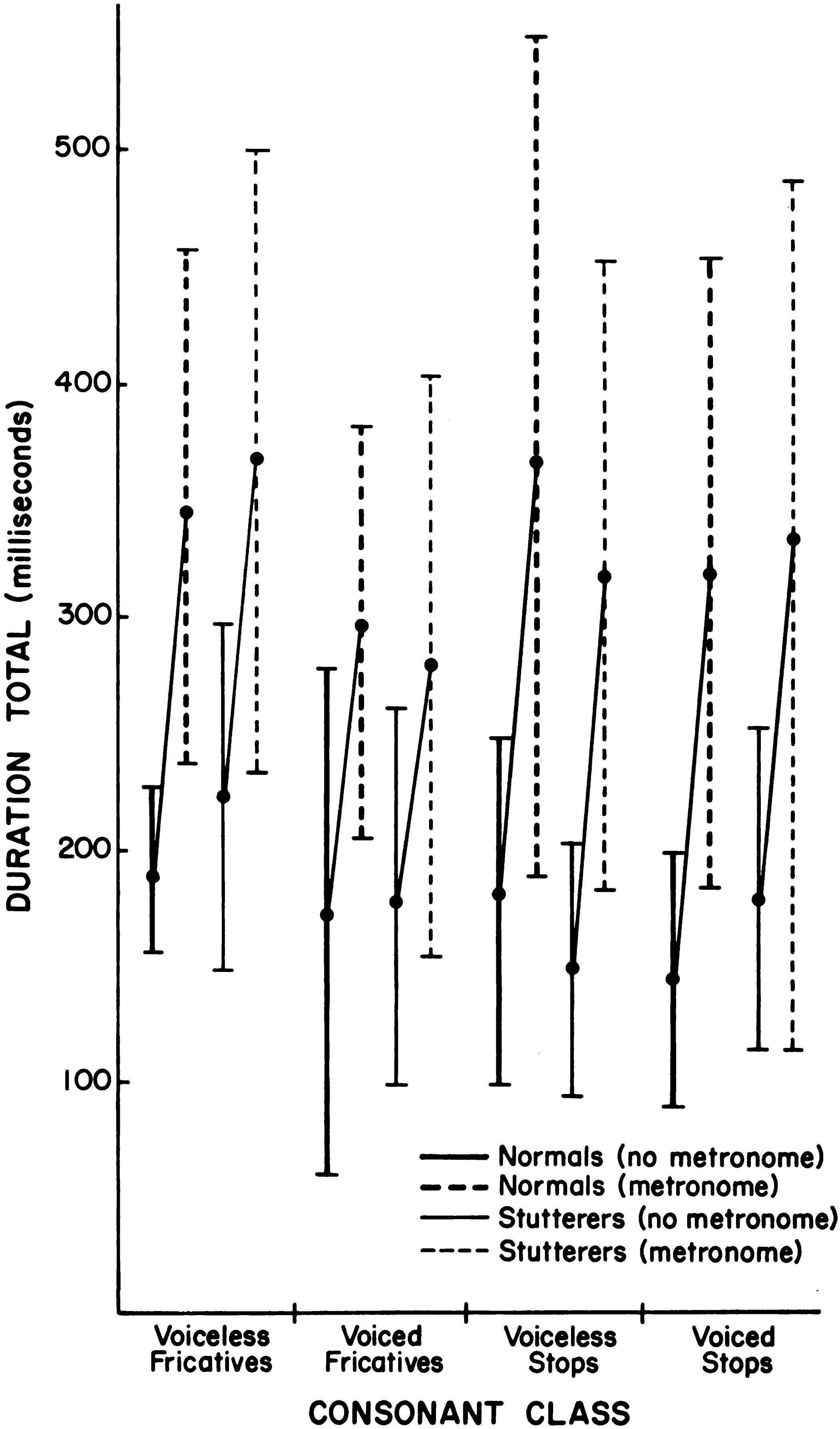


Figure 5. Summary of mean total durations and standard deviations.

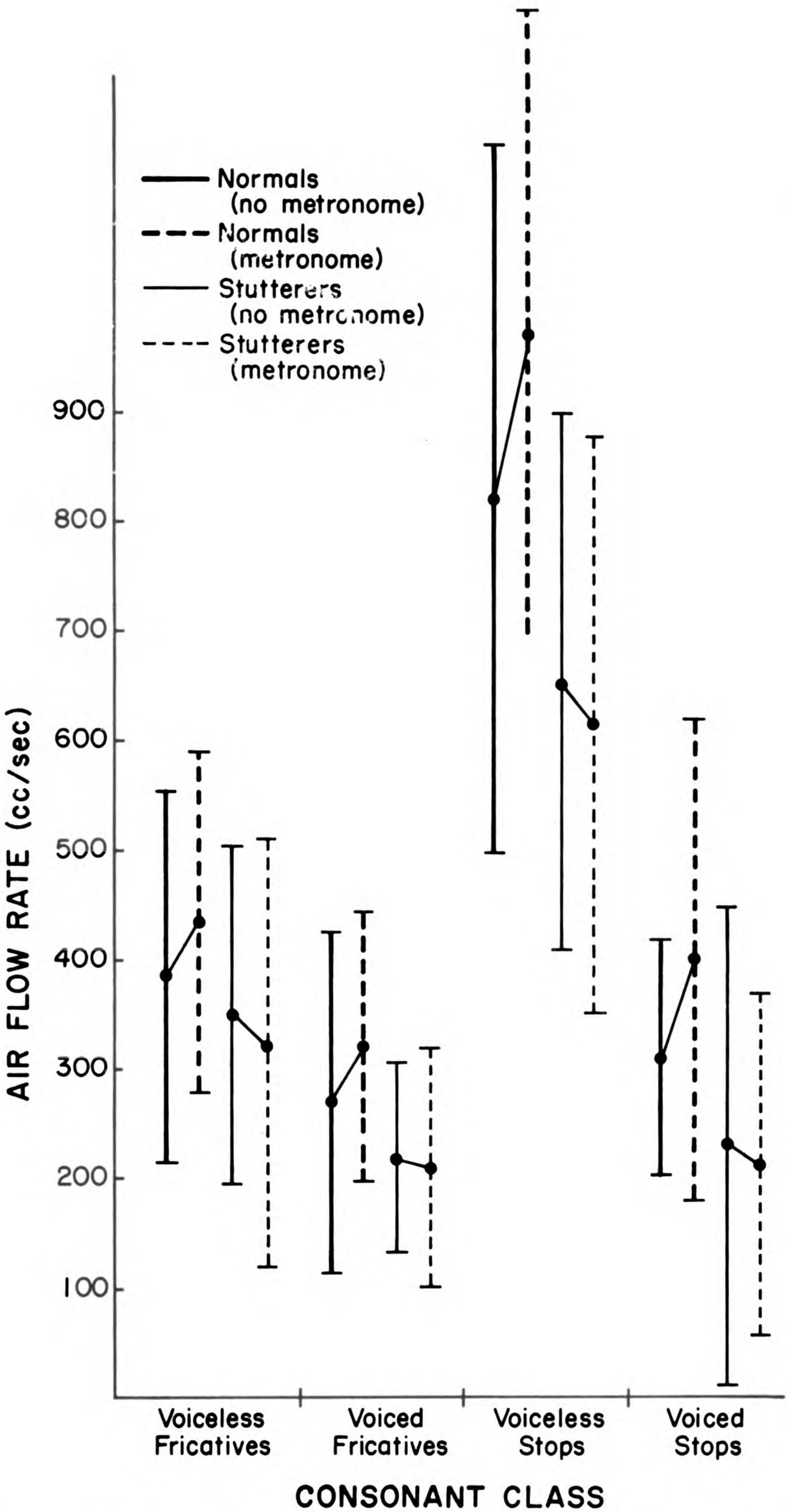


Figure 6. Summary of air flow rates and standard deviations.

associated with the metronome condition were greater for the normal group when compared with the stutterers. Decreasing air flow rates associated with the metronome condition for the stuttering group were greatest for the voiceless consonant classes. The greatest increase during the metronome condition for the normal subjects occurred for voiced and voiceless stops.

Although the central tendency data reflect a pattern of decreased air flow rate during metronome pacing for the stuttering group, the standard deviations seen in Figure 6 warrant inspection. In three instances, (voiceless and voiced fricatives for the stutterers and voiced stops for the normals) the standard deviations for the metronome condition were large enough to completely encompass those observed for the control condition. In one instance, voiced stops, the stuttering group obtained standard deviation values for the control condition which encompassed that associated with the metronome condition. This observation requires some caution when interpreting the mean data even though consistent patterns occurred for each group.

Qualitative Results

Visual inspection of the 23 dysfluencies recorded during the control condition permitted some subgrouping on the basis of common aerodynamic characteristics. Using the classification strategy described by Hutchinson [1973], the following stuttering types were observed.

Table 1. Frequency of Stuttering Type Based on Aerodynamic Patterns

Dysfluency Type	Frequency	Identifying Characteristics
I	9	Repeated elevations in intraoral air pressure with successful release and appropriate transitions into subsequent phonetic elements.
II	9	Gradual elevation in intraoral air pressure (prolonged rise time)
IV	5	(1) Prolonged air flow rate during onset of a phoneme. (2) Excessive peak air flow rate during moment of stuttering or contingent upon its release.

In comparing the dysfluency patterns produced in the control condition with the same speech element produced in the metronome condition revealed one characteristic difference common to nearly all instances. The onset slopes for intraoral air pressure during the stuttered production were typically much steeper than observed in the metronome condition. Therefore, each dysfluency and its fluent counterpart were measured in the following way. A line was drawn, by visual inspection, to represent the slope of the intraoral air pressure onset. The angle formed by this slope gradient and the intraoral air pressure baseline was determined. The results presented in Table 2 confirmed the investigator's visual impression that onset angles were greater for dysfluencies.

Table 2. Summary of Slopes (in degrees) of Intraoral Air Pressure for all Dysfluent Phonemes During the No-Metronome Condition and the Same Phoneme During Metronome Pacing

	No Metronome (Blocks)	Metronome (Fluent)	Difference
	Degree		
/t/ Tom	88	80	- 8
/b/ bass	90	68	-22
/b/ about	85	73	-12
/t/ tackle	86	74	-12
/b/ biggest	73	67	- 6
/w/ won	71	57	-14
/g/ good	78	58	-20
/g/ got	75	56	-19
/θ/ thirty	80	72	- 8
/θ/ thirty	89	82	- 7
/k/ catching	85	78	- 7
/v/ valuable	85	61	-14
/t/ Tom	82	72	-10
/s/ several	74	72	- 2
/t/ tantilizing	82	68	-14
/s/ suggestion	83	63	-20
/z/ Zelmos	76	79	+ 3
/v/ valuable	82	77	- 5
/h/ headed	84	82	- 2
/t/ tackle	84	81	- 3
/d/ delved	82	83	+ 1
/v/ valuable	78	81	+ 3
/t/ tackle	88	74	-14
Mean:	81.74	72.09	

DISCUSSION

By way of review, the results of the present study revealed that both stutterers and normals exhibit lower peak intraoral air pressures as well as longer peak pressure onsets, offsets, and total durations during conditions of rhythmic stimulation. Air flow rate values increased for normal speakers but decreased for stutterers during metronome pacing. Figure 7 provides an example of these results. Qualitative inspection of fluent productions of words stuttered in the no-metronome condition indicated that pressure onset slopes were much more gradual with the metronome. For an example see Figure 8.

It may be recalled from the Introduction of this paper that one theoretical explanation for the fluency typically observed during metronome stimulation was the "modified vocalization" hypothesis of Wingate [1969]. Presumably, according to this theory, a simplification, routinization, and predictability characterize syllable-timed speech which, in some unknown way, promotes fluency. From the results of the present study, there is no question but what rhythmic stimulation establishes rather consistent, routine, and predictable changes in physiological function. In that sense, the results of this investigation support the theoretical construct of modified vocalization.

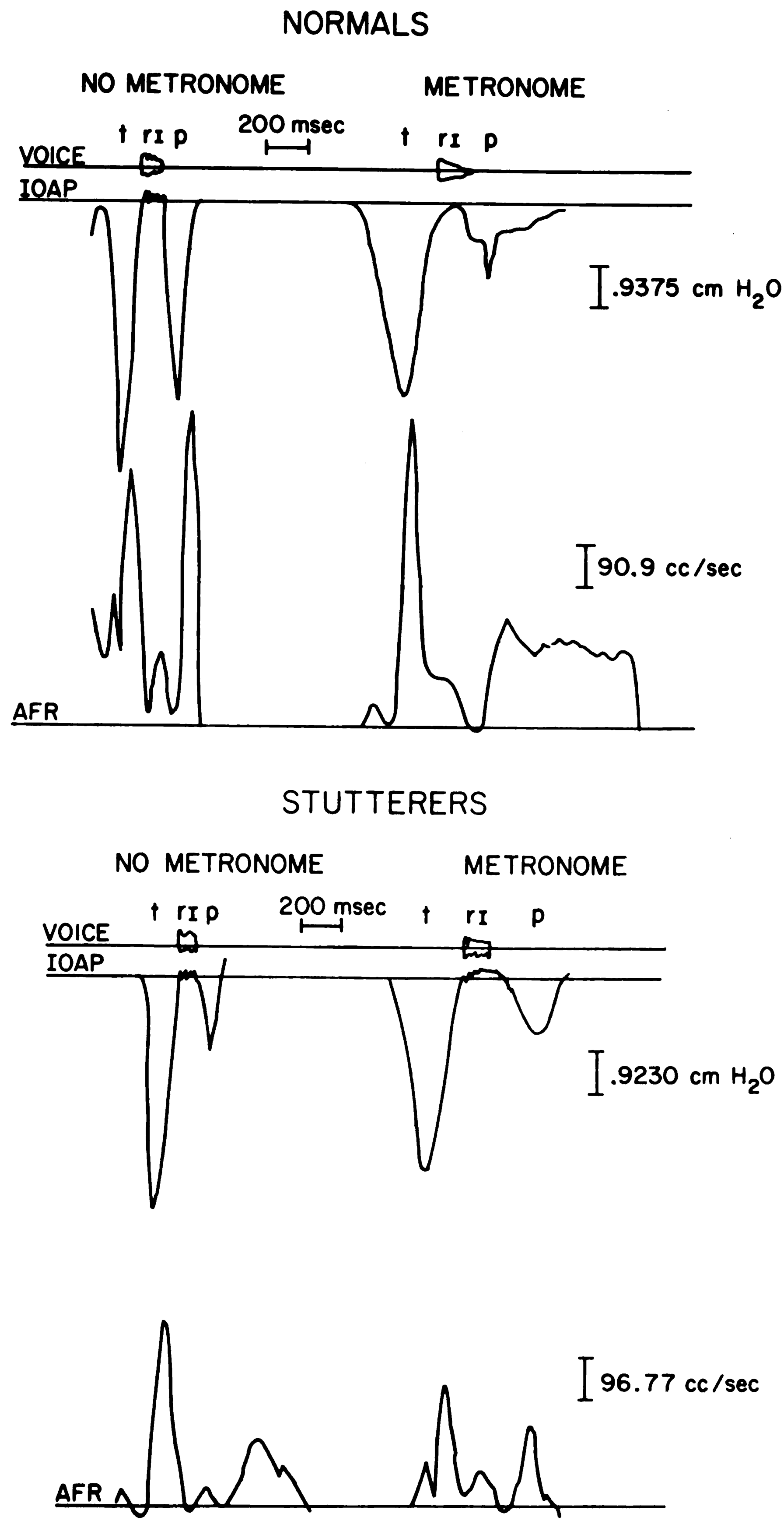


Figure 7. Example of quantitative results.

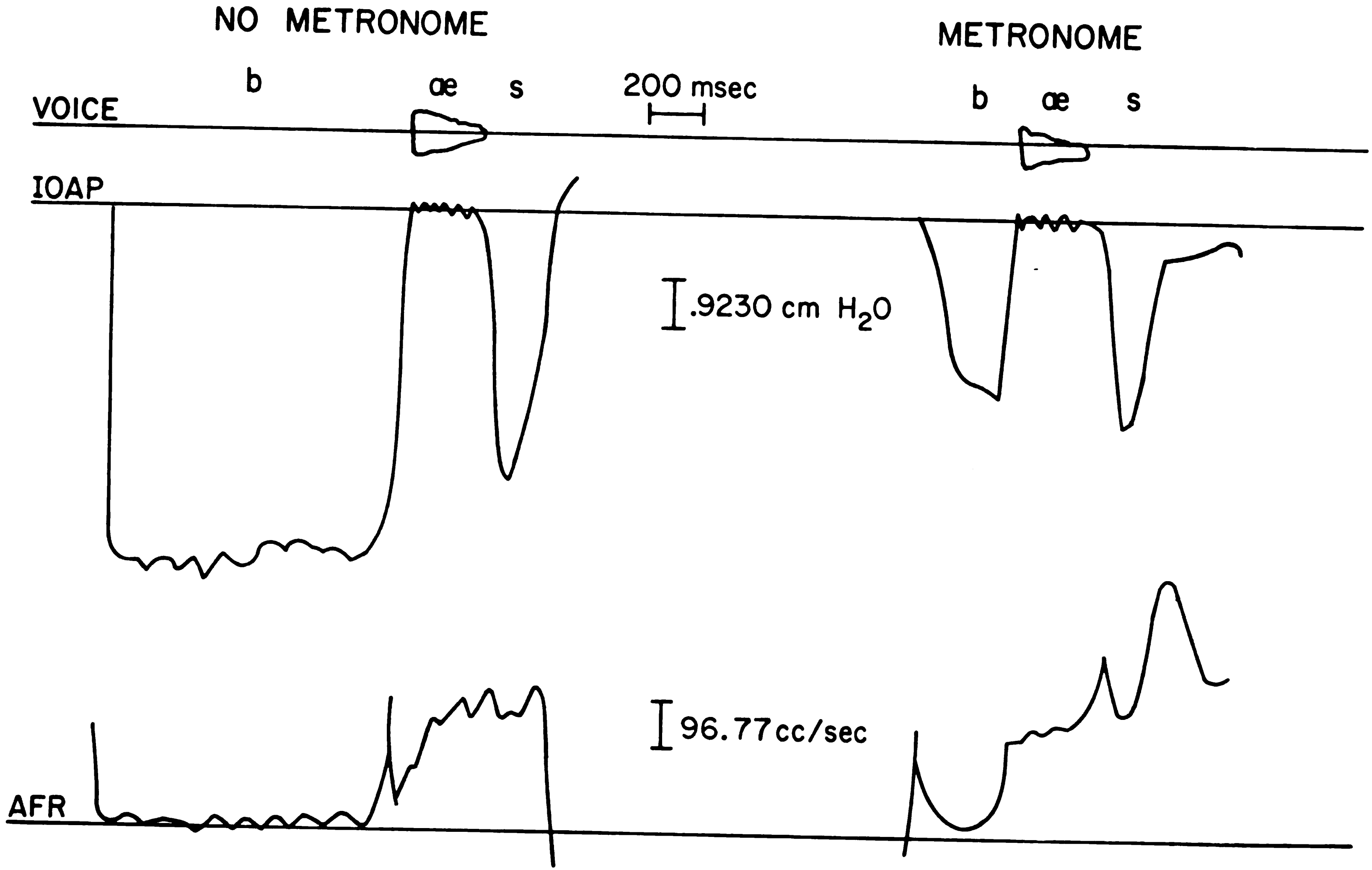


Figure 8. Example of qualitative results.

Inherent within the modified vocalization hypothesis is the assumption that the stutterer "does something different" while phonating which permits a more normal onset of vocalization and establishes conditions appropriate for uninterrupted phonation, when voicing is phonetically required. However, beyond this cursory assumption, Wingate provided no suggestions regarding the actual physiological changes which characterize modified vocalization.

Since the original formulation of the modified vocalization hypothesis, a growing body of experimental evidence had accumulated in support of this position. For example, Adams and Reis [1971] provided indirect evidence by demonstrating that dysfluency is much higher when the stutterer is asked to read a passage with numerous voiced-voiceless transitions as opposed to a passage specially constructed to minimize such transitions. Also, Adams and Hutchinson [1974] established a strong inverse relationship between vocal intensity and dysfluency. These results were discussed with reference to the obvious laryngeal adjustments required for changes in vocal intensity. Finally, recent physiological studies such as those of Conture [1974] and Freeman and Ushijima [1974] have documented clear laryngeal aberrations associated with stuttering which diminish during fluency. Depsite the growing evidence supporting a modified vocalization hypothesis, no one has yet provided a logical explanation of the salutary effects rhythmic stimulation has on laryngeal function.

It may be possible to provide some insight regarding these changes in vocalization by referring to a model of laryngeal behavior advanced by Halle and Steven [1971]. This model consists of three parameters of importance to this discussion. The first is the relationship of supraglottic pressure (P_{sup}) to subglottic pressure (P_{sub}). The difference between these vocal tract pressures was assigned to symbol ΔP. The second parameter was the width of glottal opening (Ws). The third parameter was the relative stiffness or slackness of the vocal folds. Halle and Stevens demonstrated that with slack folds, relatively wide ranges of Ws and ΔP could be obtained and vocalization would not be impeded. However, for stiff vocal folds, those respective ranges within which vocalization can occur would be markedly reduced. Moreover, severe reductions in ΔP prevent the vocal folds from vibrating regardless of Ws.

Interestingly, some of the documented vocal tract disturbances associated with stuttering may create conditions which, according to the Halle and Stevens model, would prevent vocal fold vibration. Both in the present study and that of Hutchinson [1974] there were documented instances where P_{sup} became excessive during dysfluency. This would serve to reduce ΔP and small values of ΔP minimize the chance of vocal fold vibration. In a similar vein, Konig and von Leden [1961] documented the existence of rich autonomic nerve endings in the thyroarytenoids. This would make the vocal folds a logical sight for tension under conditions of stress. The results of Conture [1974] and Freeman and Ushijima [1974] confirmed the presence of very stiff, tense vocal folds during the moment of stuttering. This too, would reduce the chances for vocal fold vibration, particularly if the aerodynamic conditions were such that ΔP was quite small. In short, the stutterer may have, even during fluent speech, vocal tract conditions which are perilously near a threshold for complete cessation of vocal fold activity. Such cessations in vocal fold activity may be fundamental to the stuttering [Adams, 1972].

It may be recalled that metronome simulation was generally associated with reductions in intraoral air pressure. Therefore a pervasive result of such stimulation is a larger ΔP which maximizes the chances for vocalization, regardless of the vocal folds.

The work on laryngeal muscle activity during stuttering permits further consideration of the positive effects rhythmic stimulation has on fluency. Two basic laryngeal disturbances have been suggested: (1) There is a breakdown in the reciprocity of laryngeal abductor and adductor activity, (2) There is often much greater laryngeal muscle activity during stuttering. The first condition suggests a central nervous system programming asynchrony and the second a rather uncontrolled or unchecked surge of physiological effort manifested in increased laryngeal muscle action potential. Perhaps these conditions are exacerbated by the stutterer's attempts to achieve very rapid physiological adjustments. For example, the angle values of the pressure onsets reported in this study suggest that the physiological events of stuttering may involve extremely rapid adjustments and high amplitude responses. If this is accurate, the metronome apparently alleviates this problem by producing very gradual, low amplitude pressure onsets. In short, the additional time afforded during the onset of an initial consonant during rhythmic stimulation may permit the stutterer to properly synchronize motoric commands and more successfully monitor the amplitude of the physiological events, particularly those involving laryngeal function.

As mentioned in the Introduction of this paper, reduced reading rates have consistently been proven effective in reducing stuttering. Recently, Adams et al. [1973] provided one explanation for this phenomenon. They suggested that reading individual words at the rate of one per second obviated the need for rapid transitional movements across word boundaries:

> Reading in this manner encourages the cessation of speech movements after the production of every word. Therefore, coordination and transition were required only as the stutterers moved from sound to sound within a word. Coordination and transition across word boundaries were not needed [p. 674].

Certainly, if this assumption is true, it supports the simplification aspect of Wingate's modified vocalization hypothesis and suggests that paced speech creates conditions more conducive to central nervous system coordination of the vocal tract events.

However, Adams et al. [1973] based their conclusion on the results of reading tasks not involving a metronome signal. In the present study it was demonstrated that a metronome signal not only slows the overall reading rate but increases the duration of phonetic elements in each utterance. Therefore, the stutterer has not only the time afforded by an overall reduction in reading rate but also the prolonged time period of the initial phoneme to monitor, control, and adjust the vocal tract events thereby reducing the possibility of dysfluency.

SUMMARY AND CONCLUSIONS

It was the purpose of this study to investigate changes in aerodynamic events for normals and stutterers while reading with metronome stimulation. Subjects were five adult secondary stutterers and five normal adult speakers matched for sex. To determine the effects of metronome pacing on physiological events each subject was requested to read under two conditions. The first condition involved reading with the beat of a metronome. Under the second condition the subject was requested to read without using any devices to reduce stuttering. Aerodynamic analysis was used to evaluate physiological changes. Four experimental questions were asked: (1) How is peak intraoral air pressure affected by metronome stimulation? (2) What changes occur in duration as a result of metronome stimulation? (3) How does air flow rate change during metronome stimulation? (4) What qualitative differences occur when comparing metronome-induced fluency and dysfluent production of the same phoneme?

The salient results of this investigation may be summarized as follows:

1. Both stutterers and normals exhibited lower peak intraoral air pressures during conditions of rhythmic stimulation.
2. Both stutterers and normals exhibited longer peak

pressure onsets, offsets, and total durations during metronome pacing.

3. Air flow values increased for normal speakers but decreased for stutterers during metronome pacing.

4. Qualitative inspection of fluent productions of words stuttered in the no-metronome condition indicated that pressure onset slopes were much more gradual with the metronome.

The results of this investigation support Wingate's [1969] "modified vocalization" hypothesis, inasmuch as consistant, routine and predictable changes in physiological function occurred with rhythmic stimulation. In addition the results of this study were interpreted with reference to a model of vocal tract functioning presented by Halle and Stevens [1971]. Specifically, the lower peak pressures associated with metronome stimulation would, according to this model, facilitate vocal fold vibration. Finally, it was suggested that increased consonant durations noted during rhythmic pacing may permit the stutterer more time to coordinate properly the physiological events necessary for fluent speech.

Implications for Further Research

A considerable body of literature has documented that rhythmic stimulation increased fluency. Distraction and auditory perceptual deficits have lent little insight into the effects of metronome pacing. The results of the present study support the modified vocalization theory since the data revealed consistent physiological changes occurring when speech was paired with rhythmic stimulation. However, two important improvements should be incorporated into a study of this nature. First, a larger number of subjects would verify the distinctive patterns of physiological changes that occurred with metronome stimulation. Secondly, controlling for the number of previous metronome pacing therapy hours each subject had received, would allow for a more accurate determination of both the qualitative and quantitative changes occurring.

The findings of this study provide some additional impetus for further research. Given the ability to measure physiological occurances associated with metronome pacing, in a theoretical sense, it would prove interesting to observe differences resulting from emotional states and speaking situations. That is, how do a stutterer's physiological changes vary during a relaxed state versus an anxiety situation. It might be possible to establish a hierarchy of situational fears by examining systematic differences in physiological behavior as a function of anxiety arousal.

Another implication for research might involve a study of the effect different reading rates (determined by a set metronome beat) have on aerodynamic events. A similar study designed to observe physiological changes occurring when a speaker paces his reading without a metronome could also prove interesting. Finally, a study such as the present could be extended to evaluate the physiological changes associated with fluency during delayed auditory feedback and masking, conditions also subsumed under the modified vocalization hypothesis. All of the above could easily be applied to children, adding considerable information to the minimal literature available concerning physiological events during stuttering and therapeutic techniques to control stuttering for younger clients.

APPENDICES

APPENDIX A

INDIVIDUAL PROFILES OF STUTTERING SUBJECTS

Stuttering severity was determined using Johnson, Darley and Spriestersbach's rating scale of stuttering.

Subject 1. Stuttering was reported to have occurred since the age of 3. Stuttering severity was rated moderate to severe--stuttering on about 8 to 12 percent of words; disfluencies average about 2 seconds in duration; a few distracting sounds and facial grimaces; a few distracting associated movements.

Subject 2. Subject awareness of stuttering was reported to have occurred at age 9. Stuttering severity was rated mild to moderate--stuttering on about 2 to 5 percent of words; tension noticeable but not very distracting; most disfluencies do not last longer than a full second; patterns of disfluency mostly simple; no distracting associated movements.

Subject 3. Subject reported noticing disfluencies at age 10. Stuttering severity was rated moderate to severe--stuttering on about 8 to 12 percent of words; consistently noticeable tension; disfluencies average about 2 seconds in duration; a few distracting sounds and facial grimaces; a few distracting associated movements.

Subject 4. Subject reported having always thought of himself as a stutterer. Stuttering severity was rated severe--stuttering on about 12 to 25 percent of words; conspicuous tension; disfluencies average 3 to 4 seconds in duration; conspicuous distracting sounds and facial grimace; conspicuous distracting associated movement.

Subject 5. Subject awareness of stuttering was reported to have occurred at age 6. Stuttering severity was rated moderate to severe--stuttering on about 8 to 12 percent of words; consistently noticeable tension; disfluencies average about 2 seconds in duration; a few distracting sounds and facial grimaces; a few distracting associated movements.

APPENDIX B

PASSAGE READ BY SUBJECTS

Today Tom thought about a fishing trip. The possibility of catching several beautiful bass was a very tantalizing suggestion. Zelmos's Tackle Shop will put up a valuable cash reward for the biggest one caught. In nineteen seventy-four, a thirty pound fish won and a very good friend of Tom's got the prize. Finally Tom couldn't resist the thought and headed for the dock. When he got there he delved into his tackle box for his favorite lure--the zesty minnow.

APPENDIX C

RANDOMIZED ORDER OF EXPERIMENTAL CONDITION FOR NORMALS AND STUTTERERS

Subject	1st Condition	2nd Condition
1	Metronome	No Metronome
2	Metronome	No Metronome
3	No Metronome	Metronome
4	Metronome	No Metronome
5	No Metronome	Metronome

APPENDIX D

INSTRUCTIONS TO SUBJECTS

Condition without Metronome:

During this portion of the experiment, you will be requested to read a passage which will be placed before you. Read the passage without any timing techniques, such as tapping your foot, fingers, etc. or any other control devices you use to help reduce stuttering. At my signal, place your mouth tight against the face mask and we will begin. Do you have any questions?

Condition with Metronome:

During this portion of the experiment, you will be requested to read a passage placed before you. Through the headphones you will hear a beat. Listen carefully to the beat and then begin reading one word to each beat. If you get off the beat, let a couple of beats go by and then continue reading with proper synchrony. When you are ready, place your mouth tight against the face mask and read the passage. Do you have any questions?

APPENDIX E

Summary of mean intraoral air pressures (in centimeters of H_2O). All entries in the difference column represent reduction in pressure in the metronome condition.

	Control	Metronome	Difference
	-------Centimeters of H_2O---------		
	Stuttering Group		
Voiceless Fricatives	5.76	4.91	-0.69
Voiced Fricatives	4.07	3.53	-0.54
Voiceless Stops	6.46	5.76	-0.7
Voiced Stops	5.11	4.75	-0.36
	Normal Group		
Voiceless Fricatives	7.3	6.23	-1.07
Voiced Fricatives	4.75	4.72	- .03
Voiceless Stops	7.7	6.39	-1.31
Voiced Stops	6.57	5.9	-0.67

Summary of the mean durations (in milliseconds) for onset, offset and total. All entries in the difference column represent longer durations in the metronome condition.

Onset	Control	Metronome	Difference
	-----------Millisecond-------------		
Stuttering Group			
Voiceless Fricatives	112.5	250.45	+137.95
Voiced Fricatives	99.0	181.66	+ 82.56
Voiceless Stops	138.6	281.66	+143.06
Voiced Stops	112.22	248.97	+136.75
Normal Group			
Voiceless Fricatives	106.67	257.78	+151.11
Voiced Fricatives	86.19	203.11	+116.92
Voiceless Stops	102.67	283.11	+180.44
Voiced Stops	87.0	224.0	+137.0
Offset			
Stuttering Group			
Voiceless Fricatives	89.5	112.22	+ 22.72
Voiced Fricatives	74.0	98.63	+ 24.63
Voiceless Stops	94.14	105.22	+ 11.08
Voiced Stops	72.22	87.69	+ 15.47
Normal Group			
Voiceless Fricatives	82.66	96.88	+ 14.22
Voiced Fricatives	66.36	91.36	+ 25.0
Voiceless Stops	80.44	104.89	+ 24.45
Voiced Stops	57.0	77.5	+ 20.5
Total			
Stuttering Group			
Voiceless Fricatives	229.33	363.9	+134.57
Voiced Fricative	180.0	280.93	+100.93
Voiceless Stops	223.33	384.66	+161.33
Voiced Stops	182.22	336.15	+151.93
Normal Group			
Voiceless Fricatives	189.33	348.88	+159.55
Voiced Fricatives	167.72	295.56	+127.84
Voiceless Stops	183.11	371.56	+188.45
Voiced Stops	144.0	321.5	+177.5

Summary of the mean air flow rates (in cc/second) for the four consonant classes.

	Control	Metronome	Difference
	------------cc/second------------		
	Stuttering Group		
Voiceless Fricatives	350.13	320.7	-29.41
Voiced Fricatives	216.29	209.95	- 6.34
Voiceless Stops	648.9	614.39	-34.51
Voiced Stops	232.9	213.19	-19.71
	Normal Group		
Voiceless Fricatives	385.51	436.67	+51.16
Voiced Fricatives	270.61	321.59	+50.98
Voiceless Stops	823.41	983.75	+160.34
Voiced Stops	310.15	399.68	+89.53

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