Haskins Laboratories Status Report on Speech Research
1992, SR-111/112, 111-120

Effects of Alterations in Auditory Feedback and Speech Rate on Stuttering Frequency*

Joseph Kalinowski,† Joy Armson,† Andrew Stuart,† Marek Roland-Mieszkowski,† and Vincent L. Gracco

This study investigated the effects of altered auditory feedback on stuttering frequency during speech production at two different speech rates. Nine stutterers, who exhibited at least 5% dysfluency during a reading task, served as subjects. They read eight different passages (each 300 syllables in length) while receiving four conditions of auditory feedback: nonaltered, masking, delayed, and frequency altered. For each auditory feedback condition, subjects read at both a normal and a fast rate. Results indicated that stuttering frequency was significantly decreased during conditions of delayed and frequency altered auditory feedback at both speech rates ($p < 0.05$). These findings refute the notion that a slowed speech rate is necessary for fluency enhancement under conditions of altered auditory feedback. Considering previous research and the results of this study, it is proposed that there may be two interdependent factors that are responsible for fluency enhancement: alteration of auditory feedback and modification of speech production.

INTRODUCTION

The finding that stuttering is ameliorated when stutterers speak under conditions of altered auditory feedback has been well documented (see reviews by Starkweather, 1987a; Van Riper, 1982). Two conditions which have been investigated extensively are delayed auditory feedback (DAF), in which there is a delay imposed on the delivery of the feedback speech signal to a speaker's ears, and presentation of a masking noise, which serves to compete with a speaker's auditory feedback.

Recently, the fluency enhancement effect of a different altered auditory feedback condition, frequency alteration, was described by Howell, El-Yaniv, and Powell (1987). Specifically, the frequency components of the speaker's voice were shifted down an octave. The results suggest that frequency altered feedback may be as effective as DAF and masking in the reduction of stuttering. To date, however, there has been no attempt to further investigate the fluency enhancing properties of frequency altered feedback.

The fact that frequency altered feedback has received scant attention in the research literature may be attributed to a general lack of interest in the relationship between altered auditory feedback and stuttering. This attitude stands in direct contrast to the research climate of previous years. Immediately following the initial studies of altered auditory feedback, researchers were intrigued by the possibility that stuttering might be attributed to disordered auditory function, and a number of theoretical models were developed to explain the nature of a possible cause/effect relationship (e.g., Cherry & Sayers, 1956; Mysak, 1966; Webster & Lubker, 1968). A decline in the initial enthusiasm seems to have occurred for two reasons. One reason is that theorists have minimized the role of audition in the control of normal speech production: It has been suggested that auditory information is unlikely to contribute to on-line regulation of speech sound production because information via this modality is not available to motor control centers rapidly enough to be useful (see a review by Borden, 1979). A

Preparation of this paper was supported in part by NIH Grant DC-00121 awarded to Haskins Laboratories. Joy Armson, Andrew Stuart, and Joseph Kalinowski should be considered equal authors of this paper.

second reason relates to widespread acceptance of an idea first advanced by Wingate (1970, 1976): Wingate proposed that artificial disturbance in auditory feedback leads to fluency enhancement only because it alters the speech production characteristics of stutterers. Wingate (1976) argued that the specific change in speech pattern that is induced by altered auditory feedback is "emphasis on phonation...[which] is expressed primarily in slowing down as developed through extended syllable duration" (p. 237).[1] He also argued that increased emphasis on phonation as expressed through slowed speech rate is the primary agent of change which is common to all fluency enhancement conditions (i.e., conditions under which fluency is induced temporarily).

Wingate's suggestion that slowed speech rate is important to fluency enhancement has received powerful empirical support. For example, Perkins, Bell, Johnson, and Stocks (1979) found that stuttering was essentially eliminated when speakers reduced speech rate by approximately 75%. They also found that slow rate achieved through extended syllable duration (as opposed to increased pause time) was optimally effective in promoting fluency. In addition, reductions in speech rate and/or extended segment durations have been found to characterize most conditions of fluency enhancement: for example, singing, and rhythmic speech (Andrews, Craig, Feyer, Hoddinott, Howie, & Neilson, 1983; Andrews, Howie, Dosza, & Guitar, 1982). The importance of slow rate to fluency enhancement is further underscored by the fact that almost all stuttering therapies from the 1800's to the present day have used slow speech rate in some form as a therapeutic strategy (see Van Riper, 1973, and Peters & Guitar, 1991 for reviews).

Consistent with findings for other fluency enhancement conditions, changes in speech rate have been found to occur under conditions of altered auditory feedback. For example, the speech rate of stutterers speaking under DAF has been reported as slow relative to normal rates (see Wingate, 1976, and Andrews et al., 1983, for reviews). According to Wingate (1976), "a general slowing down of speech" (p. 236) is the most commonly reported effect of DAF. With respect to speech produced by stutterers under masking noise, Brayton and Conture (1978) found an increase in vowel durations compared to a control condition, though the differences were not statistically significant. They did report, however, that increases in vowel duration were correlated with decreases in stuttering frequency. The temporal characteristics of speech produced under frequency altered auditory feedback have not been reported.

While it is undeniable that slow rate can induce a reduction in stuttering, there is evidence that it may not be the only variable which is involved in fluency enhancement. Support for this notion is provided by Andrews et al. (1982). These authors studied the temporal patterns underlying 15 conditions known to be fluency enhancing and found that slowed speech rate, characterized either by extended syllable duration or increased pause time, occurred in only seven conditions. The question arises, then, as to how necessary a slow rate is to the artificial inducement of fluency which occurs under conditions of altered audition. Correlation of two variables, here parallel reductions in speech rate and stuttering frequency, does not necessarily constitute causality. As such, the argument that slow speech rate may be responsible for inducing fluency under conditions of altered auditory feedback should be viewed as only one possible interpretation. Another interpretation is that speech rate slowing may be merely a naturally occurring by-product of conditions of altered audition which is not necessary for fluency enhancement under these conditions. In such a case, the primary effect of fluency enhancement would be related to some other variable(s). In order to determine how necessary slow speech rate is to the fluency inducing effects of altered auditory feedback, it seems reasonable to investigate whether stuttering decreases when speakers do not exhibit a slow speech rate. One way of counteracting any natural tendency that speakers may have to reduce speech rate under conditions of altered auditory feedback would be to instruct them to speak as quickly as possible.

To the best of our knowledge, an investigation in which stutterers are required to speak as quickly as possible under conditions of altered auditory feedback has not been conducted. There is, however, the practical problem of eliciting a fast rate of speech from a speaker while he/she is experiencing altered auditory feedback. For example, the typical response by speakers to DAF is to slow speech rate as a means of compensating for the imposed feedback delay (see Van Riper, 1982, for a review). However, there is evidence to suggest that normal speakers can override the typical speed-governing effects of DAF. In a study by Siegel, Fehst, Garber, and Pick (1980), adult normal speakers produced speech under delays of

250, 375, 500, and 675 ms at two different speech rates. When instructed to speak as rapidly as possible, these nonstutterers increased their speech rate by 34% as compared to conditions in which they were instructed to speak normally. In contrast to DAF, masking and frequency altered auditory feedback do not involve temporal alterations in the structure of the auditory signal, and there is no reason to believe that a speaker's rate of speech would necessarily be limited by this type of feedback. Thus, these latter two altered auditory feedback conditions seem appropriate to employ in an investigation requiring a fast speech rate.

The purpose of this study, therefore, was to investigate the relationship between speech rate and stuttering frequency under conditions of altered auditory feedback. Specifically, we wanted to determine the effects of masking, frequency altered auditory feedback, and DAF on stuttering frequency when stutterers were instructed to speak at a normal rate and as fast as possible. In keeping with the results of previous investigations, it was predicted that, when instructed to speak at a normal rate, stutterers would exhibit less stuttering under conditions of altered auditory feedback compared to a control condition of nonaltered auditory feedback. Further, if slow rate is a necessary prerequisite to the fluency enhancement process, then altered auditory feedback should not promote fluency when subjects attempt to speak as rapidly as possible. If, on the other hand, slow speech rate is not essential to the induction of fluency under conditions of altered audition, stutterers should exhibit reduced stuttering frequency while speaking rapidly. The latter finding would suggest that the fluency enhancing effect of altered auditory feedback is not solely contingent on decreasing speech rate.

Methods

Subjects. Seven male and two female stutterers, ages 16 to 52 years, participated. For inclusion in the study, subjects were required to demonstrate at least 5% stuttering frequency during a reading task under conditions of nonaltered auditory feedback. All subjects had a history of therapy although none had been enrolled in a program in the last two years.

All but one subject presented with normal bilateral hearing sensitivity, defined as thresholds of 20 dB HL (American National Standards Institute, 1969) or better at octave frequencies of 250 to 8000 Hz. The remaining subject, a 52 year old female, displayed a flat mild sensorineural loss on one side and normal hearing to 2000 Hz with a mild high frequency loss at 4000 Hz on the other. All subjects presented with normal bilateral middle ear function (American Speech-Language-Hearing Association, 1990).

Apparatus. All testing was conducted in a double-walled audiometric test suite (Industrial Acoustics Corporation). The equipment array provided the subjects with four auditory feedback conditions: nonaltered auditory feedback (NAF), masking auditory feedback (MAF), delayed auditory feedback (DAF), and frequency altered auditory feedback (FAF). In all conditions subjects spoke into a microphone (AKG Model C460B) held with a boom on a stand. The distance from the subjects' mouth was 15 cm with an orientation of 330° azimuth and -30° altitude. The microphone output was fed to an audio mixer (JVC Model MI-5000) and routed to a processor and amplifier (Yamaha Model AX-630) before being returned to the subjects' ears through insert earphones (EAR Tone Model 3A). Subjects' speech samples were video recorded with a camera (JVC Model S-62U) and video stereo cassette recorder (Sony Model SL-HF860D).

For the NAF and MAF conditions the speech input was routed through the processor unaltered. For the MAF condition a white noise masker, generated by an audiometer (Beltone Model 10D), was fed to the mixer and routed to the subjects via the same pathway as for their speech input. The masking output from the insert earphone was calibrated to a level of 85 dB SPL in a 2 cm^3 coupler (Brüel and Kjær Model DB-1038) employing a precision sound level meter (Brüel and Kjær Model 2209) and pressure microphone (Brüel and Kjær Model 4144). A level of 85 dB was used for the masking noise in an attempt to produce a noise-to-speech ratio of zero (see below).

In the DAF condition, the processor introduced a 50 ms delay to the speech input. Delays of 50 to 200 ms have previously been reported as optimally effective in enhancing fluency (see Starkweather, 1987a, for review). The smallest of these delays was selected for the present experiment because it was reasoned that a short delay would be less likely than a long delay to limit or restrict speech rate. This was further supported by pilot data which revealed that speakers were able to read rapidly while experiencing a 50 ms delay in the return of auditory feedback.

In the FAF condition, speech input was shifted up in frequency one half an octave by the processor. In contrast, in the Howell et al. (1987) experiments, frequency was shifted down an octave. The latter type of frequency alteration, in our opinion, results in less intelligible speech feedback as opposed to smaller shifts in frequency (e.g., one half an octave). It was considered preferable to use intelligible rather than unintelligible feedback in a FAF condition. Further, our preliminary testing showed that stutterers experienced a reduction in stuttering under the auditory feedback condition of a one half octave frequency shift. The decision to shift frequency up, rather than down, was arbitrary.

During all auditory feedback conditions the amplifier gain for speech input was preset. The output to the insert earphones was calibrated such that a speech signal input of 75 dB SPL to the microphone had an output in a 2 cm^3 coupler of approximately 85 dB SPL. The calibration procedure attempted to approximate real ear average conversation SPLs of speech outputs from normal hearing talkers. That is, an attempt was made to provide a speech level output to the speakers' ears that is consistent with auditory self -monitoring during their normal conversation.[2]

Procedures. While seated in the audiometric test suite, subjects read eight different passages taken from two junior high school level texts (Sims, G. [1987]. *Explorers*, Creative Teaching Press Inc. and Taylor, C. [1985]. *Inventions,* Creative Teaching Press Inc.). Each passage was slightly in excess of 300 syllables. Subjects were instructed to read a given passage at one of two speech rates: normal and fast. At each speech rate, subjects received four conditions of auditory feedback: NAF, MAF, DAF, and FAF. Passages were randomized with respect to auditory feedback condition. Between passage readings, subjects produced approximately one to two minutes of self-formulated monologue speech under NAF in order to minimize any possible carry-over of fluency enhancement from one auditory condition to the next. The auditory feedback conditions were randomized across subjects for each speech rate. Speech rate conditions were counterbalanced for all subjects.

During the fast speech rate condition, subjects were asked to read as fast as they possibly could while maintaining intelligible speech. In the normal speech rate condition, subjects were asked to read at their "usual" or "normal" reading rate. In order to minimize use of fluency-facilitating motor strategies learned in therapy (e.g., slowed speech, gentle voice onset), subjects were instructed to speak as naturally as possible and not to "control" or attempt to minimize their stuttering.

Stuttering was defined as part-word repetitions, part-word prolongations, and inaudible postural fixations. The frequency of stuttering was determined for the first 300 syllables of each video-taped sample by the second author, a certified speech-language pathologist. For one third of the samples, stuttering events were counted a second time by the same judge. Intrajudge reliability for total dysfluencies was .98. A second judge independently determined stuttering event frequency for all samples. Interjudge reliability for total dysfluencies was .95.

Analogue audio signals, from the video recordings of each subject, were digitized at a sampling rate of 10 kHz and analyzed at Haskins Laboratories using an in-house software waveform editing application (WENDY). To determine speaking rate, sections of fluent speech were identified within passages such that the fluently produced syllables were contiguous and the entire fluent speech sample was separated from stuttering episodes by at least one syllable. Separation between fluent speech samples and stuttering episodes was undertaken because it has been shown that the duration of a fluently produced syllable is greater when it is adjacent to a stuttering episode than when it is adjacent to fluent speech (Viswanath, 1986). In most cases, the fluent speech samples consisted of 50 contiguous fluently produced syllables. Identification of samples on the basis of multiple, contiguous fluent syllables was considered important in order to allow speakers to "get up to speed" following a stuttering episode. Fifty syllables was an upper limit for such a sample because of the large number of stutterings which occurred in many of the conditions. As it was, when stuttering frequency was very high, it was not always possible to find 50 fluent syllables which were contiguous. In a few cases, when the fluent syllable count was close to, though less than 50, a slightly smaller syllable count was accepted. In no cases were fewer than 43 syllables used. For some subjects there were conditions for which no samples of fluent syllables could be identified. Durations calculated for the fluent speech samples obtained represented the time between acoustic onset of the first syllable and the acoustic offset of the last fluent syllable, minus pauses that exceeded 100 ms. Most pauses were between 300 and 800 ms and were typically used by the speakers for an inspiratory gesture. Because most of these pauses had an audible inspiratory record, it is unlikely that they were silent stuttering moments. Fluent speech rate in syllables per second was calculated by dividing the duration of each fluent speech sample by the number of syllables in the sample.

Results

Stuttering frequency and syllable rate for each subject by condition are presented in Table 1.

Table 1. *Individual syllable rates and stuttering frequencies as a function of altered auditory condition and speech rate condition(n=9).*

		Syllable Rate				Stuttering Frequency	
Subject Number	Condition	Normal		Fast		Normal	Fast
1	NAF	5.17	(50)	*		2	102
	MAF	4.73	(50)	5.73	(50)	5	4
	DAF	4.57	(50)	4.75	(50)	2	7
	FAF	4.15	(50)	6.22	(50)	2	2
2	NAF	6.30	(45)	*		27	27
	MAF	5.50	(50)	7.68	(50)	10	8
	DAF	5.66	(50)	6.44	(50)	4	1
	FAF	5.85	(50)	7.06	(50)	2	0
3	NAF	*		*		28	36
	MAF	4.87	(50)	5.72	(50)	21	10
	DAF	4.54	(50)	6.00	(50	16	15
	FAF	5.07	(50)	5.48	(50)	6	5
4	NAF	*		*		73	57
	MAF	*		*		67	51
	DAF	4.81	(50)	6.75	(50)	3	0
	FAF	5.05	(50)	7.45	(50)	1	1
5	NAF	4.81	(50)	*		12	33
	MAF	4.50	(50)	*		13	20
	DAF	4.12	(50)	6.61	(50)	0	0
	FAF	4.91	(50)	6.02	(50)	0	0
6	NAF	5.40	(43)	*		11	24
	MAF	5.11	(50)	5.57	(50)	11	17
	DAF	5.38	(50)	5.42	(50)	12	10
	FAF	5.75	(50)	6.22	(50)	9	9
7	NAF	6.46	(50)	*		31	69
	MAF	7.54	(50)	*		18	86
	DAF	4.68	(50)	7.63	(50)	13	9
	FAF	5.34	(50)	*		14	50
8	NAF	3.89	(50)	*		7	37
	MAF	4.45	(50)	4.93	(50)	1	18
	DAF	4.11	(50)	4.84	(50)	1	2
	FAF	3.77	(50)	4.51	(50)	3	2
9	NAF	5.04	(50)	*		13	24
	MAF	5.55	(50)	6.99	(50)	5	13
	DAF	5.12	(50)	5.59	(50)	8	9
	FAF	5.17	(50)	5.94	(50)	5	10

Note: Numbers in parentheses represent contiguous syllable sample size. * represents samples where contiguous sample size criteria were not met.

The means and standard deviations for stuttering frequency and syllable rate, as a function of altered auditory feedback and speech rate conditions, are shown in Figures 1 and 2 respectively. Due to the fact that a number of subjects could not produce the required number of contiguous fluent syllables under certain conditions, means were calculated from eight values for the MAF-normal and FAF-fast speech rate condition, seven values for the NAF-normal speech rate condition, and six values for the MAF-fast speech rate condition. No subject met criterion for a fluent speech sample under the NAF-fast speech rate condition.

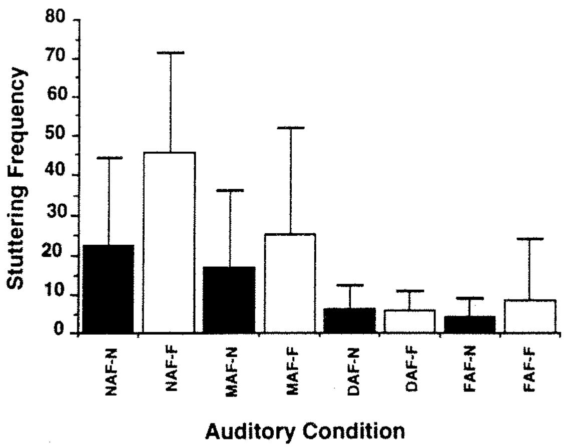

Figure 1. **Mean values for stuttering frequency as a function of speech rate and auditory condition (n=9). Error bars represent plus one standard deviation.**

Differences in stuttering frequencies and syllable rates, as a function of altered auditory feedback and speech rate, were tested using separate two-factor repeated measures analyses of variance (ANOVA). The NAF condition was not included in the ANOVA for syllable rate because, as noted above, there were no values for the NAF-fast speech rate condition.

The main effect of auditory condition on stuttering frequency was found to be significant [F (3,24) = 11.32, $p<0.0001$]. Paired t-tests were performed to ascertain which auditory conditions differed significantly. The mean stuttering frequency for NAF was found to be significantly higher than the mean stuttering frequencies for both DAF and FAF (8) = -4.46, $p < .01$ ($p < 0.01$).[3] All other pair-wise comparisons were nonsignificant ($p > 0.01$).

A probability value of 0.096 was found for the main effect of speech rate on stuttering frequency [F(1,8) = 3.55] and a probability value of 0.080 was found for the interaction of speech rate and auditory condition [F(3,24) = 2.54]. Thus, both the main effect and interaction approached significance. Inspection of mean values of stuttering frequency at normal and fast rates revealed marked differences for at least two auditory conditions (see Figure 1). Because of this observation and the near-significance of the main effect and interaction, paired t-tests were performed to test the differences in stuttering frequency as a function of speech rate for each auditory condition. A probability value of 0.072 was found for the difference between NAF-normal speech rate and NAF-fast speech rate. No other t- tests yielded results which approached significance.

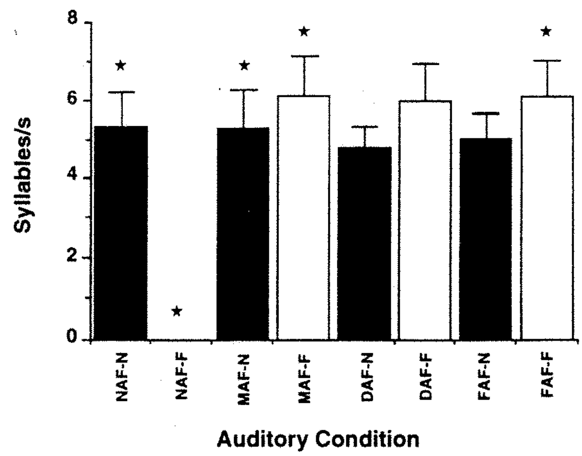

Figure 2. **Mean values for fluent syllable rate as a function of speech rate and auditory condition (n=9). Error bars represent plus one standard deviation. (Note: * as some subjects could not produce the required number of contiguous fluent syllables, means were calculated from eight values for the MAF-normal and FAF-fast speech rate condition, seven values for the NAF-normal speech rate condition, and six values for the MAF-fast speech rate condition. No subject met criterion for a fluent speech sample under the NAF-fast speech rate condition).**

The main effect of speech rate (i.e., normal vs. fast) was significant for syllable rate [F(1,5)=34.5, $p < 0.05$]. There was no significant difference in syllable rate as a function of auditory condition [F(2,10)=2.54,$p>0.05$] as well as no significant interaction of speech rate and auditory condition [F(2,10)=1.00, $p > 0.05$].

DISCUSSION

There are three principal findings in this study: (a) Subjects were able to achieve normal and fast speech rates under conditions of altered auditory feedback, including DAF; (b) there was a tendency for subjects to exhibit more stuttering under instructions to speak rapidly than under instructions to speak normally; and (c) stuttering decreased under conditions of DAF and FAF without respect to speaking rate.

Confirmation that subjects were successful in attaining the targeted speech rates was provided in two ways: First, for the three conditions of altered auditory feedback, all subjects increased speech rate in the fast rate condition compared to the normal rate condition. Second, the absolute values for both speech rates achieved by subjects in this study were consistent with norms from other sources. Specifically, the mean normal speech rates of the present subjects were in the range of 4.8 - 5.3 syllables/s (s/s), which are comparable to values of 4 - 5 s/s found to be characteristic of normal conversational speech (Netsell, 1981; Pickett, 1980; Walker & Black, 1950). Subjects in this study also exhibited mean fast speech rates in the range of 6.0 - 6.1 s/s. These rates clearly exceed the values typically cited as representing a normal conversational speech rate. In addition, these fast rates may also be compared to values provided by Pickett (1980) who judged his own rate of 5.6 s/s as "fast conversational" and 6.7 s/s as the "fastest clear articulation possible" (p.166). It is also interesting to note that the mean fast speech rate achieved under DAF was minimally different from the mean fast rates achieved under MAF and FAF (see Figure 2). Thus, for subjects in this study, a 50 ms delay in return of auditory feedback did not impose a limit on speech rate.

With respect to the second finding, the tendency for subjects to exhibit more stuttering under instructions to speak rapidly than when speaking at a normal rate, it may be noted that differences as a function of rate approached significance for speech produced under NAF only, although this trend was also observed under MAF. It was not possible to verify that, under NAF, subjects were able to comply with instructions to increase speech rate under because for many subjects, sections of fluent speech were too short to permit calculation of this measure, according to our criterion. However, it should be noted that subjects were able to increase speech rate in all other conditions and reported a similar intent under NAF-fast speech rate.

Previous findings regarding stuttering frequency as a function of instructions to increase speech rate are equivocal. Johnson and Rosen (1937) reported that stuttering frequency increased above a baseline level when stutterers were instructed to read as fast as possible. These authors described one subject in particular for whom stuttering increased over 100% in the fast rate condition compared to the baseline conditions. More recently, Armson (1991) reported fluent speech rates and stuttering frequencies for two stuttering speakers who had been asked to read utterances at slow, normal, and fast rate of speech. One of these subjects was able to increase his speech rate to a level which was commensurate with the fast rate of normal speakers. This subject experienced a dramatic increase in stuttering frequency at the fast speech rate compared to the normal rate. On the other hand, Young (1974) instructed stutterers to speak at a normal rate, a faster rate, and finally as fast as possible, and found that the mean ratings of stuttering severity did not differ significantly across these conditions. Ingham, Martin, and Kuhl (1974) reported that two out of three subjects increased speech rate relative to a base rate using words per minute (WPM) as a measure. They stated that "under no circumstances did stuttering frequency exceed that of the initial base rate sessions" (p. 495). Thus, the accumulated data suggest that there may be considerable intersubject variability with respect to the effect of increasing speech rate on stuttering frequency. It may be noted that in the present study, under conditions of nonaltered auditory feedback, seven of the nine subjects exhibited an increase in stuttering frequency as a function of increased speech rate, one subject exhibited fewer stutterings and the remaining subject exhibited no change. Further investigation of this effect is clearly warranted.

The most important finding of this investigation is that stutterers decreased stuttering frequency under certain conditions of auditory feedback alteration at both fast and normal speech rates. As such, the present results refute the notion, first advanced by Wingate (1970, 1976), that under conditions of auditory alteration, a slowed speech rate is a necessary antecedent for fluency improvement.

It is important to note that conditions of altered auditory feedback were similarly efficacious in reducing stuttering at both normal and fast speech rates. That is, the mean percent reductions in stuttering which were associated with a particular auditory feedback condition were not found to differ significantly across speech rates (although there was tendency for greater reductions in stuttering frequency to occur at the fast rate than at the normal rate; e.g., relative to the control condition, stuttering reduced by 87% under DAF at a fast rate and 72% under DAF at a normal rate). Further, the amounts of stuttering reduction which occurred in the present experiment are similar to levels which have been previously reported. For example, Andrews et al. (1983), in a review of studies of fluency enhancing conditions, concluded that reductions in the range of 50-80% are characteristic of speech produced under auditory feedback delays of 50-150 ms and masking. Similar values were obtained in this study under DAF and FAF. Percent reductions in stuttering under MAF were less robust but are consistent with the values reported by Martin and Haroldson (1979). Hence, use of normal and fast rates does not appear to reduce the fluency enhancement effect of these conditions.[4]

If speech rate reduction is not a necessary accompaniment for stuttering amelioration under conditions of altered auditory feedback, then another explanation must be offered. It seems reasonable to speculate that the relevant variables for fluency enhancement under conditions of auditory feedback pertain to auditory function. As such, it is important to search for clues within the present data which might lead to their identification. Toward this end, it may be recalled that the auditory conditions of the present experiment were not equally effective in reducing stuttering frequency. Reduction in stuttering frequency was greater and more consistent across subjects for DAF and FAF than for MAF. Only mean stuttering frequencies for DAF and FAF were found to be significantly different from the control NAF conditions. Given that FAF and DAF are similarly effective in inducing fluency, it is important to consider what properties these conditions may share and how they may differ from MAF.

During MAF, speakers receive two auditory signals: a masking noise and their own speech signal. It is assumed that the masking noise interferes with or impedes reception of the speaker's speech. During DAF and FAF, on the other hand, speakers receive only one auditory signal: their own speech, which is altered slightly in terms of either temporal or frequency characteristics. Therefore, common to DAF and FAF may be the fact that stutterers use their own speech signal (albeit in slightly altered form) to enhance fluency. Further, the fact that alterations in two different parameters of the acoustic signal (i.e., frequency and temporal structure) yield similar fluency enhancing effects seems worthy of note. It may suggest that the effects are not due to the correction of some specific deficit in the stutterer's auditory perceptual processes but to something more global. In this context, it is interesting to note that several subjects reported that speaking under FAF was similar to unison speech. It may be speculated that both DAF and FAF are essentially electronic forms of the "double speaker" phenomenon. The double speaker phenomenon refers to the finding that stuttering is markedly reduced when stutterers speak in combination with another speaker. These phenomena have typically been referred to as "shadow speech" (when the stutterer is slightly delayed relative to the other speaker) and "choral (or unison) speech" (when the two speakers are nearly synchronous) (see Andrews et al., 1983). It is suggested that DAF is a form of "inverse shadow speech" in that the "other speaker" is slightly delayed (e.g., 50 ms) and FAF is a form of choral speech in that the other speaker is speaking simultaneously using either a higher voice (the present study) or a lower voice (Howell et al., 1987).

These speculations about the role of altered auditory feedback in fluency enhancement, in combination with the finding that rate reduction is not necessary for fluency improvement, have important implications with respect to the prevailing view of the nature of stuttering, specifically that stuttering is a disorder of speech timing. In the past, explanations of fluency enhancement have been used to support this view. For example, Kent (1983) argued that "fluency enhancing conditions generally reduce temporal uncertainty ...or allow more time for the preparation of temporal programs" (p. 253), and concluded that stutterers may have "reduced capacity to generate temporal programs" (p. 253). In other words, the key variables responsible for fluency enhancement are either slow speech, which provides a stutterer with more time for motor planning, or an external source of support, which assists the stutterer in generating the temporal patterns of speech. Examples of conditions involving an external source of temporal support are choral and shadow speech. In these conditions, the external source of support is another speaker. That is, it is speculated that the stutterer receives temporal support by relying on the unimpaired timing system of the other speaker (Starkweather, 1987b). According to Kent's argument, the fact that stutterers benefit from an increase in motor planning time or a reliance on externally generated timing patterns indicates that stuttering must somehow result from a speaker's deficiencies in generating these patterns. The present study shows, however, that fluency enhancement may be achieved under certain auditory conditions both when stutterers speak rapidly and when there is no external source of support for generating the temporal patterns of speech (i.e., when subjects use altered/processed versions of their own rapidly produced speech to enhance fluency). If fluency enhancement does not depend on either reduction in temporal uncertainty or more time for preparation of motor programs, then one must question the claim that the underlying deficit in stuttering is reduced capacity to generate temporal programs.

It is evident that studying the fluency enhancement process may be an important route to understanding the nature of stuttering. As noted above, researchers have attempted to identify motor factors which underlie conditions of fluency enhancement and have used this information to develop a theoretical framework for explaining the cause of the disorder. Of the motor patterns which have been studied, slow speech rate is probably the most frequently reported. However, it is likely that other motor patterns are important for fluency enhancement as well. For example, changes in diaphragmatic breath control (Story, 1990), reduction in peak velocity and displacement of the upper lip, lower lip and jaw (Kalinowski, Alfonso, & Gracco, 1991; Story, 1990), and low levels of laryngeal muscle activity (Armson, 1991) have been found to be associated with fluency improvements. One or all of these variables may ultimately prove to be necessary to such improvements. Undoubtedly there are other changes in speech motor patterns which may be also associated with reductions in stuttering.

It is proposed that in addition to modification of speech production characteristics, alterations of auditory feedback may also be responsible for fluency enhancement. These changes in auditory feedback may involve external alterations in the stutterer's own voice (e.g., DAF, FAF) or careful monitoring of another speaker (e.g., choral speech and shadow speech). There are probably other changes to auditory input, as well, which are fluency enhancing. It is further suggested that if auditory and motor factors are inseparable aspects of the speech motor control process, as seems likely, modifications in one will automatically produce changes in the other. In some manner, these sensory-motor modifications may stabilize an intermittently unstable system.

The idea that stuttering is a disorder involving both sensory and motor factors is not novel. Neilson and Neilson (1987) proposed a theoretical account which attributes the problem to "inadequate resources for sensory-motor information processing" (p. 325). According to their model, "feedback...participates in establishing, verifying, and, if necessary, modifying the relationship between motor commands and their... sensory consequences" (p. 327). These sensory-motor relationships are represented in the nervous system by internal models. Neilson and Neilson proposed that stuttering occurs when demands for modeling new sensory-motor relationships exceed the stutterer's limited resources. They suggested that fluency is assured only if some central processing resources which are usually used to form sensory-motor models are freed, or else if sensory-motor processing can be extended in time. However, the existence of fluency enhancement conditions which involve alterations of a speaker's own voice, independent of speech rate reduction, as found in the present experiment, seem to pose a problem for Neilson and Neilson's theory. Specifically, it is difficult to understand how central resources used for modeling sensory and motor relationships would be freed while the speaker is receiving altered auditory feedback and at the same time is speaking rapidly. On the contrary, it would seem that additional, rather than fewer, demands would be made on neuronal resources for sensory-motor processing. Thus, while the present data may be interpreted as supporting the general notion that stuttering is a disorder involving both sensory and motor factors, they do not support the details of Neilson and Neilson's theory. Further research is needed to explore the relationship between speech input/output changes in order to better delineate how this relationship may affect stuttering, and to suggest the nature of a specific sensory-motor deficit which may underlie the disorder.

REFERENCES

American National Standards Institute (1969). *Specifications for audiometers* (ANSI S3.6 - 1969). New York, NY

American-Speech-Language-Hearing Association (1990). Guidelines for screening for hearing impairments and middle ear disorders. *ASHA*, 32 (Suppl. 2), 17-24.

Andrews, G., Craig, A., Feyer, A., Hoddinott, P., & Neilson, M. (1983). Stuttering: A review of research findings and theories circa 1982. *Journal of Speech and Hearing Disorders, 45*, 287-307.

Andrews, G., Howie, P.M., Dozsa, M., and Guitar, B. E. (1982). Stuttering: Speech pattern characteristics under fluency-inducing conditions. *Journal of Speech and Hearing Research, 25,* 208-215.

Armson, J. (1991). *A study of laryngeal muscle activity during stuttering episodes: Searching for an invariant physiological correlate.* Doctoral dissertation, Temple University, Philadelphia, PA.

Bentler, R. A., & Pavlovic, C. (1989). Transfer functions and correction factors used in hearing aid evaluation and research. *Ear and Hearing, 10*, 58-63.

Borden, G. J. (1979). An interpretation of research on feedback interruption in speech. *Brain and Language, 7*, 307-319.

Brayton, E. R., & Conture, E. G., (1978). Effects of noise and rhythmic stimulation on the speech of stutterers. *Journal of Speech and Hearing Research*, 21, 285-294.

Cherry, E., & Sayers, B. (1956). Experiments upon total inhibition of stammering by external control and some clinical results. *Journal of Psychomotor Research, 1*, 233-246.

Cornelisse, L. E., Gagné, J. P., & Seewald, R. C. (1991). Ear level recordings of the long-term average spectrum of speech. *Ear and Hearing, 12*, 47-54.

Howell, P., El-Yaniv, N., & Powell, D. J. (1987). Factors affecting fluency in stutterers. In H. F. M. Peters & W. Hulstijin (Eds.), *Speech motor dynamics in stuttering* (pp. 361-369). New York: Springer-Verlag.

Ingham, R. J., (1984). *Stuttering and behavior therapy: Current status and experimental foundations*. San Diego, CA: College Hill Press.

Ingham, R. J., Martin, R. R., & Kuhl, P. (1974). Modification and control of rate of speaking by stutterers. *Journal of Speech and Hearing Research, 17*, 489-496.

Johnson, W., & Rosen, P. (1937). Studies in the psychology of stuttering: VII. Effect of certain changes in speech pattern upon stuttering frequency. *Journal of Speech and Hearing Disorders, 2*, 105-109.

Kalinowski, J. S., Alfonso, P. J., & Gracco, V. L. (1991). *Modifications to stutterers lip and jaw kinematics following therapy*. Paper presented at the Annual Convention of the American Speech-Language-Hearing Association, Atlanta, Georgia.

Kent, R. D. (1983). Facts about stuttering: Neurolinguistic perspectives. *Journal of Speech and Hearing Disorders , 48*, 249-255.

Lotzman, V. G. (1961). Zur Anwendung variierter Verzögerungszeiten bei balbuties. *Folia Phoniatrica, 13*, 276-312.

Martin, R., & Haroldson, S. K. (1979). Effects of five experimental treatments of stuttering. *Journal of Speech and Hearing Research, 22*, 132-66.

Mysak, E. D. (1966). *Speech pathology: Feedback theory*. Springfield, IL: Charles C. Thomas.

Neilson, M. D., & Neilson, P. D. (1987). Speech motor control and stuttering: A computational model of adaptive sensory-motor processing. *Speech Communications, 6*, 325-333.

Netsell, R. (1981). The acquisition of speech motor control: A perspective with directions for research. In R. Stark (Ed.), *Language behavior in infancy and early childhood* (pp. 127-153). Amsterdam: Elsevier-North Holland.

Perkins, W. H., Bell, J., Johnson, L., & Stocks, J. (1979). Phone rate and the effective planning time hypothesis of stuttering. *Journal of Speech and Hearing Research, 29*, 747-755.

Peters, T. J., & Guitar, B. (1991). *Stuttering: An integrated approach to its nature and treatment*. Baltimore, MD: Williams and Wilkins.

Pickett, J. M. (1980). *The sounds of speech communication: A primer of acoustic phonetics and speech perception*. Baltimore: University Park Press.

Seigel, G. M., Fehst, C. A., Garber, S. R., & Pick, H. L. (1980). Delayed auditory feedback with children. *Journal of Speech and Hearing Research, 23*, 802-813.

Starkweather, C. W. (1987a). *Fluency and stuttering*. Englewood Cliffs, NJ: Prentice Hall.

Starkweather, C. W. (1987b). Laryngeal and articulatory behavior in stutterers. In H. F. M. Peters & W. Hulstijin (Eds.), *Speech motor dynamics in stuttering* (pp. 3-18). New York: Springer-Verlag.

Story, R. (1990). *A pre- and post-therapy comparison of respiratory, laryngeal, and supralaryngeal kinematics of stutterers' fluent speech*. Doctoral dissertation, University of Connecticut, Storrs.

Van Riper, C, (1973). *The treatment of stuttering*. Englewood Cliffs, NJ: Prentice Hall.

Van Riper, C, (1982). *The nature of stuttering*. Englewood Cliffs, NJ Prentice Hall.

Viswanath, N. S. (1986). *An investigation of pre- and post-cursive effects of a stuttering event in the context of a planning unit and temporal reorganization of adapting utterances*. Doctoral dissertation, City University of New York.

Walker, C., & Black, J. (1950). *The intrinsic intensity of oral phrases* (Joint Project Report No. 2). Pensacola, FL: Naval Air Station, United States Naval School of Aviation Medicine.

Webster, R. L., & Lubker, B. B. (1968). Interrelationships among fluency producing variables in stuttered speech. *Journal of Speech and Hearing Research, 11*, 754-66.

Wingate, M. E. (1970). Effect on stuttering of changes in audition. *Journal of Speech and Hearing Research, 13*, 861-863.

Wingate, M. E. (1976). *Stuttering: Theory and treatment*. New York: Irvington.

Young, M. A. (1974). Stuttering severity and instructions to increase speaking rate. *The Illinois Speech and Hearing Journal, 8*, 3-6.

FOOTNOTES

Language and Speech, 36(1), 1-16 (1993).

†Dalhousie University.

[1] It has been shown that extended syllable duration and an increase in pause time are the primary strategies for reducing speech rate (Ingham, 1984).

[2] A speech signal input of 75 dB SPL to the microphone was selected to be consistent with the average conversation levels from adults and children to a microphone located 15 cm from the talker's mouth (Cornelisse, Gagné, and Seewald, 1991). The 2 cm^3 output level of 85 dB SPL was derived with a 2 cm^3 behind-the-ear hearing aid microphone to ear canal correction from Bentler and Pavlovic (1989) applied to the same ear level recordings from the average conversational speech found by Cornelisse et al. The input signal to the microphone was a speech weighted composite noise generated by a Fonix 6500 Hearing Aid Test System. The stimulus was composed of frequencies from 100 to 8000 Hz (in 100 Hz intervals) with a flat amplitude for the low frequency components and a roll-off slope of 6 dB per octave starting at 1000 Hz. The output of the insert earphones was measured in the 2 cm^3 coupler with the precision sound level meter and pressure microphone.

[3] In order to account for multiple t-tests, a significant alpha level of 0.01 was adopted.

[4] Andrews et al. (1983) reported reductions in the range of 90-100% as characteristic of prolonged speech under DAF (i.e., speech produced under delays which exceed 150 ms). This finding suggests that the fluency enhancement effects under conditions of altered auditory feedback may be enhanced by a subject's use of exaggerated prolongation of speech segments.