65-13,892

STARK, Rachel Elizabeth, 1923-
EFFECTS OF DELAYED AUDITORY FEEDBACK UPON A SPEECH-RELATED TASK IN STUTTERERS.

The University of Oklahoma, Ph.D., 1965
Speech-Theater

University Microfilms, Inc., Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

EFFECTS OF DELAYED AUDITORY FEEDBACK UPON A SPEECH-RELATED TASK IN STUTTERERS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

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Oklahoma City, Oklahoma

1965

EFFECTS OF DELAYED AUDITORY FEEDBACK UPON

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APPROVED BY

DISSERTATION COMMITTEE

ACKNOWLEDGMENT

The writer wishes to express her appreciation to the director of this study, Dr. Bruce R. Pierce, for his invaluable help, guidance, and encouragement in all phases of this investigation.

The writer is indebted to Dr. Howard B. Ruhm for his advice as to the experimental design of this study and for the use of the instrumentation concerned.

Thanks are extended to Dr. Edward N. Brandt, to Dr. M. Clinton Miller, and to other members of the staff of the Biostatistical Unit of the Department of Preventive Medicine and Public Health, University of Oklahoma Medical Center for their assistance in developing the statistical design of the study and in the statistical analysis of the data; and to many others, especially Dr. William A. Cooper and Dr. Darrell E. Rose, who contributed freely of their time, encouragement, and support.

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CHAPTER I

INTRODUCTION

From ancient times it has been held that a basic physical or physiological defect of one kind or another has a direct causal relationship with stuttering. Although theories as to the nature of this defect have become more sophisticated with the increase of scientific knowledge in general, and of knowledge and experience in the field of speech pathology in particular, they have remained notoriously difficult of proof. The search for such a factor has not, however, been abandoned. While the importance of psychological and learning factors in stuttering cannot be denied, the fact that surveys in different areas and at different times in the United States of America (12, 68) and the United Kingdom (65) have consistently reported the incidence of stuttering in the school-age population to be in the region of one per cent suggests that a basic organic defect is reflected in this pathology. Higher percentages have been reported only for atypical groups - for example, among the mentally handicapped (38, 42, 81) and in communities where parents are particularly apt to put undue pressures on their children to achieve or conform, especially where speech skills are concerned (62, 68).

It may be objected that incidence figures suffer from a lack of a uniform or widely accepted definition of stuttering, of the kind which Wingate (107) has recently outlined, or by implementation of the survey by inadequately or variously trained personnel. On the other hand, findings for special groups may indicate that the relative importance of psychological and learning factors, and of a basic physiological defect or defects, should these be found to exist, may vary from one instance of the disorder to another.

Attempts to discover the nature of the hypothesized physiological defect have met with signal failure. Investigations purporting to demonstrate gross physical or metabolic differences between stutterers and nonstutterers have been nullified by later, more sophisticated study. Anomalies of the neurophysiological bases of speech, not well understood in the normal speaker, have been implicated and studies made of such factors as hand dominance, cortical potentials, and motor skills in stutterers, so far without conclusive findings.

More recently, concepts from the field of cybernetics have been applied to the study of the neurophysiology of speech and language. It has been suggested that stuttering is a disorder not of motor initiation or coordination but, rather, of sensory monitoring. Such a view has found particular support over the last two decades from investigations into the effects of delayed auditory feedback. Lee (60), who first studied this phenomenon in normal speakers, has referred to one of these effects as "artificial stuttering". Soderberg (86), Lotzmann (61), Goldiamond (41), and others suggest, on the other hand, that delayed speech feedback may be of benefit to the true stutterer; this suggestion has been qualified by Neelley (70), Ham (44), and others. The breakdown in the servo-mechanism of speech which is speculated to underlie stuttering has been variously described as originating in the auditory system itself (3, 96) or in any one of the receptive, inner, or expressive language processes (69).

It is felt, however, that before attempts are made to define more precisely the nature or site of such a breakdown, the existence of differences in the functioning of sensory feedback mechanisms related to speech in stutterers and nonstutterers should be demonstrated more clearly. These mechanisms might well be studied in the absence of communication so that the word cues and fear of failure to communicate associated with stuttering are not present in the experimental situation.

The present study was designed to compare the performances of stutterers and nonstutterers on a speech-related task under varying conditions of delayed auditory feedback. It was felt that any significant difference between the responses of the two groups might reflect differences in sensory feedback functioning underlying speech and suggest ways in which these differences should be subjected to further study.

CHAPTER II

REVIEW OF THE LITERATURE

The hypothesis that stuttering may be related to a neurophysiological defect or dysfunction has not yet been confirmed or denied by experimentation. Such a theory is supported by observations that confirmed neurological defect or lesion, in the form of cerebral palsy (12), aphasia (30), and Parkinsonism following bilateral thalamotomy or similar surgical procedure (23), and stuttering, at least in transient form, occur in the same individual more often than would be expected on the basis of chance alone. Further support is offered by those studies indicating the incidence of stuttering in exogenously mentally retarded children to be considerably higher than in persons of normal intelligence and somewhat higher than in endogenously mentally retarded children (38, 81).

It has been objected that the speech behavior manifested in persons afflicted by these neurologically based disorders is not "true" stuttering. However, it remains to those who take this position to define true stuttering and the features which distinguish it from "pseudo" stuttering; it would hardly be defensible to label the speech behavior as "true" or "pseudo" merely on the basis of its supposed etiology. It is entirely possible that the features which Wingate (107) cites as having "universal applicability", namely:

(a) Disruption in the fluency of verbal expression

> which is (b) characterized by involuntary, audible or silent, repetitions or prolongations in the utterance of short speech elements, namely: sounds, syllables and words of one syllable. These disruptions (c) usually occur frequently or are marked in character and (d) are not readily controllable

are common to the stuttering which appears in association with neurological impairment and stuttering in persons who appear normal neurologically. Other features, referred to by Wingate as "associated" or "ancillary", for example, struggle activities involving the speech apparatus or unrelated body structures and unpleasant emotional states, may not be universally present, and may, indeed, be more commonly found in persons, apparently normal neurologically, who have stuttered from childhood. The same may be true of the consistency and adaptation effects (12, 53).

The importance of psychological factors in the onset and development of stuttering cannot be denied. Evidence is strong that environmental pressures, frequently arising from perfectionism, over-concern, and rigid training practices on the part of the parents, are associated with stuttering (68). In many instances, stuttering appears to be precipitated or aggravated by emotional stress. The application of learning theories to the development of the disorder would appear to be valid.

This is not to deny, however, that neurophysiological differences are present at least in certain instances of stuttering. Studies purporting to reveal differences of this kind have, generally speaking, been negated by later studies of greater technical sophistication. At the same time, more sophisticated hypotheses as to these differences have been advanced. In the 1930's, Travis (100) and Orton (72) suggested that lack of cerebral dominance, as revealed in anomalies of sidedness, was related to stuttering. However, studies, chiefly that of Johnson and King (54), employing the vertical angle-board devised by Van Riper, rather than cruder tests or questionnaires, demonstrated that stutterers and nonstutterers alike are placed on a continuum with regard to left or right dominance. Electroencephalographic studies (29, 58, 101) have, generally speaking, revealed no significant differences in cortical potentials between stutterers and nonstutterers. Computer investigations of cortical potentials in stutterers have not yet been attempted, however. Contemporary studies of gross physical abilities and oral diadochokinesis (25, 35, 97), skills which may be said to depend upon neurophysiological integrity, have revealed no significant differences between stutterers and nonstutterers.

Attention has, of late, been focused on the sensory rather than the motor processes involved in speaking, chiefly audition. These processes, too, depend upon neurophysiological integrity, and it has been suggested that anomalies in the functioning of the auditory nervous system may be related to stuttering. Gregory (43), for example, submitted stutterers and nonstutterers to audiological tests devised to detect aberrant functioning of the auditory nervous system, namely simultaneous binaural loudness balancing, intracranial sound localization, and discrimination of filtered speech. While the validity of these tests has not yet been firmly established, it is of interest that the stutterers showed consistently poorer responses on the distorted speech tests in this study.

Other recent investigations of auditory nervous system functioning have employed as experimental conditions systematic alterations in auditory feedback of the stutterer's own speech. Most of these derive from the concept of speech as a servomechanism or closed-cycle system.

Speech as a Servomechanism

In a closed-cycle system, information about on-going activity feeds back through receptor systems to be utilized in the processing of future output. Chase (16) refers to the probable synthesis of inputs and their utilization for error detection and error correction programming. Fairbanks (31), in his model of this system, describes the error signal as the amount by which a unit goal of output has not yet been achieved by the effector unit and the error correction as the function of a "mixer", which combines the error signal and input signal in such a way as to effect the desired transition to a succeeding steady state. He further proposes that a "comparator", the function of which is to compare input and feedback signals, includes a predicting device which plots the error signal and extrapolates to the point in time when this will be zero. Gibbs (39), too, emphasizes "the anticipatory cues of the kinesthetic discharge".

The role of sensory feedback in the initiation and continuation of speech or other motor activity is not clearly understood. Nor is the concept of the closed-cycle system as applied to speech universally accepted. It has proved useful, however, and suggested further experimentation.

The functioning of sensory feedback processes may be studied both experimentally, by introduction of alterations in feedback, and clinically, in syndromes characterized by abnormalities of sensori-motor functions. Alterations of sensory feedback may take the form of experimentally reduced or cancelled feedback information, as in the use of anesthesia or auditory masking, or of experimental alterations of frequency, intensity, phase, or temporal or spatial relationships in feedback information. Various combinations of these conditions may be applied to one sensory modality or to more than one sensory modality at a time.

Alterations in Sensory Feedback

In general, reactions to alterations of sensory feedback appear to demonstrate an effort on the part of the subject to maintain homeostasis or to compensate for any disruption of motor activity so introduced. Alterations of feedback have been applied to a number of non-speech motor tasks, for example, tapping, clapping, tracing or tracking, and whistling. The effects of such alterations, as Smith (84) points out, are difficult to quantify, since motion is multi-dimensional, and a single measure of efficiency is difficult to justify. Tracking tasks are influenced by alterations in visual feedback. Adaptation to spatial displacement, for example, the substitution of mirror images, appears to be more effective than adaptation to temporal displacement or delayed visual feedback (84). Delayed auditory feedback has been found to disrupt tasks such as clapping, the playing of musical instruments, and whistling (56).

Chase et al (20) found that decreased sensory feedback (visual, tactile, and proprioceptive) led to changes in performance on a regular tapping task. The changes were those of increased intensity or decreased rate of performance, especially when decrease in proprioceptive feedback was achieved by masking, that is, by vibration on the forearm; when the conditions were combined, a cumulative effect appeared. Delayed sensory feedback, where each tap might trigger a click presented through earphones, a flash of light, or a tap on the arm at a specified delay time, produced similar effects. When a patterned tapping task was performed, greater disruption was evident under delayed feedback than on the regular tapping task in terms of rate decrease, intensity increase, and introduction of the additional feature of pattern error.

Completely effective adaptation to delayed sensory feedback does not appear to occur (2), and the sensory feedback system seems unable to separate out information in sensory modalities not ordinarily associated with the task at hand, as in the case of the flashes of light triggered by tapping mentioned above.

Altered Speech Feedback

Smith and Smith (85) point out that, since the time characteristics and kinetics of different types of component movements differ, they will be affected quite differently by altered feedback. Nevertheless, some similarities can be traced in the effects of altered feedback upon different motor tasks, for example, tapping and syllable repetition.

Ringel and Steer (77) have shown that, under reduced auditory, tactile, and kinesthetic feedback produced by anesthesias and masking noise, the intensity of speech production increases and rate of performance decreases in a manner very reminiscent of that demonstrated by Chase with regard to changes of tapping performance under similar conditions. Similarly, too, the combined conditions of decreased feedback showed a cumulative effect upon speech performance, and obliteration of feedback (by masking noise) was more effective than withdrawal of feedback (by local anesthesia), at least where rate of performance was concerned.

Chase et al (19) have further shown that, under delayed auditory feedback, performances of rhythmic tapping and consonant-sound repetition breakdown in similar ways, i.e., the intensity or pressure of performance increases, rate decreases, and number errors appear. In general, too, misinformation in the form of delayed feedback appears to be more disrupting on both kinds of task than decreased feedback, at least up to a certain critical point. Altered kinesthetic feedback may also be more devastating for both tapping and speech than altered feedback in any other modality. A comparison of Chase's results and those of McCroskey (66), who reports a greater disturbance of articulation under local anesthesia than under delayed auditory feedback, illustrates this point. A delay in the arrival at the cortex of kinesthetic impulses cannot, of course, be produced artificially, but this might prove more disturbing to speech than delayed auditory feedback.

Certain features distinguish the speech feedback system. Information from tactile and kinesthetic receptors must be integrated in the central nervous system with the air-conducted and bone-conducted sidetone information arriving from the cochlea; under normal conditions, sidetone reaches the cochlea with the short delay imposed by the travel of sound impulses through the air or body tissue. Internal (bone-conducted) sidetone, as Black (8) points out, varies with vertical movements of the larynx and mandible, clenching of the teeth, and so on. External (air-conducted) sidetone varies with each set of reflecting surfaces. In neither case do delay times remain constant. Stromsta (93) estimates the average delay of air-conducted sidetone to be .001 sec and the average delay of bone-conducted sidetone to be .0003 sec, varying with frequency. This discrepancy between air- and bone-conducted sidetone is apparently small enough to allow their integration at higher neural levels. Bekesy (5) has further estimated that air- and bone-conducted sidetone are equal in intensity at the cochlea; Stromsta (95) points out, however, that they are probably not equal in frequency or phase. It seems likely that higher frequencies will be filtered out in transit through the large masses of the skull and, thus, bone-conducted sound given a low frequency emphasis.

Alterations in auditory speech feedback may facilitate or inhibit the rate of speech, increase or decrease intensity of speech sound production, or lead to increased or decreased precision of articulation. Decreases in intensity of external sidetone associated with a conductive hearing loss, may, by virtue of the occlusion effect and possibly other mechanisms, increase the loudness of internal sidetone and cause the individual to speak more softly. According to Black and Tolhurst (10), binaural occlusion of air-conducted feedback by insert-type ear-defenders may increase intelligibility. A sensorineural loss, on the other hand, reduces internal sidetone and, apparently by way of compensation, the loudness of the subject's voice increases. Profound hearing loss with onset in adulthood gives rise ultimately to a loss of precision of articulation; rhythm and intonation are likewise affected. In the presence of masking noise, the over-all intensity of speech increases, the rate of speaking is reduced, and syllables are prolonged (45).

In the presence of artificially increased intensity of air-conducted sidetone, the speaker reduces his vocal intensity, and vice-versa (73); the rate of output also varies with the intensity level of external sidetone (44). Alteration of the frequency of one's own sidetone, by filtering of the speech spectrum, differentially affects the rate of speech in pathological groups, especially stutterers (44); this effect may be related, in the latter group, to a reported decrease in stuttering blocks. Intelligibility improves in the normal speaker when the frequencies above 600 cps are attenuated (74).

Alterations in phase of air-conducted sidetone have been applied only to the production of single vowel sounds. Dolch and Schubert (28) report that, when accelerated sidetone is transmitted to the ears 180° out of phase to the signal emitted at the mouth, the subject phonates harshly, with greater effort, at a slower rate, and with increased intensity. Stromsta (95), however, found that the effects of altering the phase of the air-conducted sidetone of a vowel signal were not easily discernible, even with high amplification, unless the feedback signal was distorted, for example, by improper use of line preamplifiers or introduction of a delay. Phonatory blockages, resembling those of a stutterer, occurred significantly more often when both delay and phase distortion were present.

Presentation of delayed speech feedback is almost always by air conduction; delay times may be made to vary independently or together with filter conditions or intensity levels. It has been found that an artificial decrease in the normal delay of air-borne feedback enables the subject to speak more rapidly (26, 73). Increase of delay time, however, tends to produce rather different effects upon speech production, depending upon the amount of delay, frequency spectrum, and intensity of feedback. These effects include:

a. Increase in intelligibility, at .05-sec delay, where the average s.p.l. of the sidetone is subjected to automatic gain control (1).

b. Increase in intensity of speech production; according to Black (7), this effect reaches a maximum at .09-sec delay.

c. Increase of frequency of fundamental, apparently related to the increase of intensity caused by the increased delay time (32).

d. Reduction in rate of output, as measured by indices such as words per minute, mean rate reduction score, mean syllable duration time, or phonation time ratios. This effect has been found by Black (7), Atkinson (1), and Fairbanks (32) to become more marked as a function of delay up to .18 sec and then to decline. Spilka (89) found no differential effect across delay times at high intensities (125 dB). Rate of output also decreases with intensity of delayed feedback; the suggested interaction between delay and intensity has been confirmed by Butler and Galloway (13). Yates (108) points out, that ". . .there is an optimal range of intensities within which various delays will be differentially effective. Outside these limits, differential delay effects may be swamped by direct intensity effects at all delays."

e. Articulatory disturbance, which may be estimated by making a tally of errors, so determining the number of correct words, or the ratio of this count to the total reading time, an index referred to as the correct word rate. Errors take the form of varied and often unusual substitutions, omissions, and additions. The latter are sometimes referred to as intrusions and may be irrelevant insertions between or within words or repetitive additions. Fairbanks and Guttmann (33) have shown that the majority of these errors peak at .20 sec, but that the distribution of errors varies across delay times. At .20 sec, errors of non-repetitive addition were most common, increasing twenty-fold over the number present in the undelayed condition; repetitive errors peaked at .40 sec.

Rawnsley and Harris (76) analyzed errors of repetition and addition under delayed auditory feedback spectrographically. They observed increased duration and emphasis on most of the syllables involved, vowel distortion, and slurring across stop-gaps; in the case of a repeated syllable, no anticipation of the sound to follow, in the form of vowel transitions, was evident in the first articulation of the syllable.

Lee (60) refers to such errors as "artificial stuttering" and states that they appear only if the subject attempts to maintain a normal rate of speech. This may explain a contrary finding in McCroskey's (66) study, where a marked decrease in rate rather than a change in number of articulatory errors was detected. Furthermore, McCroskey's maximum delay of .18 sec was below the delay time producing maximum articulatory error in the study by Fairbanks and Guttmann.

Yates (108) presents a discussion of the asynchrony of units of information from different feedback systems as a critical factor in speech disruption under delayed speech feedback. Chase and Guilfoyle (18) show that, where synchronous auditory feedback is enhanced, the disrupting effects of delay lessen, although Ruhm and Cooper (80) point out certain difficulties in interpreting their results related to order effects. It would appear that the functioning of a central controlling mechanism or comparator must be affected under delay.

Lee suggests that, lacking the feedback signal necessary for the release of the next unit of speech under delayed speech feedback, the speech mechanism may halt until this condition is satisfied. Chase (15) points out that repetition of the elements of speech is facilitated by delayed speech feedback; speech units appear to be circulated and recirculated in an auditory feedback loop when release of the following unit is not achieved. This may lead to repetition of consonants or prolongation of vowels. Fairbanks (32) feels that disturbed articulation and decrease in rate are direct effects of delay while increase in intensity is an indirect effect, an attempt on the part of the subject to enhance normal bone-conducted sidetone. Further effects under delayed speech feedback are related to struggle or stress: the subject's face becomes red, palmar sweat increases, and, according to some authors, heart and pulse rates increase.

The frequency spectrum of the delayed speech feedback signal may be altered by filtering. Under this condition, phonation/time ratios, unaffected by unfiltered delayed speech feedback, are lengthened. This in itself does not appear to be a very meaningful measure, however. Hull (50) found that, under conditions of combined filtering and delay, low-pass filtering affected the intensity, rate, correct word rate, and intelligibility of the subject in the same direction as delay alone, but more markedly. Finally, a combination of auditory flutter and delay produces effects upon speech power, words per minute, and phonation/time ratios at variance with those produced by delay alone (90).

The interactions indicated above may help to explain the inter-subject variability commonly found in studies of delayed speech feedback. The subject, for example, who employs increase of intensity to reinforce normal bone-conducted feedback automatically increases the intensity of the air-conducted delayed speech feedback. Both Studebaker (92) and Harford and Jerger (47) have found subjects with conductive hearing losses to be more susceptible to delayed speech feedback than normal-hearing subjects or subjects with sensorineural losses accompanied by recruitment. In subjects with conductive hearing losses, placement of earphones does not give rise to an occlusion effect since this is already present. It may be that subjects in this category speak more loudly under earphones than normal-hearing or sensorineural-loss subjects, so that the disrupting delayed speech feedback is also commensurately increased. How the pitch differences of air-conducted and bone-conducted sidetone may affect responses to delayed speech feedback is not known. Other confounding variables appear to be the reading rate of the subject (59), the type of reading material involved (9, 34, 37), instructions given to the subject, amount of pre-training, and reference sound pressure level employed.

Individual differences may also be traceable to methods by which speech skills are learned and to personality differences. Beaumont and Foss (4), for example, found a positive relationship between poor performance under delayed speech feedback and certain measures of perseveration and rigidity. Spilka (88) and Spear (87) have found differences of vocal intensity variation among schizophrenics under delayed speech feedback. Goldfarb and Braunstein (40) report that schizophrenic children vary a great deal more in their responses to delayed speech feedback than normal children.

Delayed Speech Feedback in Immature and Defective Speakers

While responses to delayed speech feedback have been investigated in various hearing-loss groups, more pertinent to this study are the investigations of such responses in persons presenting speech disturbances of one kind and another. There is some question as to whether or not good speakers are more subject to speech disruption under delayed feedback than poor speakers. Chase et al (21) suggest that speech becomes a more skilled motor activity with age and may at the same time become more vulnerable to undue "load". On the other hand, Atkinson (1) found that adult speakers with high initial intelligibility were less affected under delay conditions than speakers with low intelligibility.

It would appear, however, that certain groups of immature or abnormal speakers respond atypically to delayed speech feedback. In some cases of speech or language disturbance, the delay actually appears to be of benefit. According to Chase et al (21), the spontaneous speech of children in the seven- to nine-year group was more affected by delayed speech feedback than that of children in the four- to six-year group in the following ways: (a) greater decrease in number of words uttered, (b) greater increase in the number of syllables prolonged, and (c) lesser number of intrusions. He further observed that younger children who tended to repeat words and word groups in normal speech ceased to do so under delay, but, rather, showed the increase in time taken to say a word typical of the older group, or a shift towards the repetition of smaller speech units. It would be of great interest to employ delayed speech feedback with those preschool children who, according to Metraux (64), Davis (27), and others, typically repeat syllables rather than words under normal feedback conditions; these may be the very children who are particularly prone to develop stuttering. Copeland (24) has used delayed speech feedback (at a delay of one second) to facilitate the prespeech vocalizations of severely retarded children.

Stanton (91) studied the behavior of a group of aphasic patients capable of some connected speech under conditions of delay. Those who presented predominantly expressive disturbances in language tended to react like normal subjects. Patients showing a predominantly receptive involvement tended to show either no reaction to the delay or speech improvement. Stanton suggests that, in such cases, a defect or absence of auditory feedback at a central level, concomitant disorders of kinesthetic and auditory feedback, or elimination of inhibitory influences arising in "auditory association areas" may be present.

It is interesting in this connection to note that Birch and Lee (6) found speech impairment could be significantly reduced in subjects suffering from expressive aphasia by presentation of binaural auditory masking in the form of a 256-cps tone. A later study by Weinstein (103), however, failed to confirm these results, possibly because of unrecognized differences in classification and selection of patients.

House (49) compared the effects of delayed speech feedback upon the speech of non-cerebral palsied speakers and cerebral palsied speakers "with known involvement of the central nervous system and kinesthetic feedback system". He found that delay times of .03, .06, .12, and .18 sec facilitated the speaking rate of cerebral palsied speakers, while the speaking rate of the normal subjects was facilitated only at a delay of .03 sec. In addition, cerebral palsied speakers became more intelligible under the delay conditions, a different delay time being most effective for each subject in this respect.

In the experience of the writer, the precision of articulation of one patient following bilateral chemopallidectomy for the relief of Parkinsonism was improved under delayed speech feedback; his rate of speech slowed considerably, a tendency to repeat and hesitate on short speech elements disappeared, and over-all intelligibility increased.

Finally, a number of investigators (15, 41, 44, 61, 70, 86) have reported that the speech of stutterers tends to show a reduction in number of blocks under delayed speech feedback, an effect which may vary with the delay time employed. Soderberg (86) remarks that his group of "most severe" stutterers showed the greatest decrease in frequency and duration of stuttering under delay. Ham (44) describes essentially the same effect for the three "most severe" stutterers in his study. Typically, the fundamental frequency of the stuttering group in Soderberg's study was raised under the delay condition. The "least severe" stutterers showed more disturbance under delay of the kind evidenced by normal speakers and some initial increase in frequency of stuttering; at no time was the duration of their blocks decreased. In neither group did the effects persist after the removal of the delay condition; indeed, some of those in the "most severe" group stuttered more severely after removal of the delay than before its application.

The similarity between stuttering and the hesitations and repetitions produced in some normal speakers under delayed speech feedback have led a number of writers to suggest that the two phenomena have features in common. Lee (60) suggests that true stuttering, like "artificial stuttering", occurs when a failure of feedback prevents the release of succeeding cycles of speech activity. Chase (15) emphasizes the recirculation of hypothetical speech units when they fail on completion to trigger the following units. Fairbanks (32), with somewhat different emphasis, states that "the stutterer misevaluates his own speech at some point in the control system and finds error where, in reality, none exists. The results of his attempt to correct this non-existent error is stuttering behavior." Cherry and Sayers (22) refer to stuttering as a "type of relaxation oscillation" caused by instability of the feedback loop, presumably at the word, syllable, or phoneme level. Azzi (3), in more general terms, states that the stutterer has a "deficient nervous circuit", creating a condition in the stutterer which can delay auditory feedback internally.

If a sensory feedback disorder of a kind which would produce a "built-in" or native auditory delay is indeed present in some or all stutterers, it would appear that this is not in evidence at all times, since stuttering behavior has been found to vary in the individual with social situations, with degree of communicative responsibility, and with "cues" inherent in the context of read or spontaneous speech (12). At times the difficulty may be entirely absent. Moreover, the role which such a feedback disorder might play in difficulty of speech initiation is not clear. If, indeed, some intermittent electrical or electro-chemical disturbance within the central nervous system of the stutterer produces a delay, possibly for a very brief period of time, at some point in the processing of a spoken response, this would appear to be triggered by the circumstances and cues mentioned above.

The reported amelioration of stuttering under the condition of delayed speech feedback would seem to add some interesting complications to this line of thinking. Yet not all investigators agree that such improvement does take place. Ham (44) found few, if any, differences between stutterers and nonstutterers under delay. Neely (71) found that stutterers behaved like nonstutterers in terms of rate and sound pressure level of reading under delay, but at delay times very close to those obtained under normal conditions. He cites the instance of one stutterer, however, who showed the increased precision and rapidity of articulation under accelerated feedback typical of normal speakers, together with a decrease in severity of stuttering.

Neelley (70), on the other hand, found stutterers and nonstutterers to behave alike at a delay time of .14 sec, at least with regard to overall frequency of errors of articulation. He did not establish the frequency of blocks or hesitations per se under each condition but points out that listeners could not detect differences between speech disturbances of the two groups under delay conditions, especially where the stutterer was "relatively fluent". This is what one would expect if Soderberg's observations regarding his "least severe" stutterers are well founded. The speech of the stutterers in Neelley's study was judged to be different under normal feedback than under delay by listeners and by the stutterers themselves in assessing their own kinesthetic experience. Some real differences between stutterers and nonstutterers are apparent in Neelley's results, however. Approximately twenty per cent of his stutterers showed a higher correct word-rate under delayed than under normal feedback; stutterers showed significantly fewer additions and were considerably more variable than nonstutterers under the delay condition.

Neelley further showed that the adaptation and consistency effects typical of stuttering behavior are absent in series of nonfluencies produced in normal speakers by delayed speech feedback. He concludes, "the hypothesis that stuttering may be related to a delay in auditory feedback because speech produced under conditions of DAF is assumed to behave like stuttering is discredited by these findings." Certainly, fully developed stuttering, to which learning and experience may have added accessory and associated abnormalities not originally present, is not identical to the momentary disturbance produced by delayed speech feedback. This is not to say, however, that the two do not have a fundamental common factor or factors.

The fact that stuttering tends to be eliminated under masking by white noise, a finding independently reported by Cherry and Sayers (22), Shane (83), Maraist and Hutton (63), has suggested to some investigators that the hypothesized central nervous system anomaly contributing to the disorder resides within the auditory nervous system, though whether at cortical or sub-cortical levels no one has gone so far as to specify. Sutton and Chase (99) make the cautionary observation that, when white noise is applied only to silent periods and does not, therefore, mask speech at all, it is just as effective in reducing stuttering as continuous white noise or white noise applied only during phonation. It must be remembered, however, that silent periods are frequently related to repetitions and prolongations of short speech elements in the stutterer. Furthermore, the salutary effect of bursts of white noise may persist for short periods following their cessation, in the above case, across the intervening periods of speech production.

Cherry and Sayers suggest not only that stuttering results from a perceptual rather than a motor disturbance, but also that, since the lowest frequencies of bone-conducted sound must be included among those masked before stuttering is resolved, the low-pitched laryngeal components of speech, monitored through the bone-conduction pathway, are of primary significance in mediating the perceptual abnormality.

Stromsta (96) further reports that the fundamental frequency of the voice in a group of severe stutterers was increased progressively as the fundamental frequency of a 100-dB square-wave masking noise decreased from 500 to 100 cps. At the same time, a reduction in frequency of the stuttering blocks was observed. The fundamental frequency increase and reduction in stuttering may have been a function merely of the increasing efficiency of the masking noise.

Stromsta, however, feels that his results are related to the findings of another of his studies (94), in which he demonstrated certain differences in the phase angle of bone-conducted speech sound energy for stutterers and nonstutterers. Both groups were required to cancel bone-conducted tones of 500, 1000, and 2000 cps driven through the medial incisors, by adjustment of the phase and amplitude of simultaneously presented air-conduction tones of equal frequency and sensation level. The mean phase adjustment of the leading air channels at the point of cancellation differed across groups by an amount suggesting an increase of .0001 sec in stutterers as compared with nonstutterers in time taken for bone-conducted sound to arrive at the cochlea. Stromsta suggests that this condition is comparable to delayed sidetone, although Neely (71) found additional delays of this magnitude to produce no marked effects in the speech of stutterers or nonstutterers. Stromsta postulates that the "simultaneous stimulation of bilateral receptors by in-phase external sidetone and out-of-phase internal sidetone may be preserved in the neural pattern-stimulating centers". Presumably, if internal and external sidetone are out of phase with one another, this is related to some accident of skull configuration or bony content, since both internal and external sidetone signals are handled in the same manner by retrocochlear auditory pathways.

If, then, a feedback delay is inherent in the auditory nervous system or in the peripheral bone-conduction channel of the stutterer, how does it come about that a persisting, artificially produced delay in the region of .14 to .20 sec is of benefit to him? It could be argued that this artificial delay, added to that already experienced intermittently or persistently by the stutterer, produces a total delay much less disturbing than either the native or superimposed delay alone; that is, it would be greater than .20 sec, generally acknowledged to be the most disturbing, or, although this seems unlikely, than .40 sec, at which point, it will be remembered, Fairbanks and Guttmann (33) found repetitive errors to be at a maximum.

If, on the other hand, we are not prepared to grant that stuttering is related to a delay-producing disturbance arising at some level within the central nervous system, or to phase-altering anomalies of skull structure, we must still account for the fact that some stutterers manifest speech improvement under obliteration or delay of auditory speech feedback. It may be that stutterers, accustomed to anticipating blocks and circumventing them, have learned to attend closely to tactile and kinesthetic feedback and are, therefore, better able to "beat" the delayed speech feedback condition. If this were so, then the findings of Soderberg and others suggest that "most severe" stutterers demonstrate this ability to a greater extent. At the same time, such an argument does not take into account the tendency for the stutterer's own familiar stuttering patterns to disappear under delay.

It has been suggested, on the other hand, that delayed speech feedback merely acts, in a fashion common to all alterations of feedback, as a distraction device. Masking noise may be one of these devices; alterations of the intensity level or frequency spectrum of external sidetone may be others. The use of a monotone, whisper, pretended foreign accent, or choral reading, may, in fact, be homelier versions of the same mechanism. This is not to say that the distraction device is not worthy of more careful study than it has been given in the past or that there may not be an important distinction between distraction devices which are adopted by the stutterer himself, toe-tapping, whispering and the like, and those which reach him from external sources, whether or not self-initiated. In the former case the device readily loses its effectiveness upon repeated use; in the latter, adaptation does not appear to take place to the same extent.

A third explanation may be advanced, perhaps, in fact, an equally imprecise restatement of the previous one; alterations in external sidetone may inhibit a delay-producing breakdown occurring elsewhere in the nervous system, in processes underlying word finding, for example, or selection of appropriate motor patterns for speech. As Mysak (69) states it, "efficient oral input-output language depends on a series of noise-free open- and closed-cycle circuits". Or it may be that masking noise or delayed speech feedback prevent the development of a pattern of undesirable recirculation of units of speech or, indeed, of learned struggle reactions normally consequent upon such a native delay or breakdown, merely by interference with self-monitoring.

Goldiamond's recent approach to the problem of stuttering would seem to be of particular pertinence here. He reports (41) that stuttering decreased markedly in frequency, in cases of all degrees of severity, when a five-second period of delayed speech feedback (.25 sec delay) or a one-second period of white noise was made contingent upon the stuttering block; in the case of delay, the effect persisted over ninety-minute reading periods conducted five days a week for many weeks. The stutterer himself produced this response-contingent stimulus by depressing a switch at "the moment of stuttering". It is not certain whether this was the moment of becoming aware that a speech difficulty was impending or the moment of onset of difficulty, although high reliability with a monitoring investigator is reported; nor has Goldiamond studied the course of the stuttering block itself under these conditions to determine whether or not this is altered by application of the delay. Goldiamond believes that his results demonstrate Skinnerian operant conditioning or the reduction of stuttering by application of an aversive stimulus or punishment. This is not, however, in accord with the work of Van Riper (102) or Frick (37) who have shown that frequency of stuttering increases when punishment by electric shock is administered or threatened. However, as Williams (105) has pointed out, the stutterer by self-definition of the block may be identifying the onset of anticipatory struggle reactions and punishing this faulty response to the threat of a fluency breakdown, rather than the block itself. Alternatively, the five-second period of delayed speech feedback may limit or resolve a brief breakdown in the neurophysiological organization of oral language, or a set of reactions activated by such a breakdown, as has been suggested above. It is of particular interest that response-contingent delayed speech feedback is much more effective in reducing the frequency of stuttering than continual delayed speech feedback, except, perhaps, in the case of more severe stutterers for whom even response-contingent delay must be almost continual, at least initially.

Delayed Pure-Tone Feedback

As already indicated, pure tones or clicks triggered by tapping with the forefinger may be presented by delayed auditory feedback. Responses of this kind of task may show less intersubject variability than those evoked by delayed speech feedback. The task is not complicated by such factors as the presence of synchronous bone-conducted sidetone of varying and uncontrolled intensity, varying and uncontrolled frequency components of the air- and bone-conducted sidetone, and variations of material to be utilized on the primary task. Ruhm and Cooper (78) have established that the delayed feedback of a 1000-cps tone need be only 5 dB above threshold to change the time required to tap a simple pattern repeatedly and/or to introduce number errors in the tapping pattern. Responses to delayed speech feedback cannot always be detected reliably, even at 40-dB SL (14, 46). Ruhm and Cooper (79) have further established that relatively short-term performance on the tapping task is not influenced by the sex of the subject nor the frequency of the pure tone activated by the tapping. Educational level affected performance, the less highly educated or motivated subject tending to show disruption at 0 dB rather than 5 dB SL. A foreknowledge of the time relation between the tapping movement and the pure-tone signals so activated given in prior instructions enabled their subjects to resist disruption at threshold level; practice, however, did not improve the performance of these subjects. Adaptation of performance did not manifest itself, and short-term habituation to synchronous (pure-tone) auditory feedback was not necessary for subsequent deterioration of tapping patterns.

Delayed pure-tone feedback is likely to prove a reliable means of establishing the threshold of hearing in cases of non-organic hearing loss, once its application to various categories of hearing loss has been fully investigated. It may further be used to study sensory feedback mechanisms in the speech pathologies, including stuttering. This, indeed, is the purpose of the present study, to be described more fully in the ensuing chapter.

CHAPTER III

DESIGN OF THE INVESTIGATION

It has been established that the oral diadochokinesis and rhythmokinesis of stutterers and nonstutterers are not significantly different (25, 98). Such motor tasks have not, however, been studied in the stutterer under conditions of altered sensory feedback. Accordingly, it was the purpose of this study to investigate the effects of delay and intensity changes in auditory feedback on the execution of a simple, speech-related task, the patterned repetition of the syllable (mə), in stutterers and nonstutterers.

As Ruhm and Cooper (78) have shown, more precise measurement of responses to delayed auditory feedback may be obtained on simple, repetitive motor tasks than on continuous speech; perhaps even more important, complex language processes are not involved in patterned syllable repetition.

As previously stated, responses to delayed speech feedback, even on such a relatively simple task as patterned syllable repetition, may show great intersubject variability; a major source of this variability appears to be the nature of the response itself, in terms of frequency and intensity changes. In order that intensity and frequency components of the feedback signal might be subject to greater control, therefore, the subjects in this study, following a period of training in the experimental task, produced the syllable (mə) without voice or audible breath escape. Auditory feedback was in the form of a click, a 5-msec electrical pulse activated by an electro-mechanical device on lip closure, transduced by earphones or bone-conduction vibrator.

Delayed speech feedback on syllable repetition and delayed auditory feedback of pure tones and clicks triggered by finger tapping yield comparable effects (19), and it was felt that the form of auditory feedback described above might be substituted, for the purposes of this study, for delayed speech feedback. Since synchronous bone-conducted sidetone and binaural delayed air-conducted sidetone are both present in delayed speech feedback, however, it was felt that these conditions should be duplicated as nearly as possible, at least in one section of this study.

Fifteen stuttering subjects and fifteen normal-speaking subjects were asked to repeat a voiceless (mə) to the pattern of four lip closures, followed by a pause, followed by two lip closures (---- --). This pattern has been used in previous studies of delayed auditory feedback (78, 79, 80). The voiceless (mə) was chosen so that the subject would receive no feedback from breath plosion in his own performance, especially when an occlusion effect was introduced by the earphones.

The experimental task was performed with the thin, narrow, flexible tips of a custom-designed electro-mechanical transducer placed between the lips. Two small electrodes were affixed to the inner surface of the main portion of this transducer in such a way that lip closure completed an electrical circuit, an event which was recorded on a strip-chart recorder; the duration of each pattern, and of each lip closure, and any number errors within the pattern (for example, the substitution of five-pause-two for the correct pattern), could thus be quantified. Closure of the circuit also triggered a system of waveform and pulse generators so as to produce a pulse that was subsequently modified with regard to timing and amplitude and transduced by the earphones or bone conduction vibrator.

All subjects were first practiced and recorded under (a) normal feedback; that is, the subject was permitted to practice aloud the syllable (mə) in the specified pattern, (b) no auditory feedback (NAF); the subject now practiced the task without voice, and (c) synchronous bone-conducted auditory feedback (SAF) of the click signal at a sensation level of 40 dB; this same SAF condition was interposed between each two experimental conditions. This practice period insured that the subject identified the task as speech-related. In addition, these performances provided information which was considered important to the interpretation of the results of this study.

The sixteen experimental conditions, presented in random order, included:

a. synchronous bone-conducted auditory feedback of the click signal presented at a 40-dB sensation level and followed by a delayed binaural air-conducted click signal at intervals of 140 and 200 msec. The delayed click was at a sensation level of 40, 50, 60, and 70 dB. In other words, the DAF signal in this sequence equalled the SAF signal in intensity or was 10, 20, or 30 dB higher. This group of conditions, referred to hereafter as SAF/DAF, was intended to resemble delayed speech feedback most closely.

b. delayed, binaural air-conducted auditory feedback of the click signal, presented at 140 and 200 msec following lip closure and at 0-, 10-, 20-, and 30-dB sensation levels. These experimental conditions are referred to hereafter as DAF.

Thus, each condition was a combination of delay time, intensity level, and click condition (SAF/DAF or DAF). The delay times of 140 and 200 msec were chosen since previous investigations have indicated that delay times in this region were most disturbing to normal speakers and most beneficial to stutterers under DSF (7, 86).

Relevant research (5, 36) and prior experimentation had led to the conclusion that a click presented under the SAF bone-conducted condition at a sensation level of 50 dB would be closer to equal loudness with normal bone-conducted speech feedback of the syllable (me) in a group of subjects of the age range of this study (16-50 years). However, it was found that, for older subjects especially, the vibrations of the bone-conduction vibrator were quite noticeable at this level. In order that tactile sensations so introduced might not complicate the results, therefore, the bone-conducted SAF stimulus was presented at a 40-dB sensation level.

The delayed air-conducted click was presented binaurally in an attempt to simulate the conditions of delayed speech feedback most closely. It would, of course, have been possible to present the delayed click monaurally. However, in order to avoid stimulating both cochleae by the SAF signal, or the DAF signal at higher sensation levels, it would have been necessary to introduce masking noise. This, as has already been seen, would itself have an effect upon rate of performance which could hardly be separated later from that introduced by DAF.

The responses of the two groups of subjects were compared across feedback conditions with respect to:

a. pattern duration; the mean time taken to complete a pattern of four-pause-two silent lip closures computed over a total of five patterns.

b. lip-closure duration; the mean lip-closure time, computed over the total number of lip closures in five patterns.

c. number errors; the total number of pattern errors appearing in five patterns. These errors were later

> broken down by types, namely, omissions, additions, reversals, and marked changes of rhythm within the prescribed pattern.

Computation of these data were over five out of six recorded patterns only, since some subjects experienced fatigue if a greater number were introduced.

Research Questions

The following research questions were formulated for this investigation:

a. Do the stutterers show responses significantly different from those of the nonstutterers, in terms of pattern duration, lip-closure duration, or number of pattern errors, under delayed click feedback?

b. Do the stutterers show responses significantly different from those of the nonstutterers, in terms of pattern duration, lip-closure duration, or number of pattern errors, to increase of delay time under delayed click feedback?

c. Do the stutterers show responses significantly different from those of the nonstutterers, in terms of pattern duration, lip-closure duration, or number of pattern errors, to increase of intensity under delayed click feedback?

d. Do the stutterers show responses significantly different from those of the nonstutterers, in terms of pattern duration, lip-closure duration, or number of pattern errors, across the two kinds of delay condition, SAF/DAF and DAF?

Subjects

The experimental group consisted of fifteen stutterers between the ages of sixteen and fifty years, so diagnosed by the investigator and another speech pathologist, and so regarded by themselves and their families and associates. These subjects were selected from the therapy rolls of the University of Oklahoma Speech and Hearing Center and of other university speech and hearing centers in Oklahoma, and from high schools in Oklahoma City.

Individuals having a history indicative of neurological or psychiatric disorder or currently presenting either such disorder were excluded as subjects. Individuals were also excluded who:

a. presented a hearing loss of greater than 20 dB (by the ISO 1964 standards) in the poorer ear in the frequency range 500-2000 cps,

b. could not maintain normal diadochokinetic rates for (mə) over a five second period, or

c. could not maintain the pattern of voiced repetition of the syllable (mə) (---- --) in unison with a tape-recorded stimulus version without errors or blocking.

Fifteen normal speakers, matched with the stutterers on the basis of age, sex, race, and educational level made up the control group. Selection of these subjects was governed also by the criteria of absence of psychiatric or neurological disorders, or history thereof, hearing loss, and/or abnormal diadochokinesis or rhythmokinesis. In addition, it was stipulated that, so far as they were aware, the normal-speaking subjects should not have stuttered at any previous time in their lives. Both stuttering and normal-speaking subjects were to be naive with respect to the purposes of this study. Stutterers were not informed that they had been selected as subjects primarily because they stuttered, but many guessed that this was so for themselves.

The mean age of the stuttering subjects was 26.87 years, and the range 16 years to 49 years; the mean age of the nonstuttering subjects was 27.40 years and the range 16 to 49 years. There were fourteen males and one female in each group.

Instrumentation

Description

The instrumentation used in this experimental investigation included assemblies designed to afford the synchronous and delayed auditory feedback of the click signal and to make a permanent individual record of lip closures and the patterns formed by them (Figure 1). Testing was carried out in a sound-treated two-room suite.

Initially, attempts were made to affix the transducer electrodes to the lips themselves. The most successful of these involved the use of electrode tape to which very light insulated copper wire, stripped at either end, was soldered with the aid of a non-corrosive flux. It proved difficult, however, to arrange these electrodes so that slight lateral movements of the lower lip did not give rise to a double click on lip contact. The device remained in position well, but, because of individual differences in lip configuration, could not be affixed in a standard manner. An even greater objection was the distortion of lip configuration and altered tactile and kinesthetic feedback which this device introduced, and it was abandoned.

For the purposes of this investigation, then, a simple electromechanical device was designed to register lip closure and, at the same time, to interfere with normal lip movement patterns and associated sensory feedback as little as possible. Two strips of plastic, .02 inch in thickness, 7.3 cm in length, 1.2 cm in width, and rounded at one end, were separated by a cross-piece of the same thickness and width, and 3.4 cm long, inserted at the end furthest from the subject. Thin insulated copper wires (gauge #30) were run along opposing outer edges of the two strips and through an aperture, approximately .027 inch in diameter, which had been

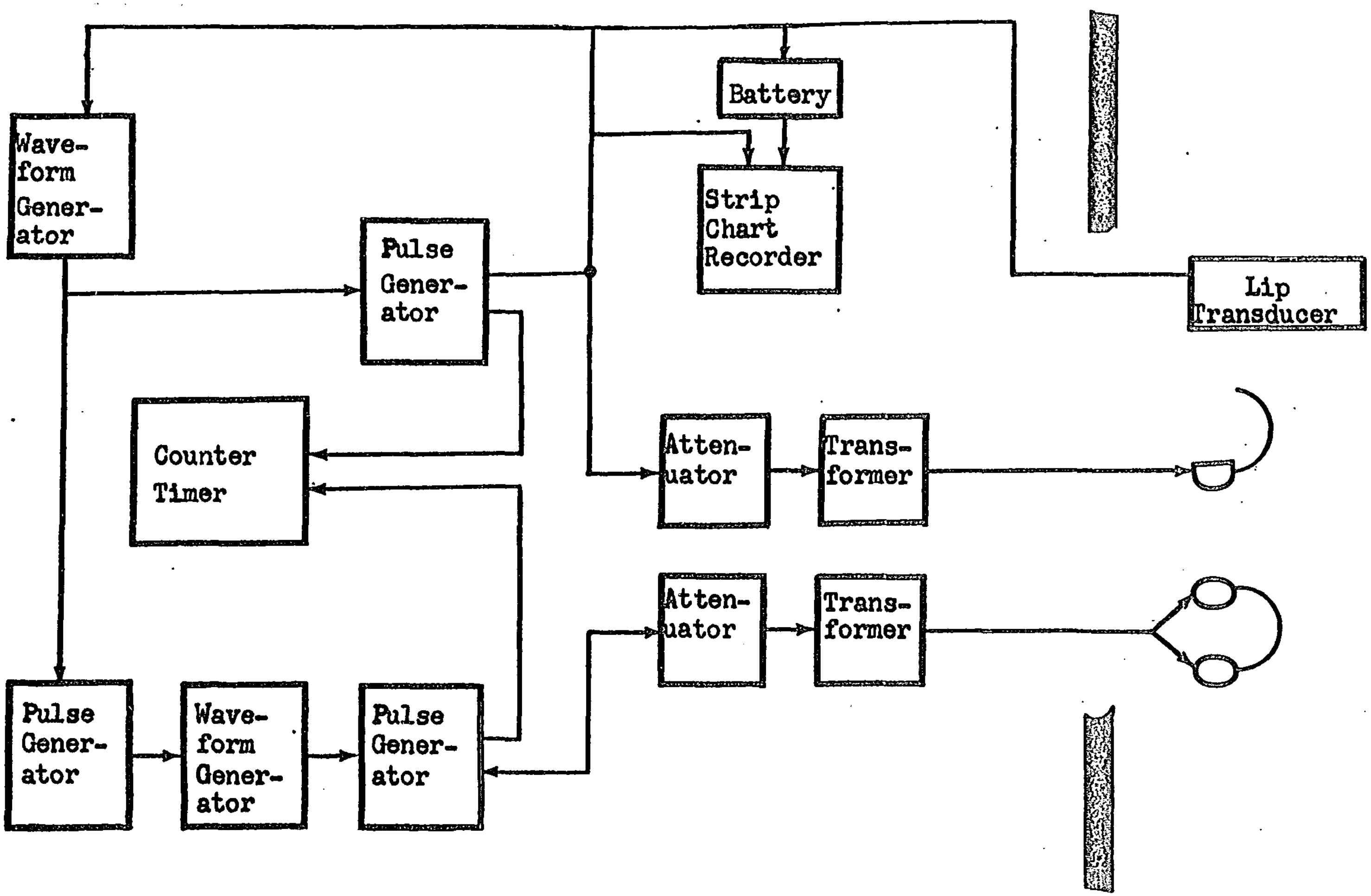

Figure 1.---Flow diagram of the experimental apparatus.

provided 6 mm from the rounded end of each, that is, the end to be placed nearest to the subject. A 6-mm portion of this wire, stripped of insulation, was arranged in a tight coil against the inner surface of each plastic strip and glued there with a conductive epoxy silver adhesive (Micro-circuits, SCE 42). The electrode-bearing strips were then shielded from breath-stream moisture, which tended to alter the almost infinite impedance associated with the manual switch of a waveform generator in the circuit so that triggering of the desired click did not take place. The shield or envelope employed was a rectangle, 8 x 7 cm, of very thin plastic (.0015 inch in thickness) folded in midline so that the folded margin was perpendicular to the long axis of the plastic strips.

Two further portions of plastic, 9.4 cm long, 4 mm wide, and .02 inch thick, were glued on the outer surfaces of the electrode-bearing strips over the plastic envelope so as to project beyond the strips by 2 cm. The rounded tips of these portions served as the lip pieces which were inserted between the subject's lips for a distance of 1 cm or slightly less. The whole device was mounted between sheets of foam rubber in a test-tube clamp, which was itself clamped to an adjustable microphone stand. The breadth of the inner plastic strips and the sheets of foam rubber damped the device sufficiently to prevent a rebound and the appearance of a second click upon lip opening. Adjustments of the clamp were made during the initial practice period to insure that contact of the electrodes would take place on lip closure and only on lip closure and that the rebound referred to above would not occur.

Contact of the electrodes on lip closure closed a circuit that included a 1.4-volt battery. Leads from this circuit were soldered to the terminals of the manual switch of a waveform generator (Tektronix, Type

162) in such a manner that closure of the circuit shorted the switch and activated a negative-going, 100-msec saw-tooth wave. This in turn triggered:

a. a pulse generator (Tektronix, Type 161), set to produce a 5-msec pulse at a minimum delay of .005 msec. This provided the click signal for all SAF conditions.

b. a pulse generator/waveform generator/pulse generator series (Tektronix, 161, 162, 161) which together produced a 5-msec pulse at a delay of 140 or 200 msec. This provided the click signal for the DAF conditions.

The output of each assembly, (a) and (b) above, was fed to a 1-dB step attenuator (Hewlett Packard, 500 ohm, Model 350 A) and through an impedance-matching transformer (United Transformer Co., Model LS33). The transformer in the SAF signal assembly was connected with a bone-conduction vibrator (Radioear, 10-ohm, B 70 A) fixed to an adjustable Maico headband. The transformer in the DAF signal assembly was connected by a Y-cord with the TDH 39 10-ohm earphones of a headset.

Closure of the 1.4-volt battery-operated circuit was also used to trigger a strip chart recorder (Sanborn, Model 60 1300 B), the tape of which was driven at 50 mm per second. Lip closure was recorded on one channel of this recorder, and the output of the pulse generator of the SAF signal assembly was recorded on a second channel for monitoring purposes. A third channel provided one per second pulses for the calibration of chart speed.

Calibration

At the beginning and end of the investigation, an audio oscillator (Hewlett Packard, Model 201 CR) and an artificial ear, comprised of a condenser microphone (Western Electric, 640 AA), an NBS 9A coupler, and a condenser microphone complement (Western Electroacoustic, Type 100 D/E) and connected with a vacuum tube voltmeter (Hewlett Packard, Model 400 H), were used to check the linearity of the attenuators and the frequency response of the earphones.

An oscilloscope (Tektronix, Type 532) in conjunction with the artificial ear, or an artificial mastoid (Beltone, Type M/5A) with its cathode follower, were used to visualize the click stimulus as it was transduced by the earphones and the bone-conduction vibrator. For this purpose, the output of the first waveform generator in the waveform generator/pulse generator complex was set on the recurrent mode and the repetition rate of both waveform generators on 100 per second in order to stabilize the image on the oscilloscope screen.

The click stimuli transduced by the left and right earphones were very similar. At the above repetition rate, the click reached an initial peak of just over seven volts and dropped back to baseline in a series of rapid vibrations of decreasing intensity over a 5-msec period. The click stimulus transduced by the bone-conduction vibrator reached a peak of approximately .06 volt and dropped to baseline in a series of three oscillations of decreasing intensity over a 5-msec period.

A counter-timer (Berkeley Universal Eput and Timer, Model 7350) was used throughout each experimental session to check the delay times of 140 and 200 msec in the DAF channel and at the beginning of each session to check the delay time (.005 msec) of the SAF channel.

A recently calibrated Beltone 10 A audiometer was available for pure-tone screening audiometry at the beginning of the experimental session. A Wollensak magnetic tape recorder, operated at a speed of 7.5 ips, was used to present the series of voiced syllable-repetition patterns to the subject at the beginning of each session.

Procedure

At the beginning of the experimental session, each subject submitted to pure-tone screening audiometry across the frequencies 250-8000 cps at a 20-dB hearing level (by ISO 1964 standards). No subject was retained whose threshold in the poorer ear exceeded this criterion in the frequency range 500 to 2000 cps.

Subjects meeting this criterion were then instructed, "I am going to ask you to repeat the syllable (mə), not merely in a long series, one after the other, but in a pattern. This pattern will be of four syllables followed by a pause followed by two syllables like this" - (here the investigator demonstrated the pattern several times, maintaining a constant rate and pitch throughout) - "I would like you to take a breath between each pattern. So that you will hear the pattern in the same way exactly as everyone else in this study, I have recorded it. Please listen carefully to the pattern one or two times, then repeat it along with the recording, until I ask you to stop."

The subject then listened as directed to the recorded stimulus patterns, uttered in a monotone at a mean rate of 1284 msec per pattern, and repeated at least six of these patterns in unison with the recorded version. Occasionally it was necessary to repeat the instructions and replay the recording.

The subject's attention was now drawn to the lip pieces of the transducing device and he was asked to practice the pattern as he had already produced it with the head positioned and the height of the microphone stand adjusted so that the lips closed at the required distance (1 cm or slightly less) along the projecting lip pieces. Once he had become accustomed to producing voiced syllable patterns with the lip pieces correctly positioned between the lips, he was given the following instruction: "Now please go through the same pattern without voice; that is, I want you to repeat the sound (mə) in the pattern we have practiced, but this time so quietly that you cannot hear yourself at all."

It was sometimes necessary at this point to caution the subject not to close the lips following conclusion of one pattern and before commencement of the next. The subject was further requested to watch himself in a hand-held mirror as he alternated in practice between the voice and no-voice conditions to insure that the movements of the articulators both looked and felt the same as he did so.

The subject was then advised that a series of six sets of patterns, three under normal auditory feedback (voiced) and three under no auditory feedback (NAF), each set comprising at least six four-pause-two patterns, were to be recorded. He was asked to stop and start on hand signals from the investigator in the adjoining control room. The normal auditory feedback and NAF conditions were imposed on the subject in random order, approximately one minute's rest being allowed between conditions.

The bone-conduction vibrator was now positioned with the aid of the headband in the center of the forehead and the headset adjusted over this as comfortably as possible. The subject's binaural threshold was then obtained for both the air-conducted and the bone-conducted click stimulus, the operating mode of the first waveform generator of the complex being set on the recurrent mode. Immediately after this, the operating mode was set to one cycle (manual) and the attenuator of the bone-conduction channel adjusted to a level 40 dB above the subject's threshold. A further period of practice, in which the subject was allowed to alternate between use of voice and no use of voice, was now given in the experimental task under the SAF condition. He was then instructed that all future trials were to be undertaken "without voice, that is, so quietly that you cannot hear yourself at all."

Some subjects had difficulty in adjusting to SAF and it was found advisable to permit all subjects to continue in practice for a few additional minutes in the absence of the investigator. Three practice trials under SAF, each comprising six patterns and separated from the next by a one-minute rest period, were then recorded. If gross pattern errors appeared at this time, the subject was reinstructed and given a further practice period before re-recording.

Any incomplete lip closures, resulting in absence of the click feedback, usually became apparent to the subject at this point. This feature, for which the transducing device could not be adjusted to compensate, was typical of normal-speaking subjects in particular; efforts to compensate by the subject himself often resulted in a change in manner of lip movement, usually accompanied by increase of tension. Subjects who manifested these occasional incomplete closures were instructed to be sure to keep to the four-pause-two pattern but not to become unduly concerned if correct patterning with incomplete closure failed to trigger the click. In other instances, which were less frequent, breakdown in patterning led to failure of the triggering of the click. These were:

a. lip tremors, usually sufficient in number to give rise to errors of addition and occurring at a higher rate than ten per second, the frequency limit of the experimental instrumentation at the delay times specified.

b. a series of prolonged lip closures, separated by minimal lip opening (20 msec or less). The contact renewed after such a brief tremor-like release appeared insufficient to trigger the first waveform generator of the waveform-pulse-generator complex.

No further comment was made upon pattern errors of any kind. The subject was now instructed, "I want you to repeat several patterns as before, each time I give you the signal to start. Continue with this until I give you the signal to stop. You will find as we go along that the click you are hearing will change from one time to another. Sometimes it will get louder, sometimes softer, even so soft that you can hardly hear it. Sometimes you will hear a double click and sometimes you will not hear the click just when you close your lips but a short time after. I want you to keep throughout to the pattern we have practiced, as best you can, and to keep throughout to the rate you have now found suitable, as consistently as you can." All subjects were further instructed that they should not tap with the finger of foot as they executed the experimental task. The experimental conditions were then administered according to the previously randomized schedule, one minute's rest being allowed between each condition and the next.

Following completion of the subject's experimental performance, he was invited to comment on his experience under the experimental conditions. He was then interviewed briefly, the following questions being asked:

a. Is there anyone else in your family who stutters or has stuttered at anytime in the past?

b. Do you suffer, or have you ever suffered from epilepsy or convulsions (where it was felt to be necessary, the words "that is, falling fits or spells" were added)?

c. Have you ever had a serious head injury? If the subject answered in the affirmative, he was asked to comment on this in some detail.

d. Do you suffer from severe headaches which are being investigated by your doctor? No subject answered this question in the affirmative.

e. As far as you are aware, do you have any neurological disease or disorder?

f. Are you under psychiatric treatment, or have you ever undergone psychiatric treatment?

These questions were asked at the end rather than the beginning of the investigation, even though this sometimes meant that data already taken had to be rejected, since it was felt that their introduction earlier might produce sufficient anxiety to influence performance. The same was felt to be true of the clinical test of diadochokinesis.

Following the short interview, the subject was asked to repeat the syllable (mə) "not to a pattern this time, but simply one after the other as fast as you can go until I tell you to stop." The number of syllables produced was counted over each of three five-second periods, timed by stop-watch. The norms applied in judging the subject's performance on this task were derived from those published by Irwin and Becklund (52) for 15-year-olds for the sound (pə). The mean rates in this instance are given as 5.44 for girls and 5.86 for boys. The mean lower tolerance limits, beyond which 2-1/2% of the population would be expected to fall, are given as 4.13 in the case of girls and 4.18 for boys. Subjects were therefore regarded as having met the criterion for this task if they were able to produce more than 20 syllables on the best of three five-second periods. Only one subject, a stutterer, failed to meet this criterion.

Summary

It was the purpose of this investigation to compare stutterers and nonstutterers on patterned, voiceless repetition of the syllable (mə) under varying conditions of delay, intensity, and click arrangement in auditory feedback. Responses were assessed in terms of pattern duration, lip closure duration, and pattern disruption, and the two groups of subjects compared with respect to:

a. responses under SAF/DAF at the two delay times and four intensity levels employed.

b. responses under DAF at the two delay times and four intensity levels employed.

As an aid to interpretation of the experimental data, the subjects' normal auditory feedback, NAF, and SAF responses were also measured and compared. Implications of the results were to be studied carefully, particularly with the aim of rejecting or accepting the research hypothesis that sensory feedback functioning, as it is revealed in responses to certain auditory feedback conditions, is different in stutterers and nonstutterers.

CHAPTER IV

RESULTS OF THE INVESTIGATION

Analysis of Data Obtained under the Experimental Conditions

The data obtained under the experimental conditions were analyzed by a partially-nested analysis of variance with factorial arrangement of treatments. The three variables measured, pattern duration, lip-closure duration, and number of pattern errors, were not independent; increasing lip-closure duration or the presence of errors of addition, for example, tended to occur with increased pattern duration. While this interdependence modified to some extent the level of significance of the F ratios obtained, the analysis of all three measures was considered justifiable in an exploratory study of this nature.

It had originally been intended that the scores obtained under the SAF condition, presented by bone conduction and preceding each experimental delay condition, should be employed as a reference criterion and that difference scores, that is, differences between these reference scores and those obtained under the immediately succeeding delay conditions, would comprise the primary experimental data. An unexpected feature of the results obtained, however, was the number of errors made by both stutterers and nonstutterers under the SAF condition. Initial computation of difference scores involved both positive and negative numbers, and it became readily apparent that such results would be difficult to analyze statistically and to interpret. The raw scores obtained under each experimental condition were, therefore, selected for analysis rather than difference scores.

Pattern Duration

Pattern duration was measured to the nearest millisecond across the pattern envelope itself, that is, from the point where the deflection of the recorded trace registering the first lip closure rose from base-line to the point where the deflection registering the last lip closure began its steep return to base-line (Figure 2). Mean duration was computed across five consecutive patterns. The decision was made to employ this measure rather than interpattern time, that is, the distance between the onset of one pattern and the onset of the next, because some of the variation in this measure was felt to be attributable to differences in inhalation time. It was observed, however, that when click feedback was introduced, some subjects found it impossible to pause for breath between patterns, even after re-instruction on this point.

A summary of the analysis of variance for the pattern duration data is presented in Table 1. Inspection of this table reveals that the delay and intensity main effects were significant at the .05 level of confidence, while the pathology and click condition main effects were not. Of the interactions, only the delay-by-intensity interaction was significant; the pathology-by-intensity interaction approached statistical significance.

The significant delay main effect ($F = 60.91$) indicates that, for both stutterers and nonstutterers, pattern duration averaged over all

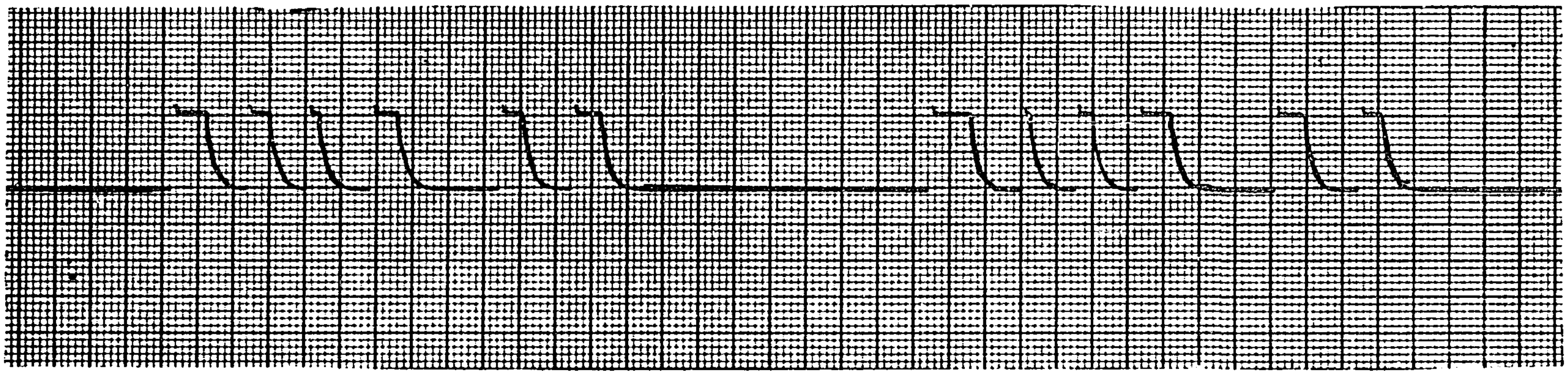

Figure 2.---Chart record of patterned syllable repetition.

TABLE 1.---Summary of the analysis of variance for pattern duration data for fifteen stutterers and fifteen nonstutterers.

Source	df	ms	F	F (.05)
Pathology (A)	1	1779011.01	2.20	4.20
Error E/A (Subjects within pathology)	28	807139.49		
Delay (B)	1	1434890.70	60.91	4.20
Pathology x Delay (AB)	1	21708.30	.92	4.20
Error BE/A	28	23559.26		
Click Condition (C)	1	3276.08	.12	4.20
Pathology x Click (AC)	1	22770.08	.86	4.20
Error CE/A	28	26512.58		
Delay x Click (BC)	1	49776.13	1.38	4.20
Pathology x Delay x Click (ABC)	1	13062.53	.36	4.20
Error BCE/A	28	36028.61		
Intensity (D)	3	466956.06	28.77	2.72
Pathology x Intensity (AD)	3	35759.73	2.20	2.72
Error DE/A	84	16230.84		
Delay x Intensity (BD)	3	77942.67	4.28	2.72
Pathology x Delay x Intensity (ABD)	3	13826.32	.76	2.72
Error BDE/A	84	18194.73		
Click x Intensity (CD)	3	10239.45	.55	2.72
Pathology x Click x Intensity (ACD)	3	384.58	.02	2.72
Error CDE/A	84	18520.61		
Delay x Click x Intensity (BCD)	3	15705.92	1.41	2.72
Pathology x Click x Delay x Intensity (ABCD)	3	5873.98	.53	2.72
Error BCDE/A	84	11102.47		
Residual	0	0.00		

click and intensity conditions was significantly greater under the 200-msec delay than under the 140-msec delay. Mean pattern duration under the 200-msec delay condition was 1585.15 msec and under the 140-msec delay condition, 1475.80 msec.

The significant intensity main effect (F = 28.77) indicates that, for both stutterers and nonstutterers, pattern duration averaged over all click and delay conditions increased significantly with increased intensity of DAF click presentation. The means for pattern duration across intensity levels are presented in Table 2.

TABLE 2.---The effect of intensity increase upon pattern duration.

Mean Pattern Duration in msec	Intensity Above Threshold or Level of Click SAF			
	0 dB	10 dB	20 dB	30 dB
	1447.64	1525.09	1553.43	1595.72

No attempt was made to compare the effects of the different intensity levels by applying a statistic such as the Duncan's Multiple Range Test, since, as a study of the delay-by-intensity and pathology-by-intensity interactions reported below will show, it is the trend of response rather than the responses to isolated treatments that is of interest here.

The pathology main effect was not significant; that is, the analysis indicates that pattern duration, averaged over all conditions, was not significantly different for stutterers and nonstutterers. Mean pattern duration over all conditions was 1591.35 msec for the stutterers and 1469.59 msec for the nonstutterers. It may be speculated that the difference in mean pattern duration failed to reach significance because of over-all subject variability with regard to this aspect of performance.

The click condition main effect also was not significant; that is, the analysis indicates that pattern duration, averaged over all subjects and all delay and intensity conditions, was not significantly different for the DAF and SAF/DAF conditions. Mean pattern duration under the SAF/DAF condition was 1527.86 msec and under the DAF condition, 1533.08 msec.

Only one interaction, that of delay-by-intensity, reached statistical significance ($F = 4.28$). This finding, illustrated in Figure 3, indicates that pattern duration, measured over all subjects and both click conditions, showed a significantly greater increase with increasing intensity at the 200-msec delay than at the 140-msec delay.

The pathology-by-intensity interaction approached statistical significance ($F = 2.20$) suggesting a tendency for stutterers to show greater increase in pattern duration, measured over all the delay times and click conditions, in response to increasing intensity than the nonstutterers. On examination of Figure 4, in which this interaction is illustrated, it can be seen that increase in pattern duration for the stutterers is particularly noticeable at the 10-dB level above threshold or above the level of click SAF; the increase is of lesser magnitude for the nonstutterers at this juncture. Furthermore, it appears that the discrepancy in pattern duration increase across subject groups becomes greater with increasing intensity. This would suggest that the pathology-by-intensity interaction might have reached statistical significance had an additional intensity level been included in the experimental design.

Lip-Closure Duration

Lip-closure duration was measured to the nearest .5 msec from

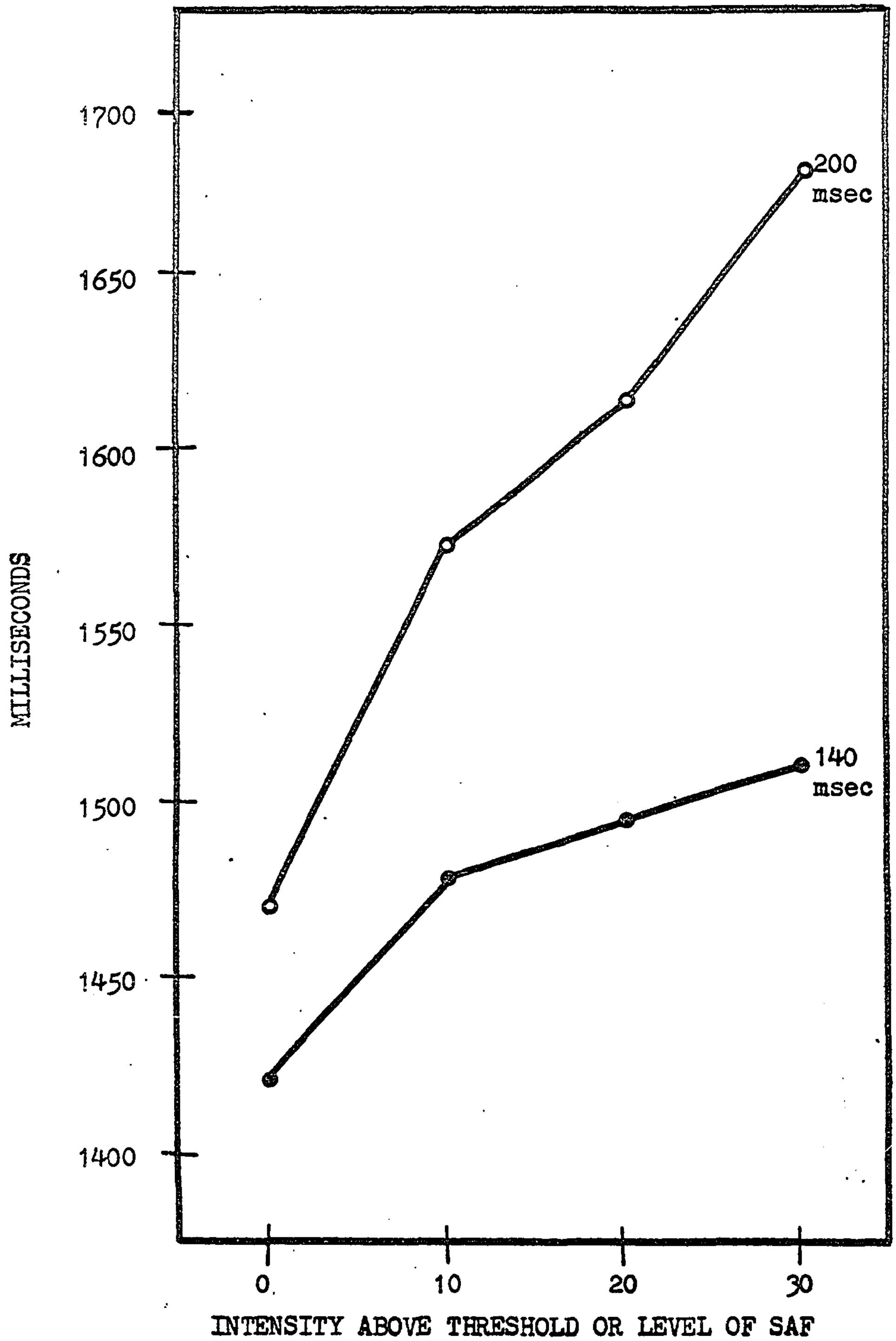

Figure 3.---Pattern duration increase for all subjects and under both click conditions at the 140- and 200-msec delay times.

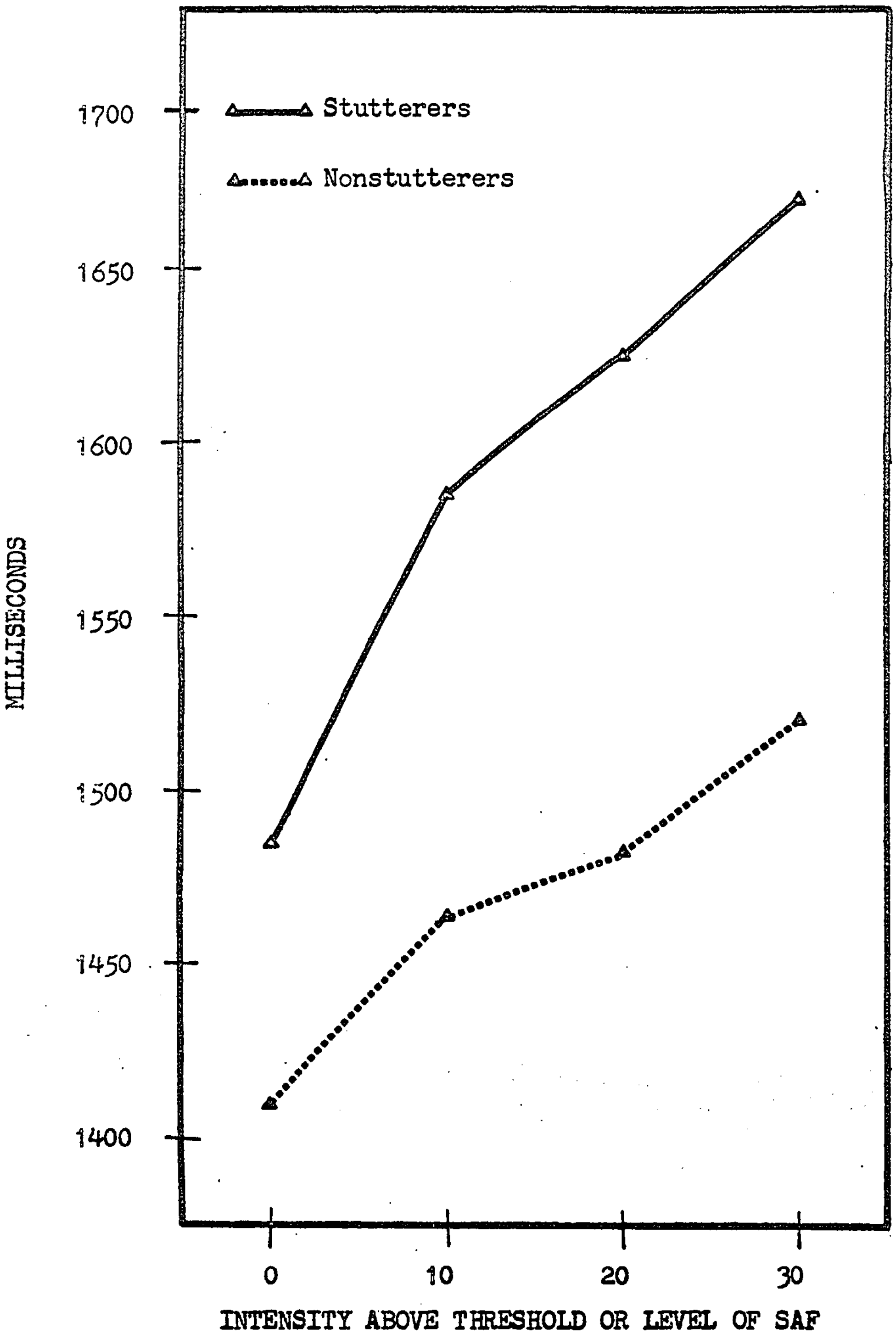

Figure 4.---Pattern duration increase for stutterers and nonstutterers in response to increasing intensity.

the point where the resulting deflection in the recording rose from baseline to the point where its steep return to baseline commenced. Mean lip-closure duration was computed across all closure deflections or "taps" present in five patterns; thus, errors of omission or addition were taken into account. Considerable variability was found on this measure, even within a single pattern, especially under the more disrupting conditions; lip closures of shorter duration tended to occur in mid-pattern rather than at either extremity. For certain subjects, and for one stuttering subject in particular, lip-closure duration showed a progressive increase across each pattern and sometimes across the five patterns measured for a particular condition.

A summary of the analysis of variance for the lip-closure duration data is presented in Table 3. Inspection of this table reveals that the delay, click, and intensity main effects were significant at the .05 level of confidence, while the pathology main effect was not. A third-order interaction, pathology-by-delay-by-click condition-by-intensity, was the only interaction to reach statistical significance.

The significant delay main effect ($F = 4.34$) indicates that, for both stutterers and nonstutterers, lip-closure duration averaged over all click and intensity conditions was significantly greater under the 200-msec delay than under the 140-msec delay. Mean lip-closure duration under the 200-msec delay condition was 99.13 msec and under the 140-msec delay condition, 96.55 msec.

The significant intensity main effect ($F = 3.64$) indicates that, for both stutterers and nonstutterers, lip-closure duration averaged over all click and intensity conditions increased significantly with increase of intensity of DAF presentation. The means for lip-closure

TABLE 3.---Summary of the analysis of variance for lip-closure duration data for fifteen stutterers and fifteen nonstutterers.

Source	df	ms	F	F (.05)
Pathology (A)	1	8291.72	2.46	4.20
Error E/A (Subjects within pathology)	28	3369.19		
Delay (B)	1	798.25	4.34	4.20
Pathology x Delay (AB)	1	292.97	1.59	4.20
Error (BE/A)	28	183.77		
Click Condition (C)	1	9319.22	34.02	4.20
Pathology x Click (AC)	1	514.60	1.88	4.20
Error CE/A	28	273.96		
Delay x Click (BC)	1	262.55	1.02	4.20
Pathology x Delay x Click (ABC)	1	105.47	.41	
Error BCE/A	28			
Intensity (D)	3	1148.07	3.64	2.72
Pathology x Intensity (AD)	3	174.04	.55	
Error DE/A	84	315.14		
Delay x Intensity (BD)	3	71.98	.59	2.72
Pathology x Delay x Intensity (ABD)	3	222.65	1.19	2.72
Error BDE/A	84	186.60		
Click x Delay (CD)	3	183.04	1.05	2.72
Pathology x Click x Delay (ACD)	3	297.95	1.71	2.72
Error CDE/A	84	174.45		
Delay x Click x Intensity (BCD)	3	265.65	1.37	2.72
Pathology x Click x Delay x Intensity	3	677.61	3.50	2.72
Error BCDE/A	84	193.51		
Residual	0	0.00		

duration across intensity levels are presented in Table 4. Again it is

TABLE 4.---Effect of intensity increase upon lip-closure duration.

	Intensity Above Threshold or Level of Click SAF			
Mean Lip-Closure Duration in msec	0 dB	10 dB	20 dB	30 dB
	93.27	98.73	100.04	99.31

the trend of responses to increasing intensity that is of interest rather than responses to isolated intensity treatments, and no comparison was made of these mean lip-closure durations.

The click condition main effect was highly significant ($F = 34.02$) indicating that lip-closure duration, averaged over all subjects and over all delay and intensity conditions, was greater under the DAF click presentation than under the SAF/DAF presentation. Mean lip-closure duration under DAF was 102.24 msec while that under SAF/DAF was 93.43 msec.

The pathology main effect was not significant; that is, the analysis indicates that lip-closure duration, averaged over all conditions, was not significantly different for stutterers and nonstutterers. Mean lip-closure duration for the stutterers over all conditions was 101.99 msec and for the nonstutterers, 93.68 msec. It may again be speculated that the difference in lip-closure duration failed to reach significance because of over-all subject variability with regard to this aspect of performance.

The pathology-by-delay-by-click condition-by-intensity interaction was significant ($F = 3.50$). This indicates that lip-closure duration varies differently for stutterers and nonstutterers in response to the click condition presented and to increase of delay time and intensity level. The interpretation of this interaction, illustrated in Figures 5 and 6, is far from clear, and, indeed, its statistical significance may be spurious. If this interaction is truly significant, it may reflect different shifts in compensatory mechanism for stutterers and nonstutterers.

Number of Pattern Errors

The total number of pattern errors occurring over five patterns were recorded for each subject, and it was this total number of errors that was subjected to statistical analysis. In addition, however, errors were broken down into certain categories for purposes of descriptive analysis. These categories were:

a. apparent omission (Figure 7), where, in the first part of the pattern, that is, within the first four recorded units of the pattern, an interval of sufficient duration to accommodate a missing tap appeared between successive taps. Careful observation of the subject indicated that these errors were related to incomplete lip closure rather than to loss of pattern or true omission. These errors tended to occur when the subject was proceeding at a rapid rate and were, in a sense, an artifact of the instrumentation, since the tension of the lip pieces could not be adjusted to compensate for incomplete lip closure without introducing a rebound of the mechanism and the generation of a second click immediately after lip opening. Where an omission occurred over the last two units, or second part of the pattern, the whole pattern was discounted, since a lack of definition of a single tap at this point as a recording of the fifth or sixth lip-closure movement precluded accurate assessment of pattern duration. This was not a problem in the first part of the pattern, where the first tap always appeared to be applied with greater force than succeeding taps, and omissions occurred in tap-positions 2, 3, or 4.

b. true omission (Figure 8), where three, rather than four, taps appeared in the first part of the pattern, with an interval appearing between successive

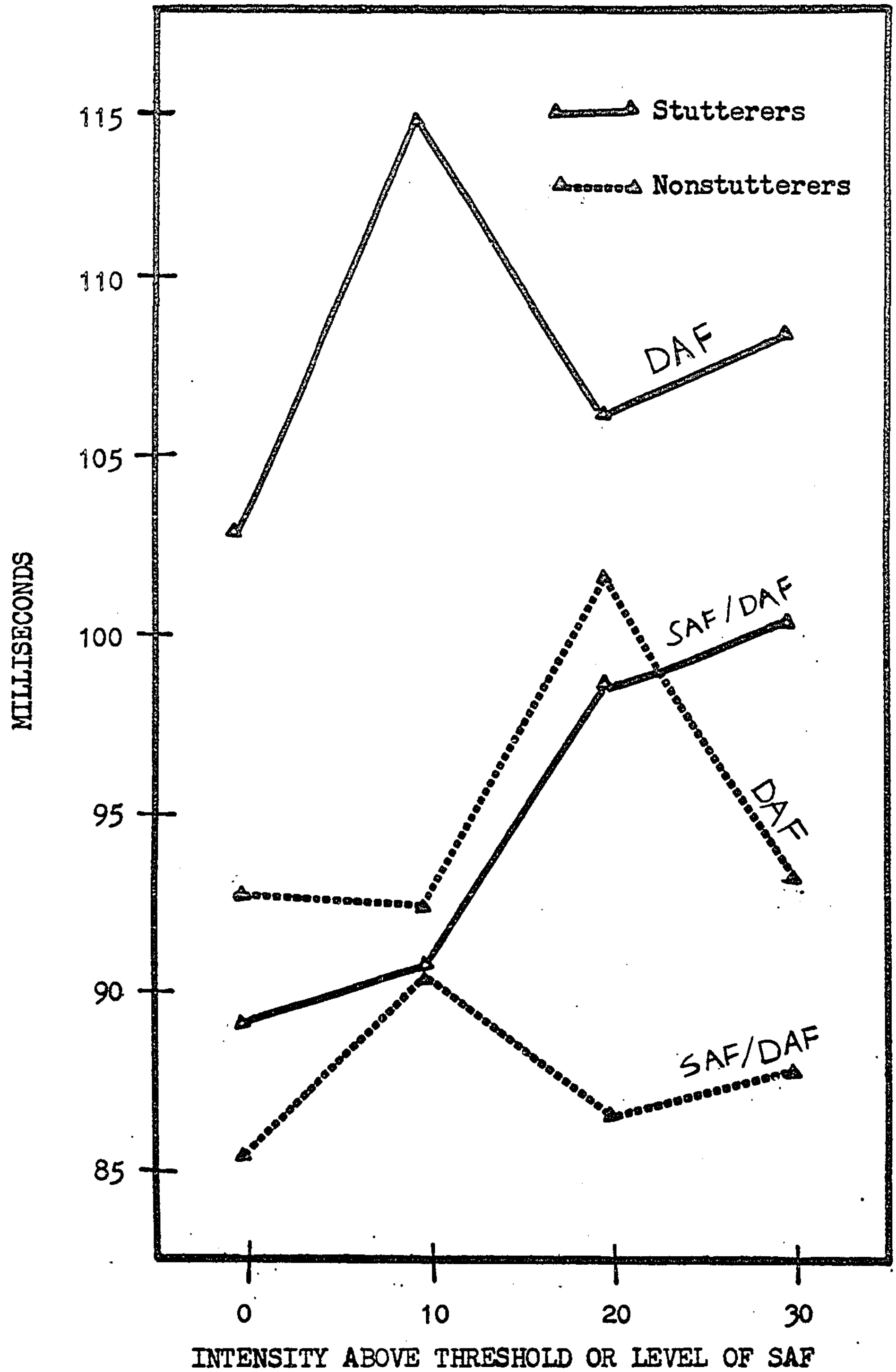

Figure 5.---Lip-closure duration in stutterers and nonstutterers in response to increasing intensity of SAF/DAF and DAF presentation at 140 msec.

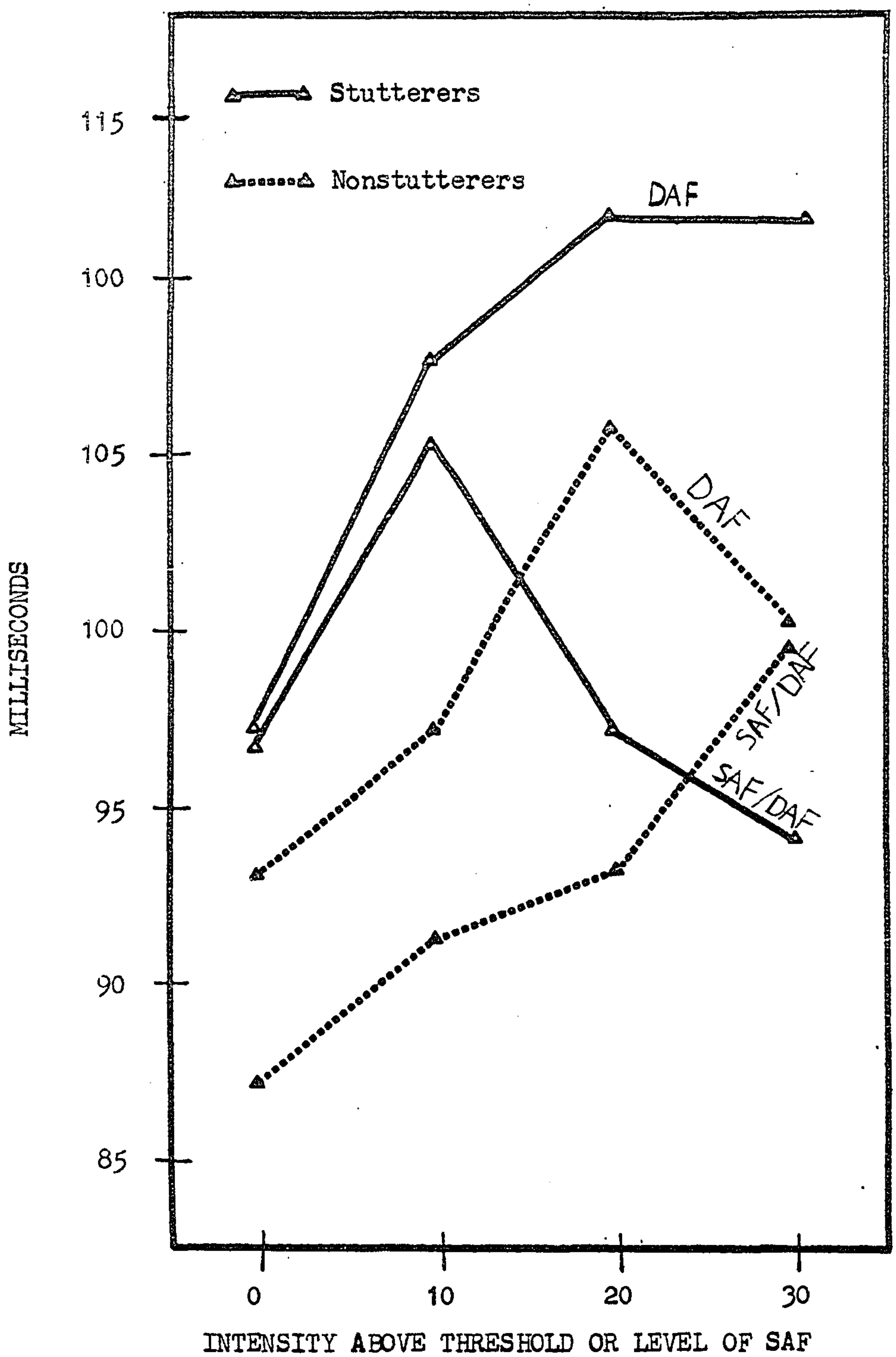

Figure 6.---Lip-closure duration in stutterers and nonstutterers in response to increasing intensity of SAF/DAF and DAF presentation at 200 msec.

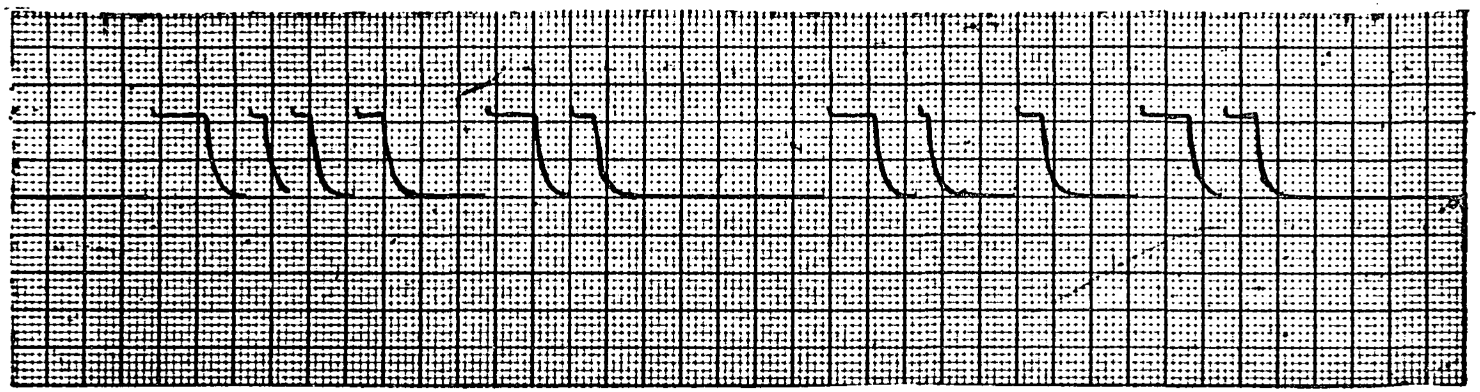

Figure 7.---Chart record of apparent omission, an error related to incomplete lip closure.

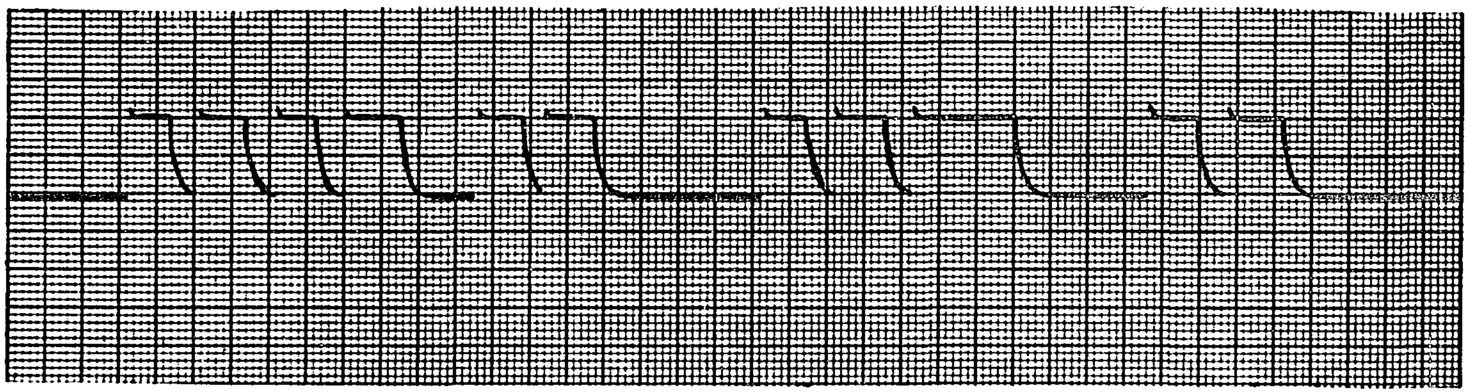

Figure 8.---Chart record of error of true omission.

taps of insufficient length to accomodate the missing tap. Usually lip closure was prolonged in these instances so that pattern duration was not appreciably altered. Careful observation of the subject indicated that these errors reflected a true loss of the pattern in which the subject had been instructed.

c. reversal (Figure 9), where a pattern of two taps followed by a pause followed by four taps was substituted for the correct pattern. Such reversals were given an error score of two, since neither part of the pattern was correct.

d. addition (Figure 10), where five or more taps appeared in the first part of the pattern, or three instead of two in the second part. Since lip-opening was occasionally of very short duration in these instances, the decision was made not to count an additional deflection in the recording as an error of this kind unless it were separated from the preceding deflection by at least 20 msec (that is, 1 mm on the chart).

e. rhythmic error (Figures 11 and 12), where the correct number of lip closures appeared but (i) the interval between two successive taps in the first part of the pattern was more than twice the interval appearing between any two other taps, (ii) the interval between the first and second part of the pattern was no greater than that appearing between successive taps in the first part of the pattern, or (iii) the interval between the two taps of the second part of the pattern was more than twice the longest interval found at this juncture across the four other patterns measured under the condition obtaining at the time; where this alteration of rhythm occurred, it was always as an isolated instance for the five patterns under consideration. The first of these rhythmic errors was by far the commonest. Occasionally errors of addition masked by incomplete lip closure may have been recorded as rhythmic errors, but, for the most part, loss of rhythm rather than complete loss of pattern was thought to be reflected here. In other instances, errors occurring in the first part of the pattern were given an error score of one, even though two additional taps might be present or two or more omissions.

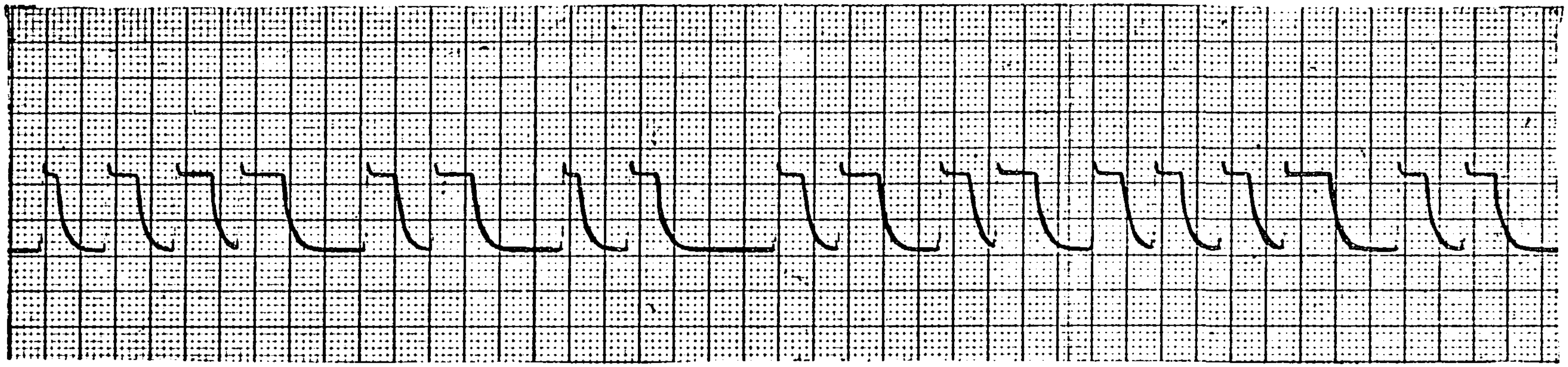

Figure 9.---Chart record of pattern reversal, occurring on the second pattern.

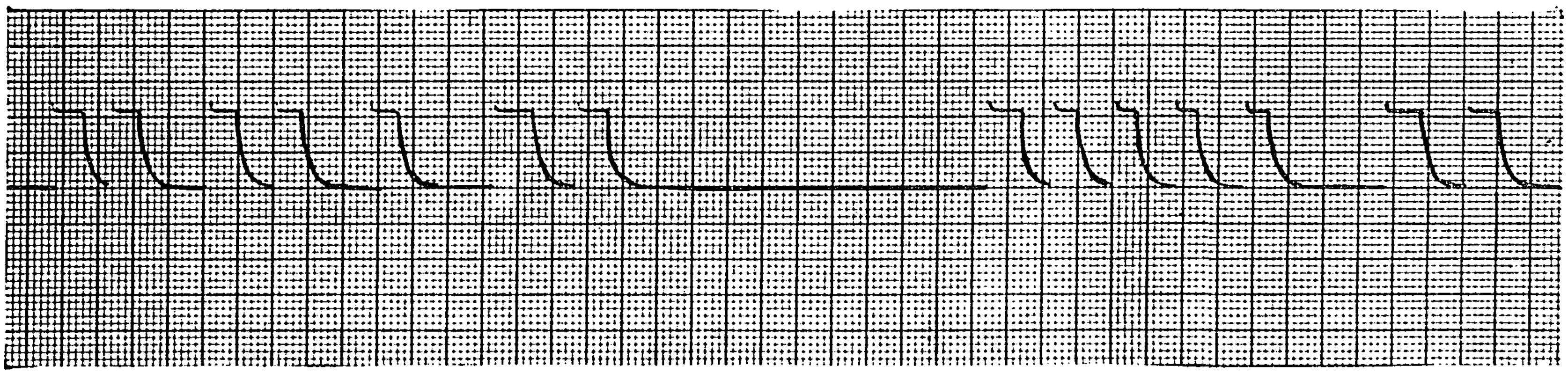

Figure 10.---Chart record of error of addition.

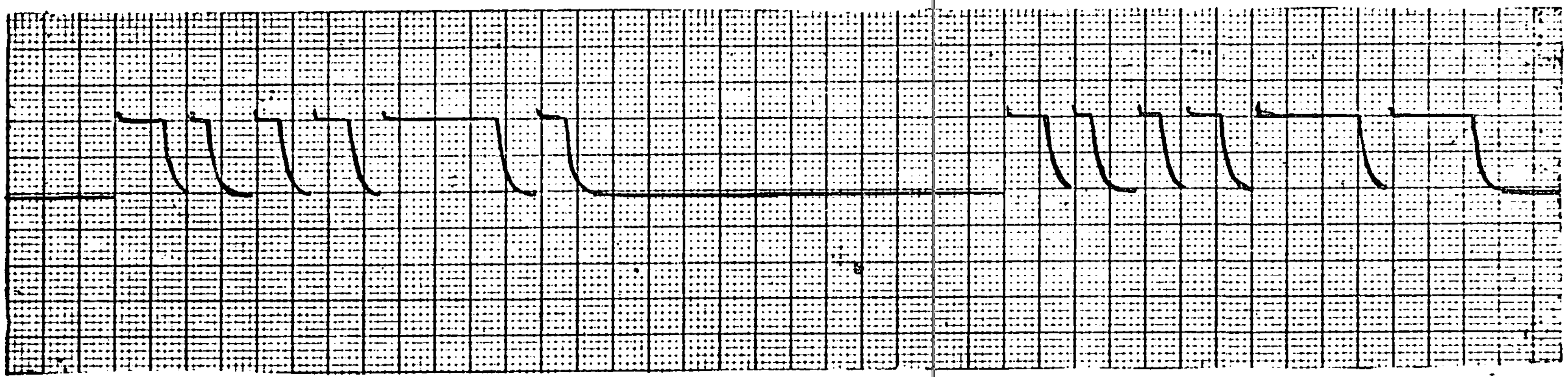

Figure 11.---Chart record of rhythmic error (1).

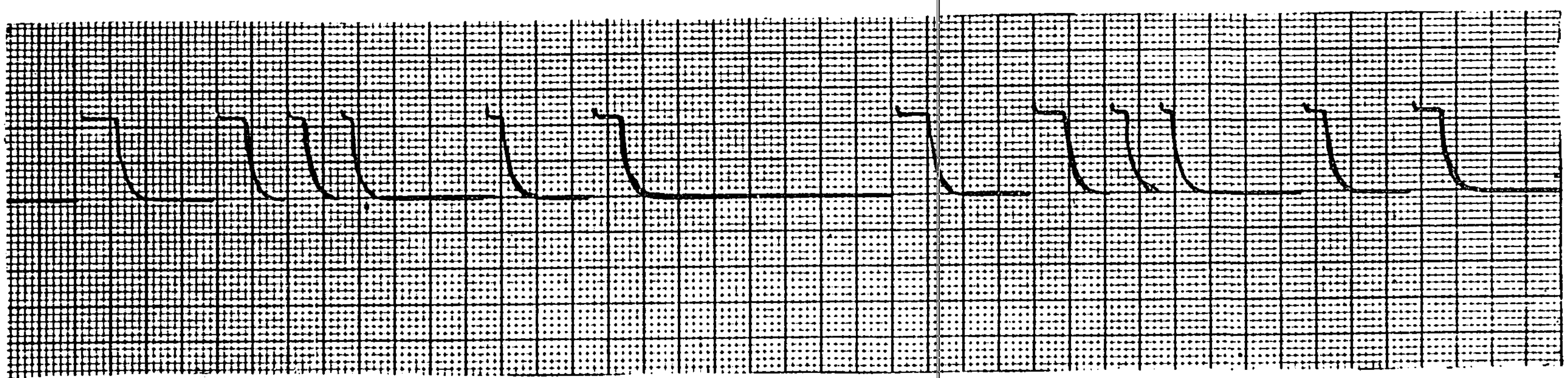

Figure 12.---Chart record of rhythmic error (2).

It was observed, in the course of this one testing session, that subjects tended to adopt a particular pattern of response to the delay conditions, for example, characterized by an increase in interval between patterns, by unusually long or short pattern duration, by progressive increase of lip-closure duration over each set of five patterns, or by the type or types of pattern error predominating. This last measure appeared to be related most closely to what might be called a "response signature". Interestingly enough, Seth (82) refers to a similar "signature" effect appearing in the graphic recordings of non-patterned or regular syllable-repetition in stutterers.

A summary of the analysis of variance for pattern error data is presented in Table 5. Inspection of this table reveals that, as for the lip-closure data, the delay, intensity, and click condition main effects were significant at the .05 level of confidence, but the pathology main effect was not. Of the interactions, only the delay-by-intensity and pathology-by-intensity interactions achieved statistical significance; however, the pathology-by-delay interaction approached significance.

The highly significant delay main effect ($F = 21.51$) indicates that, for both stutterers and nonstutterers, number of pattern errors averaged over all click and intensity conditions was significantly greater under the 200-msec delay than under the 140-msec delay. The mean number of pattern errors under the 200-msec delay was 2.44 errors per condition and under the 140-msec delay, 1.58 errors per condition.

The significant intensity main effect ($F = 11.96$) indicates that, for both stutterers and nonstutterers, the number of pattern errors averaged over all click and delay conditions increased significantly with increasing intensity of DAF click presentation. The mean number of

TABLE 5.---Summary of the analysis of variance for pattern error data for fifteen stutterers and fifteen nonstutterers.

Source	df	ms	F	F (.05)
Pathology (A)	1	1.41	.08	4.20
Error E/A (Subjects within pathology)	28	17.48		
Delay (B)	1	90.13	21.51	4.20
Pathology x Delay (AB)	1	15.41	3.68	4.20
Error BE/A	28	4.19		
Click Condition (C)	1	70.53	12.12	4.20
Pathology x Click (AC)	1	.67	.12	4.20
Error CE/A	28	5.82		
Delay x Click (BC)	1	1.20	.64	4.20
Pathology x Delay x Click (ABC)	1	3.68	1.97	4.20
Error BCE/A	28	1.87		
Intensity (D)	3	27.78	11.96	2.72
Pathology x Intensity (AD)	3	9.53	4.10	2.72
Error DE/A	84	2.32		
Delay x Intensity (BD)	3	6.38	3.82	2.72
Pathology x Delay x Intensity (ABD)	3	3.23	1.93	2.72
Error BDE/A	84	1.67		
Click x Intensity (CD)	3	2.37	.99	2.72
Pathology x Click x Intensity (ACD)	3	.33	.14	2.72
Error CDE/A	84	2.32		
Delay x Click x Intensity (BCD)	3	.03	.02	2.72
Pathology x Delay x Click x Intensity (ABCD)	3	1.69	1.24	2.72
Error BCDE/A	84	1.37		
Residual	0	0.00		

pattern errors across intensity levels is presented in Table 6. As in the case of the other measurements utilized in this study, no comparison was made of these mean error scores.

TABLE 6.---Effect of intensity increase upon number of pattern errors.

	Intensity Above Threshold or Level of Click SAF			
	0 dB	10 dB	20 dB	30 dB
Mean Number of Pattern Errors per Condition	1.45	1.96	2.00	2.63

The significant click condition main effect (F = 12.12) reveals that, for all subjects, the number of pattern errors averaged over all delay and intensity conditions was greater under the SAF/DAF condition than under the DAF condition. The mean number of pattern errors occurring under SAF/DAF was 2.39 per condition, and under DAF, 1.63 per condition.

The failure of the pathology main effect to achieve significance indicates that the number of pattern errors, averaged over all conditions, was not significantly different for stutterers and nonstutterers. The mean number of pattern errors made by the stutterers was 2.06 errors per condition, and by the nonstutterers, 1.95 errors per condition.

The significant delay-by-intensity interaction (F = 3.82), illustrated in Figure 13, reveals that, over all subjects and for both click conditions, the number of pattern errors showed a significantly greater increase with increasing intensity at the 200-msec delay than at the 140-msec delay. Of even greater interest perhaps is the significant pathology-by-intensity interaction (F = 4.10), illustrated in Figure 14. It will be seen that the stutterers showed a greater increase in number of

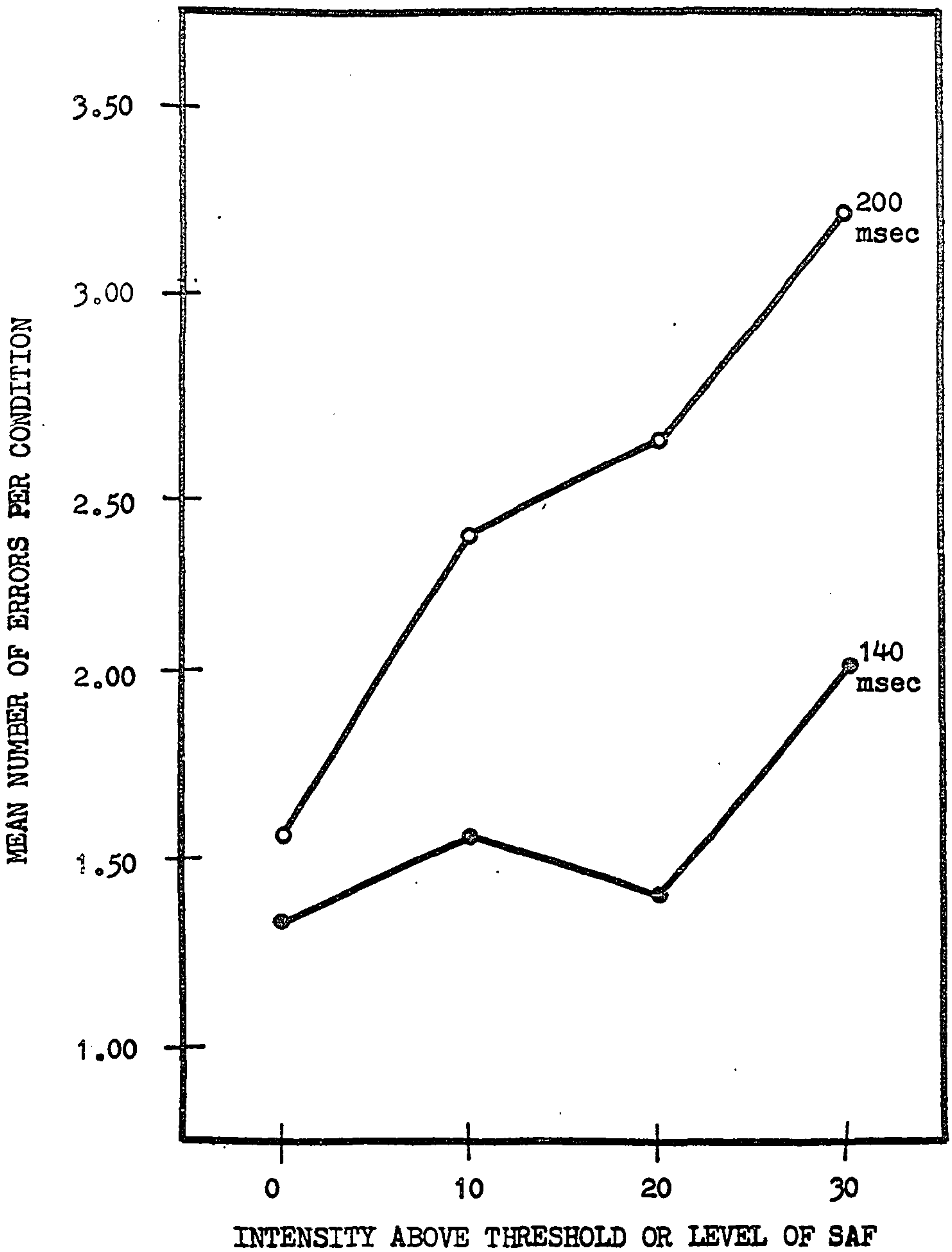

Figure 13.---Pattern error increase for all subjects and under both click conditions with intensity increase at the 140- and 200-msec delay times.

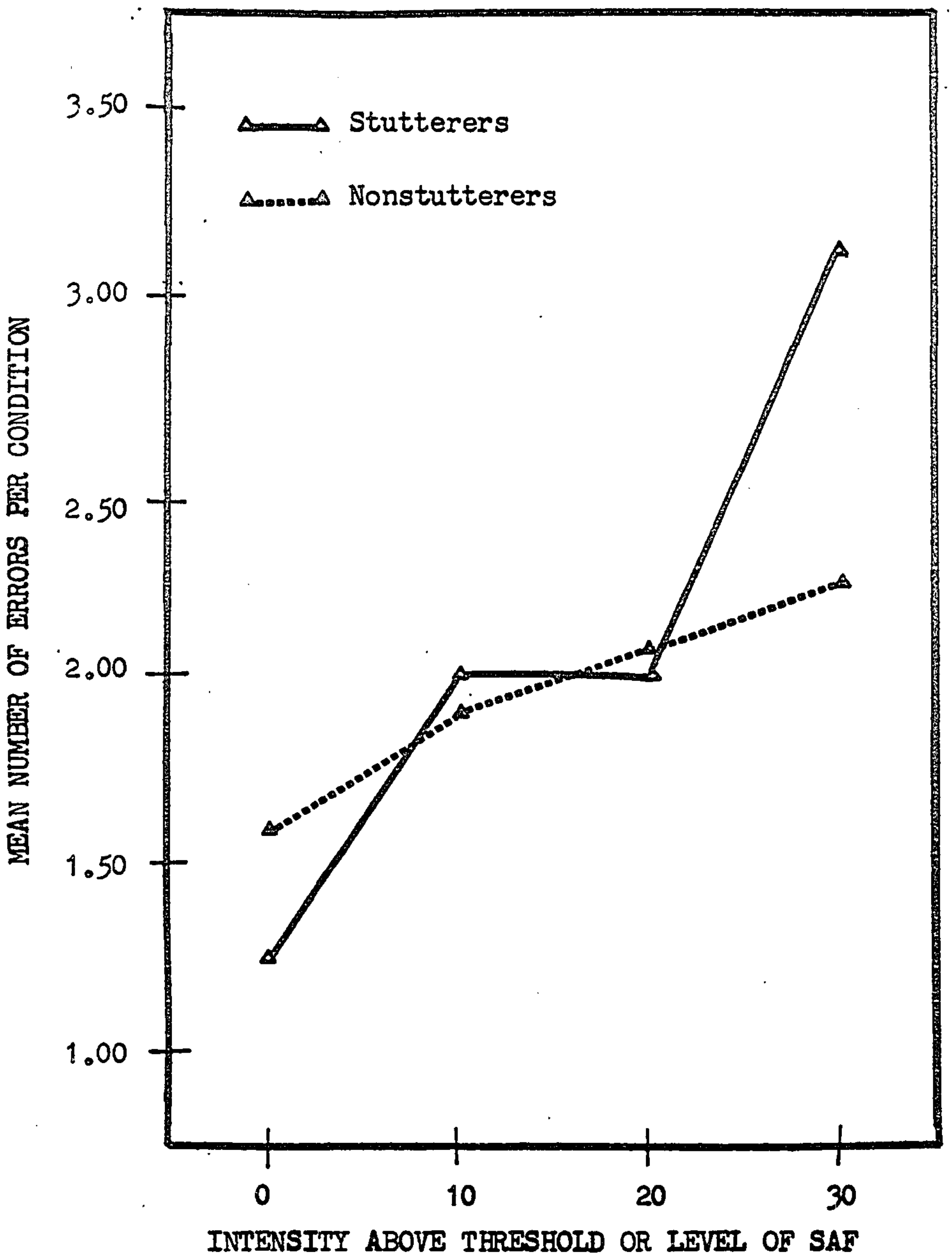

Figure 14.---Pattern error increase for stutterers and nonstutterers in response to increasing intensity.

pattern errors, measured over all delay times and click conditions, in response to increase of intensity than the nonstutterers.

The pathology-by-delay interaction, illustrated in Figure 15, approached statistical significance ($F = 3.68$). It will be seen that there is a tendency among stutterers, when the number of pattern errors is measured over all intensity levels and click conditions, to make fewer errors under the 140-msec delay and a greater number of errors under the 200-msec delay than the nonstutterers. This pathology-by-delay interaction might well have reached statistical significance had additional delay times, less than 140 msec or greater than 200 msec, been included in the design of this investigation.

The distribution of the types of pattern errors made under the experimental conditions appears to be somewhat different for stutterers and nonstutterers, as may be seen from Figure 16, although over both groups of subjects, errors of addition are the most frequent. Errors of apparent omission and rhythmic errors were more common for nonstutterers than stutterers; the reverse is true of errors of true omission and errors of addition. Reversals did not occur under the delay conditions. The distribution of the other four kinds of error was similar for stutterers and nonstutterers across both delay times and both click conditions.

Data Obtained in Practice and Between Experimental Conditions

As previously indicated, all subjects were practiced on the syllable-patterning task under normal auditory feedback, no auditory feedback (NAF), and synchronous auditory feedback (SAF) prior to the introduction of the experimental conditions. These practice responses were recorded and measured in terms of pattern duration, lip-closure duration,

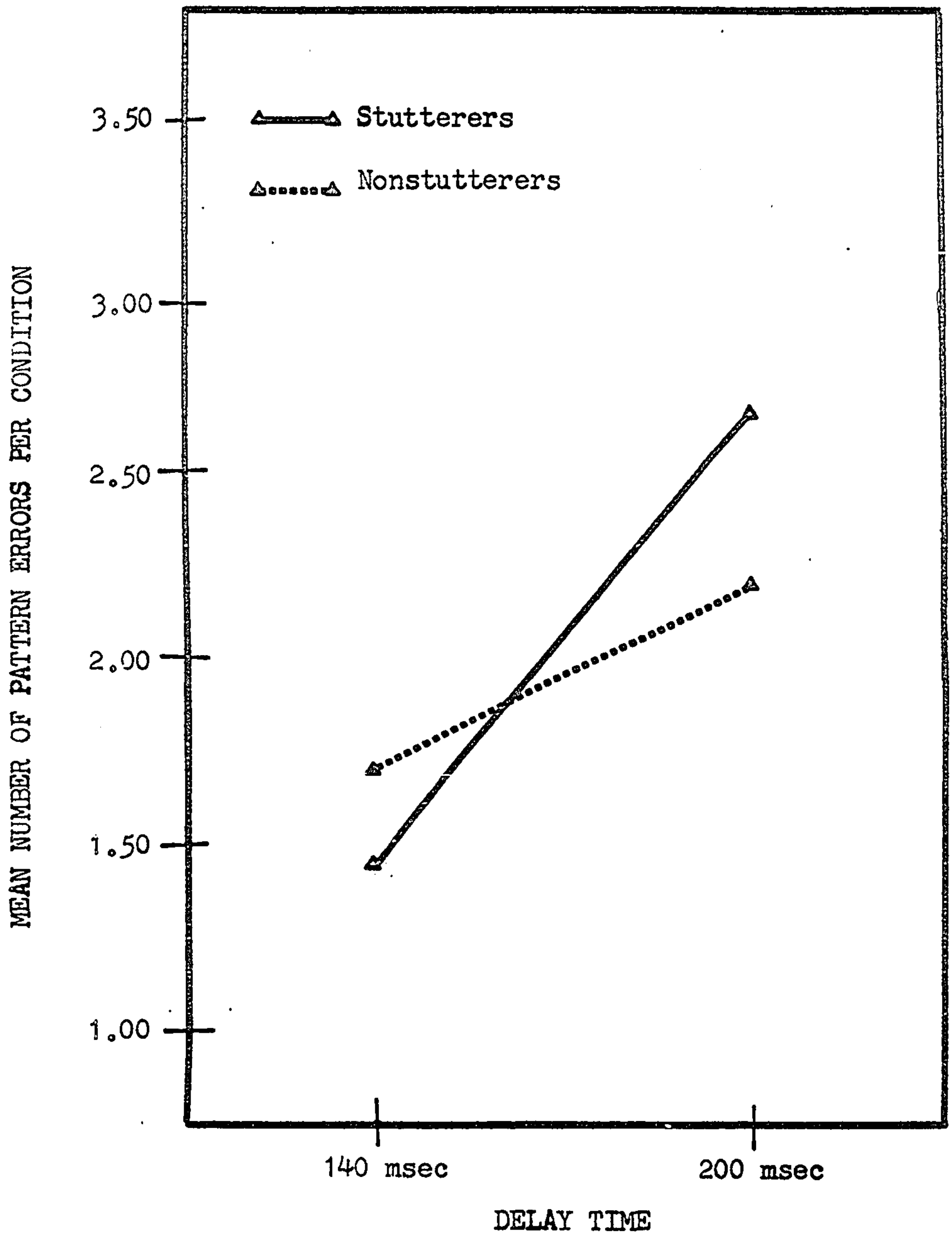

Figure 15.---Pattern error increase for stutterers and nonstutterers in response to increasing delay time.

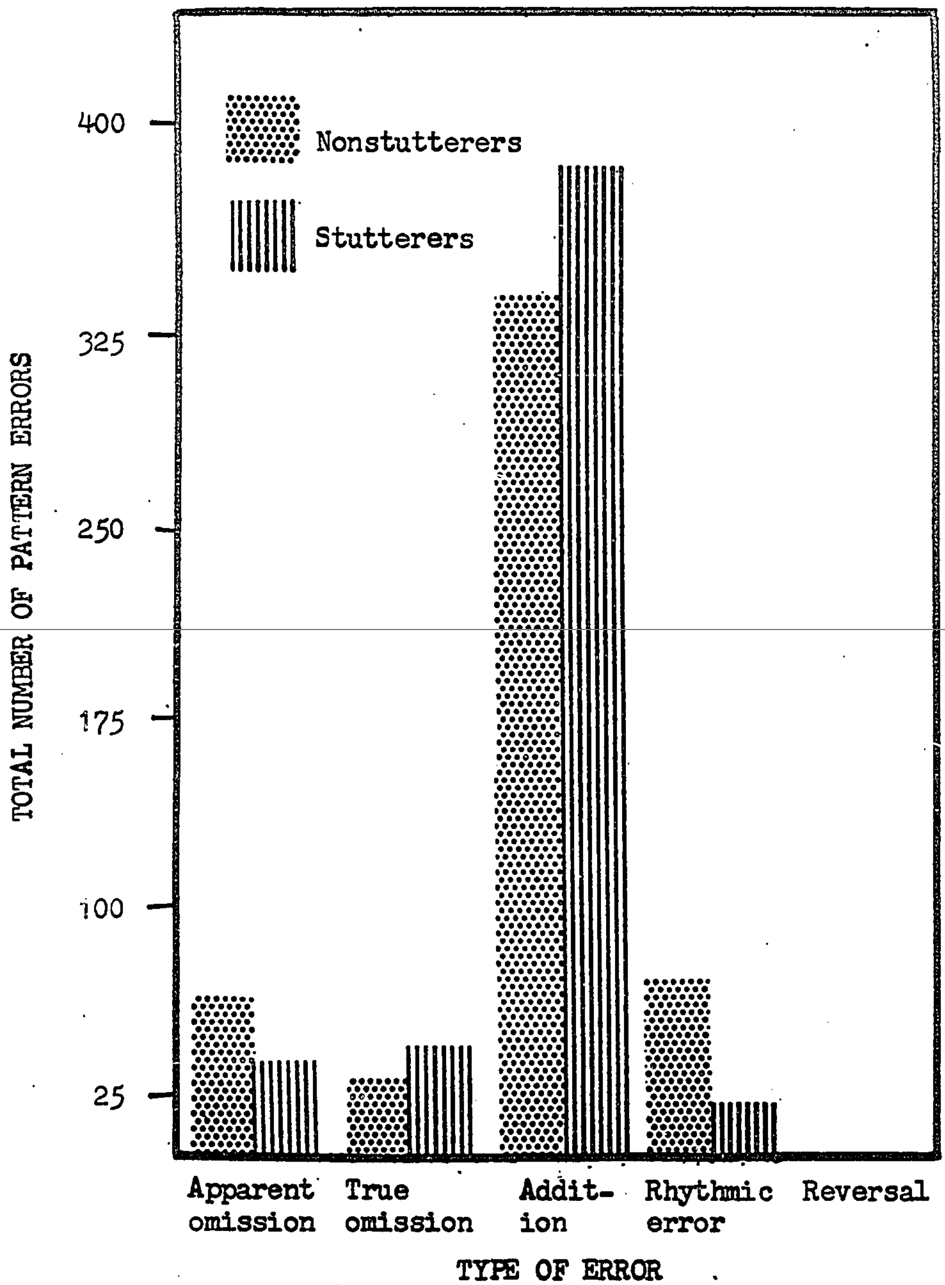

Figure 16.---Distribution of types of pattern error for stutterers and nonstutterers under delay conditions.

and pattern error. In order to insure subject identification of the experimental task as speech-related and to prevent any possible subject confusion, the three SAF trials were not randomized with the three trials given under both normal auditory feedback and NAF. For this reason, and since this was, indeed, a training period, the data obtained were not analyzed statistically. They are presented descriptively, however, since it is felt that they do contribute to interpretation of the experimental data.

Mean pattern duration for the stutterers was 1294.53 msec under normal auditory feedback, 1361.67 msec under NAF, and 1324.09 msec under SAF. Mean pattern duration for the nonstutterers was 1270.27 msec under normal auditory feedback, 1311.60 msec under NAF, and 1175.28 msec under SAF. It will be observed that for both groups of subjects, therefore, pattern duration was greater under NAF than under normal auditory feedback (See also Table 7, Appendix A). Indeed, in only two instances (stutterer #3 and nonstutterer #4), was the reverse true to any marked extent. The nonstuttering subjects show a tendency to decrease in pattern duration under SAF as compared with normal auditory feedback (Table 7, Appendix A). Indeed, for only one nonstutterer (#6) was the opposite true to any marked extent. Nine of the stutterers, on the other hand, manifested an increase of pattern duration under SAF.

Mean lip-closure duration for the stutterers was 101.07 msec under normal auditory feedback, 93.80 msec under NAF, and 85.00 msec under SAF. Mean lip-closure duration for the nonstutterers was 102.80 msec under normal auditory feedback, 99.93 msec under NAF, and 78.87 msec under SAF. Both groups of subjects, therefore, show a decrease in lip-closure duration under SAF as compared with normal auditory feedback. It was observed that under normal auditory feedback and NAF for both subject groups, the first tap in each part of the pattern (that is, tap #1 and tap #5) tended to be longer than the others. This was not true under SAF.

The mean number of pattern errors was computed over the three trials under each practice condition. Mean pattern error per trial for the stutterers was .71 error under normal auditory feedback, 1.00 error under NAF, and 1.13 errors under SAF. Mean pattern error per trial for the nonstutterers was .27 error under normal auditory feedback, .93 error under NAF, and .73 error under SAF. For both groups of subjects, therefore, the number of pattern errors showed an increase under both NAF and SAF as compared with normal auditory feedback.

In general, it was observed that, in spite of instructions to carry out the patterned, syllable-repetition task in such a way that tactile and kinesthetic feedback remained the same under SAF as under the normal auditory feedback, certain marked changes in patterning appeared under SAF which the subject seemed to be unable to avoid. He tended to go faster or slower than under normal feedback conditions, to keep the lips closed for a shorter time, to lose the pattern of lip-closure durations (long-short-short-short, long-short) where this was characteristic of his performance under normal auditory feedback and to a lesser extent under NAF, to make a greater number of errors than under normal auditory feedback, and to pause for a briefer period of time between patterns, often without taking a breath.

In an effort to minimize possible effects of one experimental condition upon the next, an SAF condition was made to precede each experimental condition; this interposed SAF condition is hereafter referred to as "buffer" SAF. Performances under "buffer" SAF were also recorded and measured in terms of pattern duration, lip-closure duration and pattern error. These data for stutterers and nonstutterers were analyzed by use of a paired t-test, with an .05 alpha level.

Mean pattern duration for the stutterers under "buffer" SAF was 1250.67 msec and for the nonstutterers 1342.40 msec. The difference between the two subject groups of 91.73 msec was not statistically significant ($t = 1.49$; $p > .05$). Mean lip-closure duration for the stutterers under "buffer" SAF was 90.29 msec and for the nonstutterers 81.75 msec. The difference of 8.54 msec did reach statistical significance ($t = 2.35$; $p < .05$). The mean number of pattern errors for the stutterers under "buffer" SAF was 1.01 errors per condition, and for the nonstutterers .85 error per condition. The difference of .14 error per condition was not statistically significant ($t = .40$; $p > .05$).

Under both practice SAF and "buffer" SAF the distribution of types of error was different for stutterers and nonstutterers, in much the same way as was reported for the experimental conditions (Figures 17 and 18). For both subject groups errors of addition are less prominent than under the delay conditions. Subject differences were related to the characteristic patterns of response, more easily identified in the records of certain individuals, which might, as under the experimental conditions, be termed a "response signature", persisting across all sixteen "buffer" conditions. This was not in all instances exactly similar to the "response signature" for the same subject under the experimental conditions, however. For example, the only stuttering subject who showed reversals under practice and "buffer" SAF, showed, rather, errors of addition under the experimental conditions. It may be of interest that five stuttering subjects and one nonstuttering subject made the highest error scores under the sixteen "buffer" SAF conditions. These six subjects were readily indentifi-

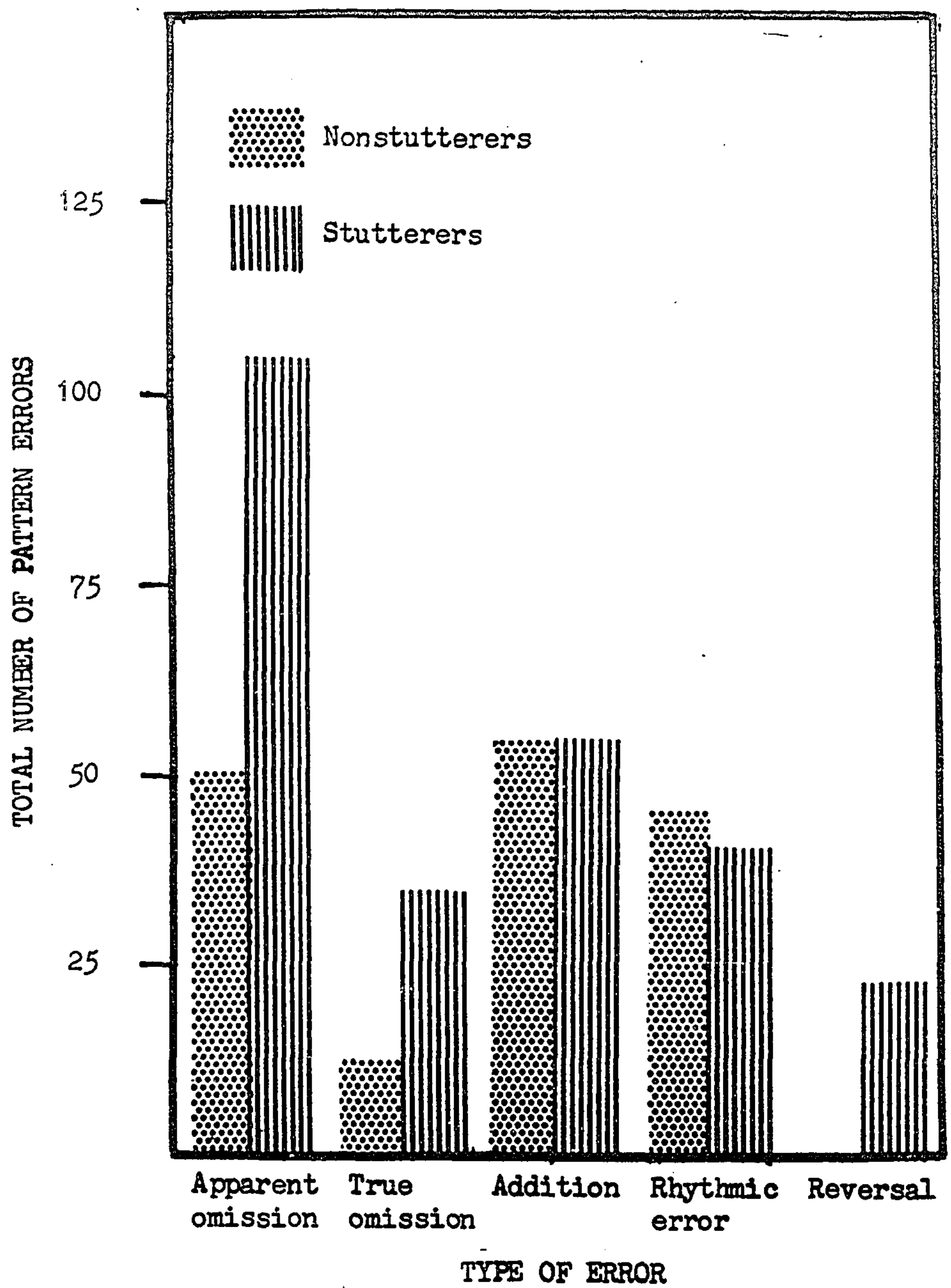

Figure 17.---Distribution of types of pattern error for stutterers and nonstutterers under practice SAF.

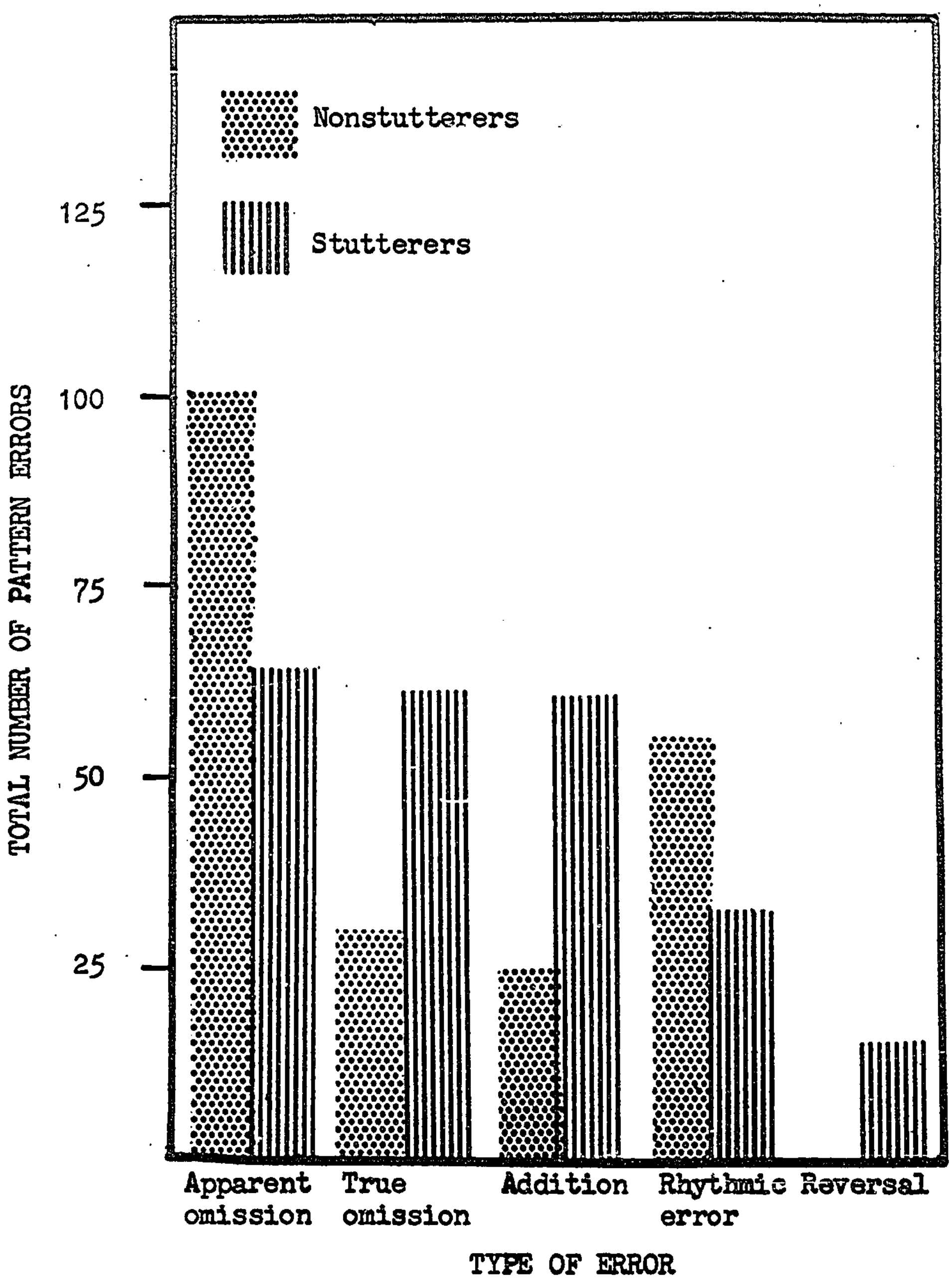

Figure 18.---Distribution of types of pattern error for stutterers and nonstutterers under "buffer" SAF.

able by visual inspection of their recorded performance. Three of these stutterers made a lower pattern error score under the delay conditions than under "buffer" SAF, a feature to be found in no nonstutterer's record.

Reliability

Pattern duration and number of pattern errors were measured and averaged on two separate occasions. Errors in measuring made on the first occasion were of a magnitude of between 1% and 2% and occurred on the average of one out of every twenty patterns measured. Since it entailed a much more laborious procedure, however, the measurement of lip-closure duration was undertaken on one occasion only. Remeasurement of a random selection of 15% of these lip-closure durations revealed a mean error of measurement on the recordings of .92 msec, or just under 1%; the range was ± 2 msec, and the mean difference between the first and second measurements was exactly zero.

For purposes of estimation of reliability, two stutterers and two nonstutterers, selected at random from their respective subject groups, were recalled for replication of the entire experimental session. Their scores for the first and second experimental sessions are shown in Tables 8, 9, and 10 in Appendix A.

In the case of the two stutterers and one of the nonstutterers, pattern duration showed a decrease over almost all experimental conditions on the second experimental session as compared with the first. This decrease was greater for all three subjects for higher intensity and longer delay conditions than lower intensity and shorter delay conditions; it tended to be greater over all conditions for the two stutterers than for the one nonstutterer. Relationships across different types of condition, however, remained essentially the same; for example, where pattern duration had increased in the first experimental session under the three initial NAF trials as compared with the three initial trials under normal auditory feedback, this was also true in the second experimental session. One exception to this was the decrease in pattern duration under the three practice SAF trials as compared with those under normal auditory feedback on the second experimental session for stutterer #1; an increase in pattern duration was observed across these two types of condition on the first experimental session.

For the second nonstutterer (#14), who presented "borderline" diadochokinetic rates, made a high error score under all conditions on the first experimental session, and had expressed anxiety over this and a determination to "beat the test", the reverse tendency was seen; that is, pattern duration showed an over-all increase for the second experimental session as compared with the first. Again, general relationships remained the same over all conditions on the second occasion as on the first.

In the case of the two stutterers, lip-closure duration showed an over-all decrease for the second session as compared with the first. General relationships of scores obtained across different types of condition appeared to show some alteration, apart from the tendency for lip-closure duration to decrease under the practice SAF conditions as compared with the normal auditory feedback condition which persisted. In the case of the two nonstuttering subjects, lip-closure duration tended to increase over all conditions on the second trial as compared with the first, and relationships across different types of condition appeared to show some alteration apart from the tendency for lip-closure duration to decrease under practice SAF as compared with normal auditory feedback which persisted. Nonstuttering subject #14 showed the greatest increase, under higher intensity and longer delay conditions, in closure duration.

For all subjects, number of pattern errors remained essentially the same across the two sessions, except under delay conditions where it decreased somewhat in the case of one stutterer (#1) and the two normal-speaking subjects and increased somewhat in the case of the second stutterer (#3). Over all conditions, errors of omission related to incomplete lip closure tended to increase with decrease of pattern duration. The predominance of certain kinds of error tended to remain, contributing, together with the reappearance of the tendency toward "crowding" of patterns produced under the SAF condition, to the persistence of the "response signature" referred to above.

In general, these results, which were not analyzed statistically since in most cases the trend was quite unequivocal over all conditions, suggest that: (a) pattern duration tends to decrease over conditions in a second experimental session, (b) the number of pattern errors tends to decrease somewhat under delay conditions in a second experimental session, and (c) lip-closure duration is an unstable measure, varying in a different manner over a second experimental session, as compared with a first, in ways not always understood; this variability or instability may be related to defects in the transducer or to the fact that lip-closure duration reflects two or more compensatory mechanisms shifting under different experimental conditions, and/or that it tends to vary with pattern duration.

Summary

The results obtained in this investigation may be summarized as follows:

a. Mean pattern duration increased over all subjects with an increase of delay time from 140 to 200 msec.

b. Mean pattern duration increased over all subjects with an increase of the intensity from 0 to 30 dB above threshold or above the intensity of SAF.

c. Mean pattern duration increased more markedly over all subjects with increasing intensity at the delay time of 200 msec than at the delay time of 140 msec.

d. Mean lip-closure duration increased over all subjects with an increase of delay time from 140 to 200 msec.

e. Mean lip-closure duration increased over all subjects with an increase of the intensity from 0 to 30 dB above threshold or above the intensity SAF.

f. Mean lip-closure duration was briefer for all subjects under the SAF/DAF condition than under the DAF condition.

g. Mean lip-closure duration appeared to be affected differently for stutterers and nonstutterers at the two different delay times within the two different click conditions (SAF/DAF and DAF) according to the level of intensity of delayed click feedback above threshold or above the level of SAF.

h. The mean number of pattern errors per condition increased over all subjects with an increase of delay time from 140 to 200 msec.

i. The mean number of pattern errors per condition increased over all subjects as the intensity increased from 0 to 30 dB above threshold or above the level of SAF.

j. The mean number of pattern errors per condition was greater over all subjects under the SAF/DAF condition than under the DAF condition.

k. The mean number of pattern errors per condition increased more markedly over all subjects with increasing intensity at the delay time of 200 msec than at the delay time of 140 msec.

l. The mean number of pattern errors per condition increased with increase of intensity more markedly for the stuttering group than for the nonstuttering group.

m. Under "buffer" SAF, mean lip-closure duration was greater for stutterers than nonstutterers.

These findings, and others which did not reach statistical significance but were in many instances as provocative or more so, are discussed in the following chapter.

CHAPTER V

DISCUSSION

The Experimental Conditions

The results reported in the previous chapter indicate that, on the speech-related task required of all subjects, stutterers did not, in general, respond differently from nonstutterers under the click conditions, delay times, and intensity levels of feedback employed in this investigation. These findings do not, therefore, support the hypothesis that sensory feedback functioning, as it has been sampled on this task and under these conditions, is different in stutterers and nonstutterers. Before the more general hypothesis, that sensory feedback functioning as it is revealed in responses to delayed auditory feedback is different for these two groups, may be rejected, however, further investigation, refined and extended at least in ways suggested by the present study, must be carried out.

It might be supposed that, if stutterers as a group presented a "built-in" or native delay in the auditory feedback system, their responses to artificially produced delay of auditory feedback would reveal an additive effect. This would be to assume that the native delay, if it exists at all, is always present, and is a constant. There is no evidence at the moment to support either of these assumptions.

The failure of the present investigation to demonstrate the effect described, or, indeed, to demonstrate over-all differences in responses of stutterers and nonstutterers to delayed click feedback on a speech-related task, may reveal a true absence of difference. Alternatively, it may be related to factors of experimental design, such as: (a) inadequate sample size, (b) insufficient control of subject variability, and (c) failure to include a broad enough range of delay times and/or intensity levels in the experimental design.

It cannot be assumed that the same delay times are most crucial for stutterers or nonstutterers under DAF of click or pure-tone signals activated by keytapping or patterned syllable repetition. The findings of Ruhm and Cooper and of Rapin et al appear to be in conflict with regard to the delay time producing maximal disturbance under pure-tone or click DAF on keytapping.

Ruhm and Cooper (78) found some shift in the responses of normal adults to pure-tone DAF in keytapping under the delay times of 100 and 200 msec. Increases of interpattern time and tapping pressure were found at 100 msec, the latter occurring at 0-dB sensation level; increases of interpattern time and of pattern errors were marked at 200 msec at a 5-dB sensation level. No increase in amount of disturbance was found when the delay time, presented at 0-, 5-, and 10-dB sensation levels, was increased to 300 and 400 msec.

Rapin et al (75), on the other hand, found increasing disturbance indicated by equivalent measures and the additional one of "time on", that is, time occupied by depression of the key in patterned keytapping, in children as the delay time of click feedback was increased to 1000 msec. The clicks, however, were presented at approximately an 80-dB hearing level.

While subjects differed in these two studies, the important difference may have been that of intensity level employed. We do not know how normal-speaking adult subjects would respond to click or pure-tone DAF on keytapping at higher sensation levels and delay times up to 1000 msec, but we may usefully compare the above studies with the factorial analysis of responses to DSF on a repetition of flashing numbers task, reported by Butler and Galloway (13). These investigators found that delay times of 85, 170, 255, and 340 msec had no differential effect on speech at a 50-dB sensation level (where the air-conducted speech-feedback signal would not exceed the synchronous bone-conducted signal to any significant extent). At an 80-dB sensation level, however, a differential influence of delay was apparent, with 170 msec producing the largest error scores. It would appear that, where a differential effect for delay times is present, it may not be detected at intensity levels close to threshold. At higher sensation levels the differential effect of delay times may be different for click or pure-tone DAF on keytapping and DSF.

It is interesting to note that Chase (17) reports high test-retest reliability for measures obtained under DSF, indicating that the vulnerability of a particular subject to disturbance in speech-motor control under this condition remains fairly constant. He found no significant correlation, however, between the degrees of disruption which the same subject showed in speech under DSF and on keytapping under DAF, the same delay times and intensity levels obtaining in each case.

There are a number of possible reasons for the differences in response to click and pure-tone DAF and DSF here suggested. As we have already seen, it is impossible to eliminate bone-conducted synchronous feedback under DSF or to control its intensity except, perhaps, by having the subject monitor the intensity of his own output on a VU meter. Moreover, the subject is also able to control the duration and frequency components of the auditory feedback signal units, or syllables, which are complex and varied. Under click or pure-tone DAF the auditory feedback units are uniform, of much shorter duration, and not under the control of the subject except with regard to the intervals of time separating them. This may well introduce a marked difference in the potential for disturbance of feedback signals which overlap succeeding units of motor activity in time. In the case of click or pure-tone feedback, a delayed auditory signal reaching the subject following the motor unit next in time to that which activated the signal will be delayed with respect to the second motor unit as well as the first. Depending on the subject's timing of his motor activity, the auditory feedback signal units presented at longer delay times under click or pure-tone DAF may, in fact, appear to be randomly delayed with respect to the motor units immediately preceding them. Because speech patterning is complex, an auditory feedback signal unit sufficiently delayed to follow the motor unit (production of the syllable) next in time to that which activated the signal, has no meaningful relationship with the second motor unit. This may account for the decrease in disturbance manifested under DSF as the delay time exceeds 200 msec by significant amounts. A situation more similar to that occurring under click or pure-tone DAF of over 200 msec might arise if a perpetually and randomly changing delay time between the limits of, say, 100 and 240 msec were applied to DSF. This might make the use of the compensatory mechanism of syllable prolonglation, for example, more difficult to put into effect and might be more disturbing to the subject than any single delay time within these limits. Butler and Galloway (13) found that random delay, in the form of playback to the subject while reading the same material which he had recorded at an earlier time, was not disturbing; the time relationships might be quite different under this condition, however, from the type of random delay mentioned above.

It is further possible that the differences in the peripheral afferent and efferent nerve pathways and the muscle groups involved are related to differences in response to DSF and click or pure-tone DAF on tapping. Ruhm and Cooper, however, suggest that there may be neurophysiological time constants common to the monitoring of various types of motor acts. These could be explored more thoroughly if the differences over different tasks inherent in the feedback units themselves, and the subject's ability to control certain aspects of them, were modified.

In the present investigation, pattern duration, lip-closure duration, and number of pattern errors were found to increase significantly as the click delay time was increased from 140 to 200 msec and as the intensity of the click was increased from 0 to 30 dB above threshold or above the level of SAF. In addition, pattern duration and number of pattern errors increased more markedly with increase of intensity under the 200-msec delay than under the 140-msec delay. These significant delay by intensity interactions are in good agreement with the findings reviewed in the previous section.

It is possible, however, that the delay times of 140 and 200 msec introduced in this study in relation to patterned syllable repetition, are not comparable to the same delay times introduced in relation to keytapping. The tendency for normal subjects to show decreases of pattern duration and for all subjects to show decreases of lip-closure duration under the practice SAF trials suggests that the effect of this condition upon patterned syllable repetition is very similar to that of accelerated feedback upon speech (26, 73). It can perhaps be speculated that the SAF signal may have been misplaced in time with respect to the activity imposed on the subject.

On utterance of the voiced syllable (me), the greatest amount of auditory feedback energy occurs on the neutral vowel at the time of lip opening. Yet the subjects in this study experienced SAF on lip closing and, apparently, often before maximum lip pressure was applied. Remarks made following the experimental session by some subjects were revealing in this respect; for example, "The click seems to come before I get my lips really closed," or "I feel as if I am waiting for the click to time the lipclosing for me." The marked decrease in lip-closure duration under the SAF/DAF conditions as compared with the DAF conditions may be related to the tendency of all subjects to show decreases of lip-closure duration under practice SAF and, indeed, would appear to lend some support to the line of reasoning suggested by the latter change.

If SAF was misplaced in time in relation to the motor activity requested of the subject in this study, then DAF was misplaced also, since the delay times were set in relation to contact of the electrodes on lip closing rather than on lip opening. Delay times must have varied as calculated from the moment of lip opening, but would in every case be shorter than the stated 140 or 200 msec. All three variables measured may well have been affected by the fact that the delayed click feedback was made contingent on lip closing rather than lip opening.

The number of pattern errors appearing under click SAF in both groups of subjects cannot so easily be explained by regarding this condition as one of accelerated feedback, since, for normal subjects at least, accelerated speech feedback does not result in errors of articulation and may possibly have the reverse effect (26, 73). It was felt that the unexpectedly short duration of the feedback signal or even its lack of symbolic association might be disturbing to the subject, at least in a single experimental session.

The significantly greater number of errors produced by all subjects under the SAF/DAF conditions as opposed to the DAF conditions may be related to the increase in number of pattern errors found under SAF, and would appear to lend some support to the line of reasoning suggested by the SAF findings and discussed at greater length below.

The unexpectedly disrupting nature of SAF may have introduced further confounding factors. It appeared that performances under "buffer" SAF were affected by the delay and/or intensity of preceding feedback conditions, especially where these were very disrupting. This effect may have carried over into succeeding delay conditions. There is, further, the possibility that, if SAF itself was disrupting, the effect of this may have carried over into the succeeding conditions. This effect might be expected to remain constant across all conditions. This would not be true of the more far-reaching effects of disrupting delay conditions mentioned above. In order to remove these effects, a counterbalanced or switchback statistical design might be necessary, with the use of covariance to remove other effects of order normally dealt with by randomization, for example, fatigue and practice.

While the results of this investigation failed to demonstrate differences between stutterers and nonstutterers in response to delay and intensity conditions, differences between subject groups are suggested by the tendency for stutterers to show greater disruption than nonstutterers in response to increasing intensity in terms of increased pattern duration and number of pattern errors. This tendency was statistically significant for pattern error only. It is interesting to compare this finding with Ham's (44) reports of the increase of "total speech time" shown by stutterers in response to increase of intensity of speech feedback. We are not here primarily concerned, however, with the response of stutterers to intensity, except insofar as a study of this variable may help us to determine which intensity level or levels might show greatest separation of stutterers and nonstutterers under DAF.

Differences in response of stutterers and nonstutterers to delay time approach significance in the case of number of pattern errors only. The trend toward steeper rise in number of pattern errors across the delay times of 140 and 200 msec might have reached significance had greater or, possibly, lesser delay times been included in the design. It is interesting that, while the mean number of pattern errors computed across all conditions is greater for the stutterers than the nonstutterers, under both SAF/DAF and DAF conditions at 140 msec, it is greater for nonstutterers than stutterers. It is probable that this tendency would be more marked if errors related to incomplete lip-closure were eliminated or disregarded.

A further difference in response to delay of stutterers and nonstutterers is suggested by the significant third-order interaction reported for lip-closure duration. This interaction may, as already suggested, be spuriously significant; on the other hand, it may reflect a different relationship between shift of compensatory mechanism and increasing delay or intensity in stutterers and nonstutterers. These relationships can only be explored further by inclusion of measurements of pressure in future experimental designs.

Normal Auditory Feedback, NAF, and SAF Data

Certain intergroup differences appeared in the practice period and under "buffer" SAF which are perhaps as interesting as those discussed above.

Both groups of subjects showed increase of pattern duration under NAF as contrasted with normal auditory feedback. This increase was not unexpected in view of the findings of Chase *et al* (20) for keytapping and Ringel and Steer (77) for speech with regard to over-all decrease in rate under decreased sensory feedback. It is of interest to compare the findings of Hixon and Hardy (48) with respect to the higher diadochokinetic rates for voiced syllable repetition than for voluntary non-speech movements of the tongue and lips in speech-defective cerebral palsied children. In the case of one stutterer (#3, Appendix B) and one nonstutterer (#14, Appendix B), pattern duration decreased markedly under the NAF condition as compared with the normal auditory feedback condition. In these two cases, the pattern error score was high for the NAF condition and subsequent SAF conditions. The nonstutterer has already been referred to as presenting "borderline" diadochokinetic rates.

The tendency of normal-speaking subjects to show acceleration and decrease of lip-closure duration under practice SAF has already been discussed. It was found, however, that, while stutterers also showed decreased lip-closure duration and sometimes decrease of interpattern time under practice SAF, their pattern duration tended to increase rather than decrease under this condition. Indeed, this difference would have been very marked had it not been for one nonstuttering subject who also showed a very marked increase of pattern duration. In no case did these changes in pattern duration appear to be the result of a deliberate decision on the part of the subject. In those stuttering subjects who showed marked decrease in rate under practice SAF, a delay-producing disturbance in kinesthetic patterning or feedback processes might be implicated, one which effectively counters a response of acceleration under this auditory feedback condition. Such a delay might interfere with the generation of patterns and standards associated with the initiation of movement.

Chase (17) describes a general model for this process which postulates simultaneous generation of the pattern of neural activity which will be translated into a motor command pattern and the pattern of neural activity which will be used as a standard for monitoring control of the motor output. He points out that Anokhin's model postulates the compounding of central and peripheral afferent activity to form an "afferent-synthesis", the neural substrate of the intention of performing a given act and eventually of the pattern for motor output and monitoring. Anokhin, according to Chase, states that ". . .the failure of coincidence of the system of excitations formed at the end of the afferent synthesis, the necessary antecedent of any motor response, and the streams of return afferentations entering the brain along different analyzers, leads to orienting-investigatory reactions. This cyclic process continues until both excitations fully coincide."

A disturbance in the generation of the command pattern for motor activity and/or re-afferentation or error detection might well account for stuttering blocks experienced at the time of initiation of speech, before any auditory feedback information in the form of voice or breath noise has been generated. If such a disturbance were always present and could be represented by a constant in time, and if the hypothesis is correct that disturbance under delayed auditory feedback is related to the degree of asynchrony existing between two functioning feedback systems (108), then a certain interval of artificially produced delay in the auditory feedback system might reduce the degree of asynchrony between the auditory and kinesthetic feedback systems and be of benefit to the stutterer. This interval of delay might vary from one stutterer to another or in one stutterer from one period of time to another, but might be less than 140 msec. However, it must be remembered that, while the stutterers in this study showed fewer pattern errors than the nonstutterers under the delay time of 140 msec, they showed many more errors than the nonstutterers at 200 msec. This does not suggest any simple or easily quantified relationship of kinesthetic and auditory feedback systems in stutterers.

The tendency for both groups of subjects to make errors under SAF and for certain subjects, most often stutterers, to make an unusually high error score under this condition has already been remarked upon. It may be that this is related to the timing of the click, that is, its presentation immediately upon lip closure, and the fact that this appears unusual to the subject and difficult to tolerate. Alternatively, it may be the fact that the signal is unusual and difficult to tolerate in other respects, for example, in duration, frequency components, or non-verbal aspect. The possibilities may easily be reduced by repeating this investigation with the provision that click SAF and DAF are made contingent upon lip opening rather than lip closure.

It is tempting to speculate that a new kind of integration has to be learned when a series of speech-related movements normally yielding speech-related units of auditory feedback are, in fact, followed by nonspeech-related units of auditory feedback. No research findings may be quoted in support of this line of thinking. However, the works of Milner (67) and Kimura (57) suggest that, in man, asymmetry of function of the temporal cortices renders one hemisphere dominant for the perception and learning of verbal material while the other is dominant for the perception and learning of nonverbal auditory material, for example, in assessment of the number of clicks presented in a series.

A tentative attempt was made, in fact, following the gathering of data for this investigation, to discover, in a group of three stutterers who had responded to SAF with an unusual number of pattern errors, whether their responses to monaural presentation of delayed click feedback might be different from those to binaural presentation. The results in two cases suggested that presentation to the left ear, that is, the ear contralateral to and probably most extensively represented in the right cerebral hemisphere, was most similar to binaural presentation in terms of amount of disruption produced. A somewhat lesser amount of disruption appeared upon presentation to the right ear. A third stuttering subject (#3), who was left-handed and many of whose pattern errors under SAF were in the form of reversals, responded in the same manner to binaural presentation and right-ear presentation. Presentation to the left ear of this subject, however, was accompanied by a reduction in pattern duration and number of pattern errors. Further investigation of the concepts here suggested would be enhanced if the subjects were first practiced until their performance became stable and if the delayed auditory stimuli were in no case sufficiently intense to stimulate the contralateral ear under monaural presentation.

The responses of the stuttering and nonstuttering subjects in this study to SAF are still subject to a number of interpretations and cannot properly be used to refute or support Stromsta's hypothesis (94) that the presence of a brief auditory feedback delay introduced by out-of-phase bone-conducted signals contributes to stuttering. Responses of stutterers and nonstutterers to SAF presented by air conduction and bone conduction might be compared in an attempt to explore this question further.

Further Implications of the Findings

An overview of the results herein reported would suggest that, at least for the delay times as they affected performance in this study, number of pattern errors is the measure most likely to differentiate between stutterers and nonstutterers, especially if errors of omission related to incomplete lip closure can be eliminated or accounted for. The limited study of test-retest reliability carried out would seem to indicate that number error is a fairly reliable measure and one which contributes in large part to persistence of the "response signature", although this "signature" is somewhat different in some cases under delay conditions, NAF, and SAF. Delay times would appear to be most effective in detecting differences between stutterers and nonstutterers at intensity levels of 10 dB or more above threshold or the level of SAF, but a pathology-by-intensity interaction is evident when the 0-dB sensation level is retained. Levels of 0 to 40 dB above threshold or SAF might most usefully be employed. The range of delay times might well be 100 to 400 msec, at least. It would not be wise, however, to dismiss the measure of pattern duration as a potential detector of differences between stutterers and nonstutterers until responses to delay times contingent upon lip opening rather than lip closure have been investigated across the range of delay times and intensity levels suggested above.

If lip-closure duration is to be used as a measure, it would probably be most effective in conjunction with pressure measurements. A strain gauge might be mounted between the upper and lower lip pieces of the transducer. Because of the sensitivity of the device to movement, the upper portion might then have to be damped and stabilized, the lower portion only being free to move in response to lip closure. Calibration might entail considerable difficulty.

Failure of pattern duration and lip-closure duration to differentiate subject groups may further be related to subject variability, reflected in the large error term used to test the pathology main effect for all measures. This problem might be overcome by increasing the number of subjects, by changing the basis of selection for stuttering subjects, or both. It is difficult to tell, however, what the basis of selection should become.

An attempt was made in the course of this investigation to create two groups of stutterers, the first meeting the predetermined criteria for subject selection and showing a high pattern error score under SAF, the second of stutterers meeting these criteria and showing a low pattern error score under SAF. This effort was defeated by the limited number of stuttering subjects available and by the fact that many of the stutterers showing a high pattern error score under SAF did not meet the criteria for subject selection. In addition, one normal subject who met these criteria was found to show a high pattern error score under SAF. A detailed study of stutterers who manifest high pattern error scores under SAF might well be rewarding.

Other bases of selection for stuttering subjects might be:

(a) the degree of severity of the stuttering blocks, (b) the predominance of certain characteristics in the stuttering block, for example, repetitions, prolongations, or tremor of lips, tongue, or jaw, or (c) the presence of factors in the individual's history such as family history of stuttering, left-handedness, or indications of neurological deficit or lesion. The present study was not sufficiently exhaustive to permit even a tentative study of any of these factors, except perhaps degree of severity of the stuttering block. However, interest in such an approach led to a more detailed study of the protocols of individual stutterers, suggesting that a particular kind of response tended to appear most often across delay conditions, either as a direct response to the disrupting influences of delay or as a means of countering them. Further attempt was made to identify "response groups" or idiosyncratic features occurring in combination with one another across the conditions of NAF, SAF, SAF/DAF, and DAF, without success. A description of these idiosyncratic features across all types of condition in the most deviant normal-speaking and stuttering subjects is given in Appendix C. No correlation was suggested in the small group of stuttering subjects between types of response to altered feedback and severity of stuttering.

This more detailed study of individual records suggested that a weighted score or index of disturbance, taking into account increases in pattern duration, lip-closure duration, and number of pattern errors, and, possibly, pressure increases in addition to these or in lieu of lip-closure duration, might be most effective in detecting significant differences in responses to delayed feedback in stutterers and nonstutterers. It might be difficult to justify any particular weighting system, however, in view of our ignorance of the factors favoring the appearance of any of these indices of disturbance, or, to put it another way, how much disturbance each one reflects.

A comparison was made of the records of stuttering subjects, whose performance was aberrant in terms of high pattern error score under SAF, unusual length of pattern under SAF or NAF, or unusual variability of pattern or lip-closure duration within a single experimental condition, and those of subjects excluded because of a history of psychiatric disorder, reading disability, mental retardation, or observed abnormality of diadochokinesis or rhythmokinesis. This tended to support the speculation that these aberrant responses might, indeed, be related to disorders variously affecting the neurophysiological processes underlying language.

A brief description of the sample of stutterers and nonstutterers excluded, together with a description of the responses of individuals from this sample excluded for the reasons mentioned in the preceding paragraph, or, in the case of normal subjects, a history of stuttering, is also given in Appendix C.

It should be noted that, while 41% of the twenty-nine stutterers considered for this study and 33% of the fifteen meeting the criteria presented a high pattern error score under SAF, only 20% of twenty nonstutterers considered for inclusion in this study appeared in this category, and two of these were former stutterers. Of the fifteen nonstutterers meeting the criteria for subject selection, only one (7%) showed a high pattern error score, and he presented "borderline" diadochokinetic rates.

It is also of interest to note that, of the six female stutterers considered for this investigation, only one met the criteria for subject selection. The performances of this one subject (#3) were aberrant in ways detailed in Appendix C. The possibility was considered that sex differences might exist of a kind which would affect performance on the experimental task imposed on the subjects in this study. Previous investigations of responses to DSF and pure-tone DAF revealed no such sex differences. However, the performance of a group of five normal-speaking females who met the criteria for subject selection but who were not matched for age, sex, or race with the female stuttering subjects who had been excluded, was recorded under the conditions of normal auditory feedback, NAF, and SAF. The records of these subjects showed no unusual features.

Suggestions for Further Research

The differences between stutterers and nonstutterers suggested by this investigation do not lend themselves to any simple explanation. It seems possible that certain stutterers are more readily disturbed than nonstutterers by any change in feedback on a task such as patterned syllable repetition. The differences reported in this study which might lead one to make this hypothesis may be compared with the findings of slowed diadochokinetic rates (11, 104) or disturbed rhythmokinesis (51) in stutterers reported from early studies, where a bulky apparatus placed in the mouth must have altered tactile and kinesthetic feedback considerably. These changes of feedback may produce different kinds of responses in stutterers which in each case may be related to different underlying characteristics of the speech and language processes, not yet understood.

Those stutterers whose responses to altered feedback on a task such as syllable repetition are most like those of normal-speaking subjects may present characteristic breakdown in speech or language processes not sampled in a task of this kind, for example, word selection, and ordering, patterning of more complex movements for speech, or certain kinds of reading disability (69).

The underlying disturbances in speech or language processes hypothesized may be neurologically or psychologically based. The possibility that the greater susceptibility of stutterers, or of certain stutterers, to altered feedback is related to anxiety over their performance on the experimental task, remains.

The hypothesis that stutterers do show this greater susceptibility, supported in part by the tendency observed in certain stutterers in this study to show greater disturbance on one or another of the measures employed under SAF and DAF, may seem contrary to the fairly well established finding that stutterers, or at least certain stutterers, tend to show greater fluency under conditions of altered auditory feedback (22, 41, 44, 70). It may be, however, that, in speech, the disturbances contingent upon extraneous alterations of feedback inhibit the internal or native disturbances which produce stuttering or that they prevent the development of accessory or auxiliary features (107) and so diminish the fear of stuttering which is widely believed to contribute to its perpetuation.

Suggestions for further research have been made throughout the previous discussion. These are summarized below, with additions or amplification in some cases.

Methodology

It is felt that the transducer should be modified in certain critical respects. The upper portion of a device as used in this study might be stabilized and damped further, the lower portion only being left free to move with lip closing and opening. This lower portion would also require damping, as in the present study, by an underlying foam rubber sheet.

It is possible that the lip pieces, though of small dimensions, may alter tactile and kinesthetic feedback sufficiently to introduce disturbing factors in performance. These effects could be studied by comparison of such measures as pattern duration and pattern error under normal auditory feedback and NAF, obtained cinematographically and by use of the lip pieces as a transducer for a graphic level recorder. The use of light relays and/or some type of anemometer as a transducer and a means of triggering the auditory feedback signal might be investigated further should it be found that the lip pieces do, indeed, introduce effects which cannot be taken into account or removed in the experimental design.

The first waveform generator of the waveform/pulse generator complex might be activated through the gate input rather than the manual switch. The latter offers a less reliable mode of triggering and is unduly sensitive to humidity. The gate input requires an input voltage of twenty-two and one-half volts for reliable triggering. A twenty-five-volt battery might be used in the circuit closed by the electrodes mounted on the lip pieces, if this were so constructed as to eliminate any likelihood of direct contact with the electrodes of the articulators. Failing this, an amplifier would have to be placed in the circuit. The waveform/pulse generator complex might be extended to permit triggering of the click by high-frequency, tremor-like lip movements (occurring, that is, at a higher rate than ten per second).

Stimulus

Click DAF and SAF should be made contingent upon lip opening rather than lip closure, at least for the purposes of comparing the responses of both stuttering and normal-speaking subjects across these two modes of timing of click conditions.

Delay times ranging from 100 to 400 msec, or even 1000 msec, should be incorporated in this and other experimental designs suggested here. Intensity levels for the DAF signal ranging from 0 to 40 dB above threshold or, in the case of SAF/DAF, above the level of click SAF might well be incorporated.

A burst of noise of, say, 50-msec duration might be substituted for the click, and responses to these two stimuli compared across delay conditions for both groups and subjects.

Mode of Presentation

The above modifications might well be included in experiments designed to:

a. contrast responses in stutterers and nonstutterers to click DAF and SAF presented by both air-conduction and bone-conduction on a patterned syllable repetition task, and

b. contrast responses in stutterers and nonstutterers to monaural and binaural presentation of click DAF on a patterned syllable repetition task. Monaural presentation should be to both right and left ears in a counterbalanced design.

Practice

In the case of both of the above experimental investigations, it would be well to practice all subjects until responses stabilize before the contrasts suggested are made. It would also be of interest to know whether the course of stabilization is similar for stutterers and nonstutterers, and for all subjects under the conditions of click contingent upon lip opening as contrasted with click contingent upon lip closing; and to know whether stabilization of this kind occurs over a series of experimental sessions for both keytapping under click or pure-tone DAF and patterned syllable repetition under click or pure-tone DAF. In the case of the latter task especially, anxiety-producing circumstances might be introduced following the expected stabilization over a number of practice sessions, and the effect of these circumstances upon performance studied.

Measures

It is felt that the measure of pattern duration should be retained, at least until its usefulness has been tested in studies incorporating the modifications suggested above.

Pressure might be included as a variable; for the purpose of measuring this, a strain gauge might be mounted in the stabilized upper portion of the mouthpiece. Tongue-tip rhythmokinesis and pressure might also be evaluated in relation to synchronous and delayed click feedback, but the instrumentation and calibration problems inherent in such pressure measurements are fully recognized.

An attempt might be made to devise a weighted score or index comprising measures of pattern duration, pattern error, and lip-closure duration in conjunction with the lip-pressure measures mentioned above, or either one of these last two.

The distribution of types of pattern error might be studied further in stutterers, in order to evaluate possible degrees of correlation between predominance of types of pattern error, such as true omission with increased lip-closure duration and/or pressure, and the predominance of similar features in the stuttering block.

Subject Selection

A group of stutterers whose performance on a patterned syllable repetition task was found to be highly aberrant under click SAF or DAF might profitably be compared in a number of ways with a group of stutterers responding most like normal-speaking subjects under these conditions; various neurological, psychiatric, psychological, linguistic, and audiological (with reference, in particular, to tests of retrocochlear lesion) measurements might be utilized.

The responses of stutterers medically diagnosed as presenting neurological or psychiatric disorders (these being, however, mild enough to permit of cooperation on a patterned syllable-repetition task), might be compared to the responses on this task under click SAF and DAF by stutterers who cannot be so classified and with normal-speaking subjects. It might also be worthwhile to simplify the patterned syllable-repetition task so that it is suitable for experimental work with children in different age groups; the responsesof children who showed signs of incipient stuttering or abnormal nonfluency might then be compared on this task under DAF with those of normal-speaking children.

Related Studies

The findings of the present study suggest that it might be of interest to study the responses of stutterers to such speech feedback alterations as: (a) accelerated speech feedback, (b) mandibular and infraorbital nerve blocks and/or topical anesthesia, and (c) delay time of DSF randomly and continuously changing between the limits of, say, 100 and 240 msec.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was designed to investigate the sensory feedback system in stutterers and nonstutterers by means of the introduction of an artificial auditory delay during the performance of a speech-related task, namely, patterned syllable repetition. The delayed signal was presented at various delay times and intensity levels and in the presence and absence of an accompanying synchronous auditory feedback signal.

The experimental task involved repetition of the syllable (mə) to the pattern of four syllables followed by a pause followed by two syllables (---- --). In an attempt to reduce intersubject variability related to subject control of the intensity, frequency, and duration of voiced syllable production, an electronically produced click signal was substituted for the subject's own voiced production of the syllable (mə).

The click stimulus was triggered at the moment of lip closure by contact of two electrodes, mounted in a transducer, the narrow flexible lip pieces of which were placed between the subject's lips; each electrical contact was recorded on the strip chart of a graphic level recorder. A system of waveform and pulse generators was employed in order that the click might be presented both synchronously and at delay times of 140 and 200 msec; the click was further modified in intensity for each experimental condition. The experimental conditions were:

a. SAF/DAF, in which a synchronous click signal was presented at a 40-dB sensation level by a bone-conduction vibrator placed on the forehead in the midline and immediately followed by an air-conducted click signal presented binaurally by headphones at the same sensation level as the synchronous click and 10, 20, and 30 dB above this level and at delay times of 140 and 200 msec.

b. DAF, in which an air-conducted click was presented binaurally at threshold or at an intensity level 10, 20, and 30 dB above threshold at delay times of 140 and 200 msec.

Each of the sixteen experimental conditions was preceded by synchronous bone-conducted click presentation at a 40-dB sensation level; this condition was referred to as "buffer" SAF. In addition, in the period of training and practice preceding the experimental conditions, the performance of each subject on the experimental task was recorded over three trials under normal auditory feedback (use of voice), no auditory feedback (NAF), and synchronous auditory feedback (SAF).

Fifteen adult stutterers, meeting certain specified criteria with regard to hearing, diadochokinesis, rhythmokinesis and absence of neurological or psychiatric disorder and fifteen matched normal-speaking adults were the subjects of this study.

Responses of the subjects were measured in terms of pattern duration, lip-closure duration, and number of pattern errors and averaged for each practice trial and each "buffer" and experimental condition across five consecutive patterns.

The hypothesis to be tested was that sensory feedback functioning, as it is revealed in responses to delayed click feedback on a patterned syllable-repetition task, is different in stutterers and nonstutterers. This study was regarded as an exploratory one, however, since the time constants governing sensory feedback in the central nervous system are not known. Furthermore, while key-tapping responses under delayed click feedback have been studied in normal-speaking subjects, these have not been studied in stutterers; nor had lip-closure responses to delayed click feedback been studied in stutterers or nonstutterers.

Analysis of the data obtained in this study revealed that pattern duration, lip-closure duration, and the number of pattern errors increased over all subjects with increasing intensity and increasing delay time. The number of pattern errors was greater and lip-closure duration was shorter for all subjects under the SAF/DAF condition than under the DAF condition. Over all subjects both pattern duration and pattern error increased more markedly with increasing intensity at the 200-msec delay time than at the 140-msec delay time.

Pattern duration, lip-closure duration, and number of pattern errors, when averaged over all conditions, were greater for stutterers than nonstutterers, but in no case did these differences achieve statistical significance. It was speculated that this failure to achieve significance was primarily attributable to intersubject variability.

Certain differences in response between these two subject groups did appear, however. Stutterers showed a greater increase in pattern error in response to increasing intensity and a greater tendency to increase of pattern duration with increasing intensity than nonstutterers; the latter difference did not quite achieve statistical significance. The same was true of the tendency shown by the stutterers to make fewer errors than the nonstutterers under the 140-msec delay and a greater number of errors than the nonstutterers under the 200-msec delay. The responses of stutterers in terms of lip-closure duration increase and decrease were significantly different from those of the nonstutterers across the delay, intensity, and click (SAF/DAF or DAF) conditions. These differences may have been chance ones, or they may reflect different shifts in compensatory mechanisms, for example, from increased pressure on lip closure to lip-closure prolongation, in the two groups of subjects over these conditions.

In the practice period, both groups of subjects showed increases in pattern duration and error under NAF as compared with normal auditory feedback. The nonstutterers showed a decrease of pattern duration under practice SAF as compared with normal auditory feedback. Stutterers, on the other hand, showed some tendency toward increase of pattern duration at this juncture. Both subject groups showed decrease in lip-closure duration and increase in number of pattern errors under practice SAF as compared with normal auditory feedback. Lip-closure duration under "buffer" SAF was significantly greater for stutterers than nonstutterers.

The decrease in pattern duration shown by the nonstutterers in response to the shift from normal auditory feedback to SAF and the tendency of both subject groups to show decrease in lip-closure duration in response to this shift suggests that, in the latter condition, the timing of the click, that is, the fact that it was contingent upon lip closure rather than lip opening, was disturbing. Indeed, the SAF condition was thought to resemble accelerated auditory feedback in some of its effects. It is not known whether the high error scores obtained in some cases under this condition are also related to the timing of the click or to its unusual nature as feedback from a speech-related activity in other respects, for example, duration, frequency components, or lack of verbal association.

Those subjects who made the highest error scores under SAF, five stutterers and one nonstutterer, resembled in this respect certain individuals, for the most part stutterers, who were excluded from the investigation because of evidence of history of neurologic or psychiatric disorder. More than half of these stuttering subjects and two of the stutterers excluded made a greater number of errors under SAF than under the delay conditions, a feature of performance found in none of the nonstutterers.

The results of this investigation do not support the hypothesis that sensory feedback functioning, as it is revealed in responses to delayed click feedback on a patterned syllable-repetition task, is different in stutterers and nonstutterers. However, the interpretation of individual protocols suggests the presence of unusual features in the functioning of feedback systems related to speech activity in certain stutterers. These are not thought to be simple, entirely confined to stutterers, or necessarily related to the same underlying neurophysiological processes in each case.

This study further suggested modifications of instrumentation and experimental design, especially with respect to criteria for selection of stuttering subjects, which might be employed in future investigation of the sensory feedback mechanisms related to speech in stutterers.

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APPENDIX A

TABLE 7.---Differences in mean pattern duration in stutterers and nonstutterers between normal auditory feedback and NAF and between normal auditory feedback and practice click SAF; all measurements are reported to the nearest millisecond.

	STUTTERERS			NONSTUTTERERS		
Subject No.	Normal Auditory Feedback	Normal Auditory Feedback Minus NAF	Normal Auditory Feedback Minus Practice Click SAF	Normal Auditory Feedback	Normal Auditory Feedback Minus NAF	Normal Auditory Feedback Minus Practice Click SAF
1	1415	84	174	1245	3	- 146
2	1640	130	- 96	1349	210	- 240
3	1209	- 184	36	1315	71	- 100
4	1411	66	- 16	1308	22	- 153
5	1316	17	- 85	1636	109	- 171
6	1065	36	18	1300	87	304
7	1399	112	92	1077	- 5	- 31
8	1236	96	163	1355	28	- 114
9	1236	51	42	1144	128	- 3
10	1337	138	80	1209	12	- 129
11	1273	68	88	1255	- 1	- 137
12	1287	238	141	1200	88	- 97
13	1229	26	- 90	1148	12	23
14	1064	47	- 5	1347	- 178	- 287
15	1291	82	- 98	1166	34	- 147
$\bar{x}$	1295	67	30	1270	41	- 95

TABLE 8.---Test-retest mean pattern duration measurements on two stutterers (#1 and #3) and two nonstutterers (#9 and #14); all measurements are reported to the nearest millisecond.

Mean Pattern Duration		Stutterer #1 Session 1	Stutterer #1 Session 2	Stutterer #3 Session 1	Stutterer #3 Session 2	Nonstutterer #9 Session 1	Nonstutterer #9 Session 2	Nonstutterer #14 Session 1	Nonstutterer #14 Session 2
All Delay Conditions		1571	1389	1670	1465	1435	1343	1344	1448
Delay:	140 msec	1506	1378	1669	1467	1375	1320	1306	1398
	200 msec	1636	1400	1670	1464	1495	1367	1383	1499
Intensity:	0 dB	1416	1313	1503	1378	1287	1266	1323	1373
Above	10 dB	1551	1382	1648	1474	1390	1368	1315	1406
Threshold	20 dB	1608	1419	1809	1470	1514	1366	1321	1596
or Level of Click SAF	30 dB	1709	1442	1718	1538	1550	1374	1417	1418
Click Condition:									
Simultaneous SAF/DAF		1580	1454	1654	1458	1365	1327	1433	1526
	DAF	1562	1325	1686	1472	1506	1360	1256	1371
Normal Auditory Feedback		1415	1212	1209	1081	1143	1129	1347	1225
	NAF	1499	1240	1025	907	1272	1225	1169	1198
Practice Click SAF		1589	1201	1245	1176	1141	1100	1060	1036
"Buffer" Click SAF		1413	1271	1333	1237	1166	1135	1078	1140

TABLE 9.---Test-retest lip-closure duration measurements on two stutterers (#1 and #3) and two non-stutterers (#9 and #14); all measurements are reported to the nearest millisecond.

Mean Lip-Closure Duration	Stutterer #1		Stutterer #3		Nonstutterer #9		Nonstutterer #14	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
All Delay Conditions	97	89	110	97	85	96	106	113
Delay: 140 msec	93	85	115	100	83	94	111	117
200 msec	102	92	105	94	88	98	101	109
Intensity: 0 dB	90	84	91	96	91	96	95	118
Above Threshold or Level of Click SAF 10 dB	93	86	121	97	83	93	109	110
20 dB	105	88	123	102	86	96	118	110
30 dB	102	96	104	93	81	100	103	113
Click Condition:								
Simultaneous SAF/DAF	91	92	106	98	84	93	108	105
DAF	104	85	113	97	86	100	105	120
Normal Auditory Feedback	104	87	112	105	97	89	105	94
NAF	85	89	91	87	94	102	93	110
Practice Click SAF	94	63	91	82	76	80	88	74
"Buffer" Click SAF	98	84	87	85	77	85	97	100

TABLE 10.---Test-retest pattern error measurements on two stutterers (#1 and #3) and two nonstutterers (#9 and #14).

Mean Pattern Error Per Condition		Stutterer #1		Stutterer #3		Nonstutterer #9		Nonstutterer #14	
		Session 1	Session 2	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
All Delay Conditions		1.06	.31	2.31	3.25	1.75	1.63	4.13	3.19
Delay:	140 msec	.63	.38	.87	2.50	1.50	1.13	3.13	2.75
	200 msec	1.50	.25	3.75	4.00	2.00	2.13	5.13	3.50
Intensity:	0 dB	.75	.50	.75	1.25	1.00	1.00	3.25	3.75
Above	10 dB	1.50	.25	1.50	2.25	1.75	1.75	3.50	3.50
Threshold or Level of	20 dB	1.00	.25	2.50	3.75	2.50	1.50	5.50	3.25
Click SAF	30 dB	1.00	.25	4.50	5.75	1.75	2.25	4.30	2.25
Click Condition:									
Simultaneous SAF/DAF		1.50	.50	2.37	3.13	1.63	1.63	5.25	3.63
	DAF	.63	.13	2.25	3.37	1.88	1.63	3.00	2.63
Normal Auditory Feedback		1.30	.30	1.60	1.00	.30	1.30	1.00	.67
	NAF	.67	1.00	3.60	3.00	1.00	.67	3.00	2.30
Practice Click SAF		.67	1.30	1.30	1.00	1.00	1.00	.67	2.67
"Buffer" Click SAF		.69	.56	.94	.94	.63	1.31	2.06	1.81

APPENDIX B

Selection of Subjects

Stutterers	Male	Female	Total
Total number of subjects considered	22	7	29
Total number of subjects excluded	8	6	14
included	14	1	15
Reasons for exclusion:			
a) Under psychiatric treatment	* 2	1	3
b) Mental retardation		* 1	1
c) Reading disability	* 1		1
d) Abnormal rhythmokinesis		* 1	1
e) Abnormal diadochokinesis		* 1	1
f) Suspected viral enchephalitis in childhood	1		1
g) Hearing loss	1		1
h) Misinstruction of subject		* 1	1
i) Stuttering not confirmed (subject presented articulation disorder; reported as a clutterer)		* 1	1
j) Included in an attempt to set up two groups of stutterers (N.B., one of these three stutterers who presented an articulation problem showed a very high error score under SAF).	3		3

Nonstutterers	Male	Female	Total
Total number of subjects considered	19	1	20
Total number of subjects excluded	5	0	5
included	14	1	15
Reasons for exclusion:			
a) Under psychiatric treatment	* 1		1
b) Former stutterer (one also under psychiatric treatment formerly)	* 2		2
c) Testing not completed	1		1
d) Hearing loss	1		1

Performance of persons starred was unusual in some respect and is described briefly in APPENDIX C, Section II.

APPENDIX C

Section I

The following is a brief description of the performances of subjects in this investigation whose records showed some unusual features:

Stutterer #3. 18-year-old white female. Twelfth-grade education. Stuttering: mild. No apparent anxiety or distress in the experimental situation.

Features of performance:

a. Mean pattern duration decreased (-184 msec) under NAF as compared with normal auditory feedback.

b. High error score (3.6 per trial) under NAF.

c. Slight increase (36 msec) in pattern duration under practice click SAF as compared with normal auditory feedback; "crowding" of patterns appeared under the former condition.

d. Moderately high error score under "buffer" click SAF (1.56 per condition).

e. Reversals predominated under click SAF; under the delay conditions, however, errors of addition predominated.

f. Mean pattern duration under the delay conditions showed marked increase (424 msec) over mean pattern duration under practice click SAF.

Stutterer #5. 16-year-old colored male. Eleventh-grade student; potential college student. Stuttering: severe. Considerable distress in the experimental situation; asked that it be terminated as quickly as possible.

Features of performance:

a. High error score under "buffer" click SAF (2.63 per condition); this error score was in fact higher than that made under delay conditions (2.31 per condition). This was true of no normal-speaking person tested.

b. Errors of true omission with lip-closure prolongation predominated under the "buffer" SAF and all delay conditions.

Stutterer #10. 19-year-old white male. College sophomore. Stuttering: moderate. Interested in the experimental task and evidenced no distress.

Features of performance:

a. Fairly marked increase in mean pattern duration (138 msec) under NAF as compared with normal auditory feedback.

b. Moderately high pattern error score (1.25 per condition) under "buffer" click SAF, chiefly of interest because the mean pattern error score under the delay conditions (.69 per condition) was of lesser magnitude.

Stutterer #11. 18-year-old colored male. Twelfth-grade education. Stuttering: severe. No apparent distress or anxiety in the experimental situation.

Features of performance:

a. High pattern error score under all conditions:

Normal auditory feedback	3.3 per trial
NAF	4.0 per trial
Practice click SAF	4.0 per trial
"Buffer" click SAF	3.56 per condition
Delay conditions	3.18 per condition

b. Again, as can be seen from the foregoing, the error scores under the SAF conditions were higher than under the delay conditions.

c. Errors of true omission predominated, often with marked increase in lip-closure duration.

Stutterer #12. 19-year-old white male. College freshman. Stuttering: moderate; stutters when alone. No distress evident in the experimental situation.

Features of performance:

a. Marked increase in mean pattern duration (238 msec) under NAF as compared with normal auditory feedback.

b. Moderate increase in mean pattern duration (141 msec) under practice click SAF as compared with normal auditory feedback.

c. Fairly high pattern error score (1.25 per condition) under "buffer" click SAF, of special interest because freedom from error was noticed under the "buffer" click SAF condition until the first high intensity delay condition was encountered. Following this, the errors of addition typical of performance under delay appeared in every pattern under "buffer" click SAF and in the three post-experimental SAF conditions. The subject was quite unaware of this pattern change, and correctly repeated the pattern of the experimental task with voice when asked to do so following the investigation.

Normal #2. 44-year-old white male. Some college education. No distress evident in the experimental situation.

Features of performance:

a. Marked increase in pattern duration under delay (953 msec) as compared with practice click SAF.

b. Fairly high error score under "buffer" SAF (1.88 per condition).

c. Rhythmic errors predominated under SAF and delay conditions, first appearing on the introduction of the 200-msec delay and present under every condition following this. Unlike most subjects making a high error score, this subject was able to correct errors of rhythm under delay when these were pointed out to him following the main experimental conditions.

Normal #14. 24-year-old white male. College graduate. "Borderline" diadochokinetic rates. Some awareness of high error score and distress over this during the investigation.

Features of performance:

a. Marked decrease in mean pattern duration (-287 msec) under NAF as compared with normal auditory feedback.

b. Essentially no change in mean pattern duration (-5 msec) under practice click SAF as compared with normal auditory feedback.

c. High pattern error score under NAF (3 per trial), "buffer" click SAF (2.63 per condition), and delay conditions (4.13 per condition). Errors of true omission predominated.

Section II

The following is a brief description of the performance of persons excluded as subjects in this investigation whose records showed some unusual features:

Stutterer S.H. 20-year-old Indian male. Twelfth-grade education. Stuttering: mild; articulation problem also present. No suitable matched normal could be found. This man showed some impatience with his poor performance at the beginning of the experimental session only.

Features of performance:

a. Mean pattern duration increase (195 msec) under practice click SAF as compared with normal auditory feedback.

b. High pattern error score under all click conditions:

Practice click SAF	6.3 per trial
"Buffer" click SAF	5.25 per condition
Delay conditions	3.88 per condition

c. As can be seen from the above, there were fewer errors per condition under delay than under "buffer" click SAF.

d. Rhythmic errors predominated under both SAF and delay conditions. Initially, highly increased lip-closure duration, sometimes extending over the whole of the first part of the pattern and, to the observer, resembling "blocks" in speech, appeared.

Stutterer M.M. 20-year-old white female. Twelfth-grade education. Stuttering: severe. Bilingual environment. Misinstructed. Some distress shown in experimental situation.

Features of performance:

a. Complete breakdown in terms of loss of pattern, initially.

b. Increase in mean pattern duration (193 msec) under practice click SAF as compared with normal auditory feedback.

c. Following this, the stutterer was mistakenly instructed to "go more slowly". Spurious increase in pattern duration of 340 msec under delay conditions so introduced.

d. Error score at same time reduced under delay conditions to .5 per condition.

Stutterer A.L.M. 19-year-old colored female. Special class placement until 18 years; now unemployed. Stuttering: moderate. Reading disability; probably mentally retarded. No distress apparent in experimental situation.

Features of performance:

a. High pattern error score under all but the normal auditory feedback conditions.

NAF	2.33 per trial
Practice click SAF	2.67 per trial
"Buffer" click SAF	4.19 per condition
Delay conditions	3.38 per condition

b. Pattern error score lower under delay conditions than under "buffer" click SAF.

c. Errors of addition (often in form of a tremor) predominated. Some reversals appeared under "buffer" click SAF, one under delay (SAF/DAF).

Stutterer A.N. 45-year-old white female. Twelfth-grade education. Stuttering: severe. Abnormal diadochokinesis; unable to repeat pattern in unison with recorded stimulus version, apparently because of difficulty in maintaining the required rate. When errors of true omission under normal auditory feedback were pointed out to her, she produced the pattern correctly but at a markedly decreased rate. At ease throughout experimental session.

Features of performance:

a. Mean pattern duration under all conditions was greatly in excess of the mean over all subjects (e.g., mean pattern duration under delay conditions was 2888 msec).

b. Mean pattern duration increased markedly (285 msec) under NAF as compared with normal auditory feedback.

c. Mean pattern duration decreased (-113 msec) under practice click SAF as compared with normal auditory feedback.

d. Following introduction of click feedback, few errors made under "buffer" SAF or delay conditions.

Stutterer K.S. 20-year-old white male. College junior. Stuttering: severe. Formerly under psychiatric treatment. No distress during experimental session; anxiety to do well was apparent, however.

Features of performance:

a. Marked increase in mean pattern duration (400 msec) under delay conditions as compared with practice click SAF.

b. High pattern error score under practice click SAF (3.6 per condition); moderate amount of pattern error under "buffer" click SAF (1.13 per condition).

c. Errors of true omission predominated under SAF initially, accompanied by excessive lip-closure duration, reminiscent of "blocking" in speech.

d. Errors of addition predominated under delay conditions.

Stutterer S.L. 20-year-old colored male. Twelfth-grade education. Stuttering: moderate. Reading disability. No distress in short experimental session.

Features of performance:

High pattern error score under normal auditory feedback (3 per trial), NAF (3.33 per trial) and practice click SAF (2.67 per trial).

Testing ceased following recording of performance under click SAF.

Stutterer P.M. 43-year-old colored female. Ninth-grade education. Stuttering: mild; often in the form of cluttering. Abnormally shaped skull. Abnormal rhythmokinesis; quite unable to follow pattern of recorded stimulus version. Some anxiety to please.

Features of performance:

a. Marked increase mean pattern duration (436 msec) under practice click SAF as compared with normal auditory feedback.

b. High pattern error score under normal auditory feedback (3 per trial), NAF (2 per trial), and practice click SAF (3.33 per trial), where reversals appeared.

c. Errors of addition predominated.

Testing ceased following trial recording of performance click SAF.

Nonstutterer G.A. 44-year-old white male. College graduate. Formerly under psychiatric care. At ease during experimental session.

Features of performance:

a. Marked increase in mean pattern duration (228 msec) under NAF as compared with normal auditory feedback.

b. Marked increase in mean pattern duration (273 msec) under practice click SAF as compared with normal auditory feedback.

c. Marked increase in mean pattern duration (658 msec) under delay conditions as compared with practice click SAF.

d. Few pattern errors under delay conditions (.44 per condition).

Nonstutterer T.B. 24-year-old white male. College graduate. Former stutterer. At ease during experimental session, in which he was interested.

Features of performance:

a. Marked increase in mean pattern duration (520 msec) from practice click SAF to delay conditions.

b. High pattern error score under most conditions, of which subject seemed unaware.

Normal auditory feedback	2.3 per trial
Practice click SAF	3.3 per trial
"Buffer" click SAF	5.3 per condition
Delay condition	6.6 per condition

c. Reversal errors predominated, or at least break down of rhythmic patterning (-- -- --) instead of (---- --), often with wider separation of the first pair of taps than of the second pair.

Nonstutterer H.W. 44-year-old white male. Some college education. Former stutterer. Formerly under psychiatric care. Head injury (nail driven through skull in frontal region) in childhood. No apparent distress in experimental session; this man was unable, however, to control hysterical laughter during his performances.

Features of performance:

a. Marked decrease in mean pattern duration (289 msec to a mean pattern duration of 888.36 msec) under practice click SAF as compared with normal auditory feedback.

b. High pattern error score under practice click SAF (2 per trial) in spite of use of foot-tapping as an aid, which this man later admitted.

Testing discontinued after presentation of two delay conditions only.