Modifying Electroglottograph-Identified Intervals of Phonation: The Effect on Stuttering

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Single-subject experiments were conducted with an adolescent and an adult male who stutter to assess the effect on stuttering of changing the frequency of phonation intervals that were within prescribed duration ranges during spontaneous speech. Electroglottograph-identified intervals of phonation were measured using a computer-assisted biofeedback system. Both subjects demonstrated that their stuttering could be controlled by modifying the frequency of phonation intervals within short duration ranges. The experimental effects not only replicated earlier findings but were demonstrated to be independent of changes in speaking rate, or alterations to other intervals of phonation, and produced little disruption to speech naturalness. The theoretic implications of these findings are discussed.

KEY WORDS: stuttering, phonation, treatment, naturainess, electroglottograph

Much of the current interest in the speech motor behavior of persons who stutter has emerged from findings concerning the facility with which they are able to initiate and terminate voicing. There is mounting evidence that adults who stutter tend to have slower voice or laryngeal reaction times than their normally fluent counterparts (see Adams, 1985; Adams, Freeman, & Conture, 1984; Peters & Hulstijn, 1987), and that this difference is even more pronounced among adults with severe stuttering (Watson & Alfonso, 1983; 1987). The apparent interaction between unusual pho- na- tory behavior and stuttering may be related to evidence that adults who stutter tend to display relatively longer intervals of phonation during stutter-free speech (Pindzola, 1987; Prosek & Runyan, 1982), a characteristic that is less evident among children who stutter (Healey & Adams, 1981b; Zebrowski, Conture, & Cudahy, 1985). One plausible explanation is that older persons who stutter may have learned to manage their disorder, however imperfectly, by using relatively slow initiations of voicing and longer intervals of phonation (Onslow & Ingham, 1987). If that is the case, then it should follow that training to control the frequency of short intervals of phonation (presumably they require faster and more frequent initiation/termination of phonation) should control the frequency of stuttering among such speakers.

Interest in the contribution that changes in temporal aspects of phonation make to the modification of stuttering was largely prompted by Wingate's (1969, 1970, 1976) modified vocalization hypothesis. Numerous attempts to investigate this hypothesis have suggested that many of the alleged "fluency-inducing" procedures also involve increases or even decreases in phonated intervals (PIs) in the speech of persons who stutter. For instance, changes in the proportion of phonation time have been found during singing (Colcord & Adams, 1979), slow speech (Healey & Adams, 1981a), and

1The notion that procedures that reduce stuttering also produce fluency is misleading. The resulting speech, as Finn and Ingham (1989) point out, may have no resemblance to the conventional concept of fluent speech.
chorus reading (Adams & Ramig, 1980). The beneficial effect on stuttering of delayed auditory feedback and/or prolonged speech (Goldiamond, 1965) has also been attributed to increases in the duration of phonation during speech (Ingham, 1984). There is also some evidence that when adults who stutter receive treatment based on prolonged speech, their posttreatment improved speech is characterized by increases in phonation time (Mallard & Westbrook, 1985; Robb, Lybolt, & Price, 1985). Similar effects have been found to occur with other types of treatment (Metz, Samar, & Sacco, 1983; Ramig, 1984; Samar, Metz, & Sacco, 1986). However, the relationship between changes in the duration of specific intervals of phonation and reductions in stuttering during fluency-inducing conditions has not been fully investigated. That relationship may also be unpredictable. Andrews, Howie, Dozsa, and Guitar (1982), for instance, found that only 4 of 12 fluency-inducing conditions (chorus reading, shadowing, singing, DAF-induced prolonged speech) produced effects that were associated with consistent alterations to measures of phonation time. Prins and Hubbard (1990), however, also reported that adaptation trends were associated with variable, rather than consistent, changes in phonated intervals.

An intriguing feature of recent research on the role of phonation management and stuttering is the absence of interest in studying the effects of directly modifying phonation time. Investigations of this type help isolate specific parameters of phonation or related variables that might functionally control stuttering (Ingham, 1990). The sole published investigation of this type was conducted by Ingham, Montgomery, and Ulliana (1983). They assessed the effect of directly altering the frequency of specified Pls during the spontaneous speech of 2 men who stuttered. An accelerometer was attached to the thyroid prominence for recording Pls, and a biofeedback procedure signaled Pls that were either shorter or longer than specified durations. The selected durations were functionally identified as the shortest that the subject could modify. The results showed that when 1 subject decreased (by at least 50%) Pls that were less than 100 msec, his stuttering was essentially eliminated. Conversely, when he increased these Pls, his stuttering increased above base-rate levels. Similar effects occurred with the other subject, but with Pls less than 150 msec. The effects of this procedure were not associated with changes in speech rate, although they did produce unpredictable changes in speech quality: 1 subject's speech was rated as normal sounding, but the other's was relatively nonsounding.

The Ingham et al. (1983) results suggested that there may be a functional relationship between certain Pl frequencies during spontaneous speech and stuttering events. They also implied that one variable that might control stuttering during some fluency-inducing conditions is the frequency of relatively short, rather than long, Pls. However, the methodology in this study was rather limited: It was not possible to identify variations in Pl durations outside of the target range, or whether changes in other duration ranges might also modify stuttering frequency. At least two developments now make it possible to make more extensive analyses of the effects of modifying the Pl frequency on stuttering. The first is a coupling of electroglottographic (EGG) measures of phonation (Childers, Hicks, Moore, Eskenazi, & Lalwani, 1990; Fourcin, 1974) with a computer-based measurement and feedback system; the second is the use of repeated speech naturalness ratings (Ingham, Gow, & Costello, 1985; Martin, Haroldson, & Triden, 1984; Onslow & Ingham, 1987) to trace variations in speech quality during experimental conditions.

The general purpose of the experiments reported below was to conduct a systematic replication of the Ingham et al. (1983) study to evaluate the effect of modifying the frequency of EGG-measured Pls on stuttering and speech naturalness. This study was also influenced by Ingham and Devan's (1987) positive findings during a preliminary application of this technology. The present study was designed to identify the Pl durations that showed maximum covariation during experimental conditions and to assess the effect of instructing subjects to control the frequency of these covarying Pls during spontaneous speech.

Method

Subjects

Two males who stutter volunteered to be subjects. Subject T.B. (34 years old) and Subject J.P. (17 years old) were assessed independently by two experienced speech-language pathologists who reported that the subjects' speech contained many of the kernel characteristics described in Wingate's (1964) definition of stuttering. Both subjects stated that their stuttering problem had begun in early childhood. Neither subject had received any formal stuttering treatment, nor training in any procedure that required the use of a specific speech pattern. Base-rate measures of each subject's stuttering frequency, speech rate, and speech naturalness were obtained as part of the experimental procedure and are described in the Results.

Apparatus

Throughout the experiment, each subject sat alone in an experimental sound-treated booth. The subject sat before a table and wore an EGG electrode neckband connected to an EGG (Synchrovoice) unit, plus a headset acoustic microphone (Toa HY-1). The microphone signal was routed to a two-channel reel-to-reel recorder (Revox PR99). The EGG signal was fed to a high-pass filter (Krohn Hite 3323) and a custom-built signal-shaping unit (J-FET Input Operational Amplifier). The EGG signal output, therefore, was amplified, high-pass filtered (60 Hz), and then rectified to a positive-going pulse so that it was suitable for the computer system's A/D conversion system. On the table facing the subject was a video display terminal (DEC VR241-A), a deck of cards containing speech topic headings, a light and tone generator that was used to emit a 750-Hz tone and illuminate a 10-mm red light, and a two-way intercom unit.
The subject was audio recorded and monitored by the experimenters (Judges 1 and 2) via headphones from an adjacent control room. Judge 1 sat before a VDT to operate the computer facility that measured, recorded, and stored all the data from this experiment. During speaking trials (see below) Judge 1 operated an electronic dual button-press counter. For each syllable spoken by the subject, Judge 1 pressed one of the buttons according to whether it was judged as stuttered or nonstuttered (see Costello & Ingham, 1984). Judge 2 operated a digital rating unit to make speech naturalness ratings on a 5-point scale (Martin, Haroldson, & Triden, 1984) at 30-sec intervals. When signalled, Judge 2 moved the switch on the rating unit to the appropriate number (1–9) according to how natural the subject's speech sounded. Neither judge had access to the other judge's scores during the course of the experiment. Audio recordings of the subject's speech were made using the two-channel reel-to-reel recorder that received the microphone signal from the booth and simultaneously routed the signal to the judges' headphones. A tone generator produced a low-frequency audible tone that was routed to Judge 2's headphones for 5 sec at 30-sec intervals during all 5-min speaking trials. This tone was a prompt for Judge 2 to assign a speech naturalness rating based on the preceding 30-sec interval of speech.

**Data recording and feedback system.** The computer facility was operated with custom-built software that performed a variety of functions during and after the experiment. During the experiment, the data recording and feedback was managed by the Real-Time Operation Program (RTOP). After the experiment, data analyses were available from the Post-Experiment Analysis Program (PEAP). The functions of each program are as follows:

Real-Time Operation Program (RTOP): This program collected the analog signals from the EGG, the subject's headset microphone, plus the judges' button-press counter and speech naturalness rating unit. For the purposes of these experiments, the EGG signal was digitized at 100 Hz. When the EGG signal was above a noise level criterion (described below), it was recorded as a PI. All PIs and NPIs (nonphonated intervals) that were less than 10 msec were ignored. Hence, a period of phonation that was interrupted by a nonphonation period of less than 10 msec would be treated as a continuous phonated interval. Thus, the program measured, in real time, the durations of PIs and NPIs from the EGG signal, syllable counts, and the speech naturalness ratings. These data were recorded, displayed when necessary, and archived to magnetic tape at the end of each recording session.

The RTOP provided a display of performance information for the subjects. Most importantly, it provided rapid (<20 msec) visual and audio feedback to the subject of each PI occurrence via the subject's VDT. Each PI occurrence was graphically displayed in real time on the VDT as a small red square in one of three display panels according to whether its duration was within the experimenter-selected target range, or above or below that range. The PIs were displayed cumulatively in relevant panels while the subject was speaking. Light and tone signals were prescribed to accompany the occurrence of PIs within one of the three panels. Counts of syllables stuttered and nonstuttered were also displayed on the VDT as short cumulative red marks along a continuous green line. Speech naturalness ratings (1–9) were shown numerically at the base of the screen and could be changed by Judge 2 at 30-sec intervals. Elapsed speaking time was displayed graphically at the base of the VDT screen. The number of PIs, syllables stuttered, and syllables spoken during each 30-sec interval were tallied and displayed for a period of 5 sec. The cumulative PI data plus the means for percent syllables stuttered, syllables per minute, and speech naturalness ratings during the 5-min speaking trial were displayed at the end of the trial.

Post-Experimental Analysis Program (PEAP): This program was used to analyze the distribution of PIs obtained from each subject to identify the phonation duration (msec) ranges for experimental manipulation and to assess the effects of those manipulations. This procedure differed from that of Ingham et al. (1983), in which PI duration ranges were prescribed 50-msec intervals. In such intervals, the subject's base-rate PI frequencies in similar size duration ranges (e.g., 0–50 msec, 50–100 msec, etc.) differ substantially. Consequently, the frequency of PIs that the subject would receive as feedback with each experimental shift in the duration range would vary quite dramatically within and across subjects. The solution introduced in the present study was to produce individualized and equivalent PI frequency duration ranges from the subject's PI frequency/duration pattern during base-rate. The advantage of this method is that the subject's PI frequency distribution then determines the size of each duration range. Hence, each subject's PI distribution was divided into decile ranges. This method identified duration ranges that contained almost equivalent frequencies of PIs for experimental manipulation and analysis for each subject's experiment. For example, in the present study, subject T.B. produced PIs that ranged from 30 to 3200 msec during the base-rate speaking trials. The PEAP determined that the decile ranges for his PIs were as follows: 30–100, 100–140, 140–200, 200–260, 260–320, 320–400, 400–490, 490–640, 640–920, 920–3200 msec. Each of these 10 ranges included approximately the same number of PIs during base-rate. In a 5-min trial, T.B. produced approximately 58 PIs in each decile range.

The PEAP was also used to conduct a Monte Carlo sampling analysis (Rubinstein, 1981) of the distribution of PIs in different experimental phases. The purpose of this analysis system within PEAP was to identify PI ranges in which the subject's PI frequencies showed maximum differences between different experimental phases within Stage II of the experiment (see Results). The analysis system randomly sampled 200–2,000 PIs from the PI distributions in each phase and then determined the duration range where the two

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3A complete description of this software and its functions, redeveloped for a PC-based system, is available from the authors.

4One artifact of our system is that the program may assign an unequal number of PIs to a particular range. This is a function of the sampling rate and the decision algorithm.
distributions showed maximum and significant differences. The particular duration range that showed maximum differ-
ence is referred to hereafter as the Monte Carlo Range. The
application of this system to identify the Monte Carlo Range
is described in the Results section for each subject’s experi-
ment.

**Procedure**

Each subject’s experiment was conducted over a number of
twice weekly 2-hour sessions with from 5–14 five-minute
speaking trials per session. For each 5-min speaking trial, the
subject was instructed to speak spontaneously on topics that
were self-generated or suggested by topic cards. Each trial
was separated from the next by a 3-min rest period.

At the beginning of each session, a routine procedure was
used to fit the subject with the microphone and EGG appa-
ratus. The headset was positioned so that the microphone
was 3 in. in front of the subject’s chin. The microphone signal
level was set to peak at 0 on the audiorecorder’s VU meter.
The EGG neckband (a 2-in. collar that incorporated the
active and grounding surface electrodes) was positioned
comfortably on the subject’s neck so that the active elec-
trodes surrounded the thyroid prominence and the resulting
signal was most clearly related to voicing. Neither subject
reported that the neckband caused discomfort despite being
worn for as long as 2 hr.

Immediately before each 5-min speaking trial, the EGG
signal was tested by two methods to identify and remove
artifactual signals. First, if the signal level exceeded a pre-
scribed resting voltage level while the subject sat quietly, the
neckband was refitted or a wrist strap was attached as a
grounding device. Second, the RTOP conducted a 5-sec
noise level test on each data-gathering channel to establish
an operating signal-to-noise-level ratio for each trial. During
the 5-sec noise-level test, the subject sat quietly and avoided
excessive laryngeal movements (e.g., coughing, swallow-
ing). The noise-level criterion was established by recording
the EGG signal level and then adding a 25% margin to that
level. Any EGG signal above this noise-level criterion during
a trial was recorded as a PI.

Immediately after the noise-level test was set for the
RTOP, Judge 2 activated the tape recorder, announced the
trial number over the intercom, and pressed the tone switch
to signal the subject to commence speaking. The RTOP was
simultaneously activated and continued for 5 min, when
another tone signalled the subject to cease speaking. The
subject could also monitor the trial time from the VDT.

Each subject’s experiment was composed of base-rate
and experimental phases (see below). During all 5-min
speaking trials in these phases, the subject was instructed to
speak spontaneously. During base-rate phases, the subject’s
VDT displayed only the elapsed time for the trial. During the
experimental phases, the subject was provided with relevant
PI feedback on the VDT plus audio tones for specified PIs. In
these phases, the subject was instructed to control the
frequency of PIs within a prescribed decile range (target
range). Prior to each experimental phase the subject was
also given 1-min practice trials designed to familiarize him
with the PI feedback display. The subject was told that each
PI was computer-recorded and immediately displayed as a
small square in one of the three panels according to its
duration. He was instructed to focus on the PIs that occurred
in a specific panel because they represented PIs within a
target range that he was expected to control. He was also
told the minimum and maximum msec durations for this
range.

Prior to all experimental phases (except those in Stage III,
described below), the subject was told the mean number of
target range PIs that were produced during base-rate trials.
He was then told that in the following trials he should try to
either decrease or increase by 50% his mean base-rate
frequency of PIs in the target range. The within-trial criterion
for each 30-sec speaking interval, therefore, was either 50% of
the mean base-rate (divided by 10), or 150% of the mean
base-rate (divided by 10). This number was displayed in
writing above the subject’s VDT. A brief practice trial was
then conducted. Typically, the subject’s practice trial was
composed of short utterances such as counting, sustaining
vowels, and reciting short sentences of familiar phrases. The
subject was never instructed to adopt a particular manner of
speech to reduce his target range PI counts.

**Dependent variables.** Four speech performance mea-
sures collected during each speaking trial were converted to
the dependent variables for each subject’s experiment. Per-
cent syllables stuttered (%SS) and syllables spoken per
minute (SPM) scores were derived from Judge 1’s scores in
accordance with the procedure described by Ingham et al.
(1983). The speech naturalness ratings were made by Judge
2 and followed the procedure described by Ingham, Martin,
Haroldson, Onslow, and Leney (1985). On this rating scale, 1
equals highly natural-sounding speech and 9 equals highly
unnatural-sounding speech. Mean speech naturalness rat-
ings were derived from the ten 30-sec ratings per trial. The
fourth measure was frequency of PIs produced within the
decile ranges derived from the subject’s base-rate phase or
PIs from ranges derived via the Monte Carlo analysis (see
below).

**Experimental Design**

The two single-subject experiments employed unfolding
time-series designs (Barlow & Hersen, 1984), with four
stages in each experiment. Each stage incorporated a series
of withdrawal and reversal phase-change designs (Barlow &
Hersen, 1984). Experimental phase changes within each
stage were based on data trends that were used to determine
whether the subject could manipulate the specified speech
performance measures. Trials were continued in each phase
until either (a) the subject’s speech performance was within
the predetermined criterion for three consecutive trials, or (b)
the subject was unable to complete three consecutive trials
to criterion within a maximum of nine trials per phase. All
phase changes occurred during a 2-hr session so as to avoid
the confound of between-session effects. Hence, the first two
stages in this experiment essentially replicated the Ingham et
al. (1983) experimental design, whereas the last two stages
were designed to test whether obtained experimental effects
were associated with changes in other speech performance measures.

**Stage I.** The purpose of this stage was to establish base-rate (A phase) data trends and identify the smallest combination of decile ranges in which the subject could both reduce (by 50%) his mean base-rate PI frequency and his frequency of stuttering. As in Ingham et al. (1983), a series of A/B~A experimental phases6 was used to identify the shortest decile range in the B~ phase that the subject could modify and produce associated effects on his stuttering frequency. When it was established that this correlated effect occurred, then that particular decile range(s) became the target range for Stage II.

**Stage II.** This stage was designed to assess the effect on stuttering frequency when a subject systematically increased (by 50%) and then decreased (by 50%) the frequency of PI counts in the target duration range identified in Stage I. This stage incorporated a B~/B+/B~/B+ experimental design. During B~ conditions, the subject was instructed to reduce PI counts in the target range to the level established in Stage I for B~ conditions. In the B~ phase the subject was instructed to increase his PI counts to 50% above the frequency recorded in the target range during the A phase.

An additional aim in Stage II was to identify the PI range that showed maximum changes in PI counts (the Monte Carlo Range) across the B~ and B+ phases (i.e., where the subject's target range PI counts were maximally increased or decreased). The Monte Carlo sampling analysis was performed by the PEAP (see above) to locate the PI range that the subject might have actually manipulated in order to control PI frequencies in his target range.

**Stage III.** This stage was designed to determine whether the subject could control and then perhaps decrease PIIs within the Monte Carlo Range identified during Stage II. The initial part of this stage involved a B~/C/B~ experimental design. The B~ phase replicated the conditions that applied in previous B~ phases and served to establish the frequency of PIIs that occurred in the Monte Carlo Range.

The C phase was introduced with a practice trial in which the subject was told that during this phase he would receive PI counts for a range that he had “appeared to control without feedback” during the previous sessions. The target PI count during the C phase was identical to the mean PI count that the subject had achieved in the Monte Carlo Range during the Stage II B~ conditions. In order to determine that the subject was able to control his PI counts it was first necessary to demonstrate that he could continue to produce similar frequency counts of Monte Carlo Range PIIs (with the assistance of feedback), and that this frequency would continue to control his stuttering frequency counts. If C condition control was established, it was planned to introduce a C~ phase.

**Stage IV.** This stage was planned to evaluate the effect of controlling variables that might have confounded changes in the relationship between the independent (PI frequency) and dependent (stuttering frequency) variables. For instance, it was anticipated that subjects might slow their speech rate or decrease speech naturalness in order to control PI counts. If there was evidence that such variables might have confounded treatment effects produced by the target variables, then it was planned to replicate the Stage II experimental procedure using appropriate controls.

**Reliability**

The reliability of the speech performance measures obtained throughout these experiments involved an independent verification of the duration of PIIs as measured by the RTOP and the assessment of the reliability of the judges’ %SS, SPM, and mean speech naturalness ratings.

The accuracy with which the RTOP measured the duration of PIIs was estimated by comparing a series of RTOP-measured PIIs with measures obtained by an independent acoustic analysis. The Interactive Laboratory System (ILS) software package (V 6.0, Signal Technology Inc., 1986) was used for this purpose. The data for this comparison were derived from a nonexperimental speaking session with one subject (T.B.), with the RTOP's operation identical to that used during the experiments. Subject T.B. orally read a randomly ordered list of 30 single-syllable words, one word per 15-sec interval. This method was chosen so that each word could be unambiguously isolated and then its PI determined via the PEAP. Because the sampling rate of the RTOP is 100 Hz, errors of plus or minus 10 msec are to be expected. Voiced segments (PIIs) in the acoustic waveform were then identified with the ILS program using a sampling rate of 20 kHz and the following operational definition: The voice onset was the point at which the first period's positive-going peak crossed the zero amplitude line; the offset was the point at which the last positive-going peak of the last period crossed the zero line (the duration was then automatically calculated).

The results of this comparison showed that 24 of the 30 (80%) intervals measured by both systems differed by 10 msec or less. The remaining 6 PIIs differed by 19–27 msec. Hence, it was concluded that the RTOP measured the duration of PIIs with satisfactory accuracy for the purposes of this study.

The reliability of each judge’s scores was assessed by arranging for two independent judges (who were also unfamiliar with the experiment) to perform the same measurement tasks on randomly selected trial recordings. At least two 5-min speaking trial recordings were selected from within relevant phases of each subject’s experiment. The independent judges were enrolled graduate students who had completed theory and practicum courses in stuttering. The selected trials were dubbed in random order onto a master tape and introduced by a sample number. Each judge then listened to the master tape via headphones and used the same procedures as the original judges to record data. One independent judge's measures were used to calculate %SS and SPM scores, and the other judge provided mean speech naturalness ratings for the selected trial. The extent to which the original and independent judges' measures agree can be

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6The “−” or “+” notation is attached to phase labels throughout this paper to indicate that the subject was required to decrease PI counts (e.g., B~) or to increase PI counts (e.g., B+).
assessed by inspecting the data trends in the Results section. The data trends were considered to be reliable if the independent judges' data trends were consistent with the original trends (Hawkins & Dotson, 1975).

Results

The results of the two single-subject experiments are presented in Figures 1, 2, 4, and 5. These figures show the experimental phases in each subject's experiment and the effect of those changes on four dependent variables: percent syllables stuttered, syllables per minute, mean speech naturalness ratings, and the frequency of PIs within specified duration ranges. The reliability data for each subject's experiment are displayed in Figures 3 and 6 and are described following the results for each subject's experiment.

Subject T.B.

The data for T.B.'s experiment are presented in Figures 1 and 2. The four stages of T.B.'s experiment were completed in 11 sessions and involved a total of 92 five-minute trials with a variable number of trials per session. The results for each of the four stages of T.B.'s experiment are summarized below.

Stage I. The first phase (A) in Figure 1 shows T.B.'s base-rate data. During this phase, T.B. completed nine trials before a relatively nonsystematic data trend was observed across all speech performance measures. The data across these trials show that T.B.'s speech naturalness ranged from 3.0 to 4.0 and his speech rate from 151.6 SPM to 175.4 SPM; his stuttering frequency stabilized around 3.0 %SS (the range was 0.7–3.5 %SS).

After the A phase, the PEAP divided T.B.'s entire base-rate

![Figure 1](http://jslhr.pubs.asha.org/) Speech performance measures for each 5-min speaking trial for the four stages (I–IV) of T.B.'s experiment. The top row shows mean speech naturalness ratings (1 = highly natural and 9 = highly unnatural-sounding speech). The second row shows the mean number of syllables spoken per minute. The third row shows percent syllables stuttered. The lowest row shows the number of phonation intervals (PIS) that were within the target decile ranges: 30–100 msec (△), 30–140 msec (●), and 30–210 msec (●). The phases are labelled with symbols to identify the target PI range. Note that all phase changes occurred within, rather than between, the 11 speaking sessions.
PI frequency distribution into decile ranges. That is, all Pls produced during the nine trials were divided so that each of 10 ranges contained approximately the same number of Pls. The lowest of these ranges (the lowest 10% of T.B.’s base-rate decile distribution) was 30–100 msec, and the second lowest decile range was 100–140 msec. Hence, the combination of these two decile ranges formed the lowest 20% of the base-rate distribution. The PI distributions for each trial were then reconfigured to show the PI frequencies within each of the ranges identified by the decile configuration. The frequencies of Pls in the lowest decile ranges throughout the A phase trials are shown in Figure 1. These data trends were considered sufficiently stable not to confound signs of treatment effects in subsequent experimental conditions. The mean number of A phase Pls in the 30–100-msec decile range was 57.7; in the 30–140-msec range it was 104.3.

In the subsequent B− (30–100) phase, T.B. was instructed to try to reduce the frequency of 30–100 msec Pls (the decile range with the shortest PI durations) by 50% of the mean base-rate frequency. The criterion for a 50% reduction of PI counts in the 30–100-msec range was 29 per trial. Hence, T.B. was instructed to try to produce no more than two 30–100-msec Pls per 30-sec interval during each B− (30–100) phase trial. In Figure 1, the data trend in the B− (30–100) phase shows that T.B. reduced his 30–100-msec PI counts, but the reduction failed to reach criterion level and his stuttering frequency was essentially unaffected.

In the next phase, B− (30–140), T.B. was instructed to reduce the frequency of Pls in the lowest 20% of base-rate decile distribution (that is, 30–140-msec decile range). In the first two phases, the Pl data for the 30–100- and 30–140-msec ranges show a generally stable trend. The criterion level for a 50% reduction in the 30–140-msec range was calculated from the A and B− (30–100) phase data and averaged 52 PI counts per trial. Hence, T.B. was instructed to speak with no more than five PI counts in this range per 30-sec interval. The B− (30–140) phase data show that T.B. slightly reduced his PI counts in this range and achieved the criterion level for three consecutive trials by the sixth trial. Figure 1 shows that the reduction in his 30–140-msec Pls during the B− (30–140) phase was accompanied by an immediate and marked reduction in stuttering frequency.

At the end of Stage I, it was concluded that T.B. could control his 30–140-msec range Pl counts and that variations in these counts might serve to control his stuttering frequency. Hence, this range became the target range for Stage II. Variations in T.B.’s stuttering frequency during Stage I were unrelated to any obvious changes in his speech naturalness ratings. However, it can be seen in the SPM data for this stage (Figure 1) that T.B.’s speech rate tended to decline whenever his PI counts in either the 30–100- or 30–140-msec range were reduced. In other words, T.B.’s speech rate may have been responsible for PI count reductions during these phases and, by implication, associated reductions in stuttering frequency.

The frequencies of Pls within the eight other decile ranges (140–200 msec, 200–260 msec, etc.) identified from the entire base-rate distribution are shown for each trial of Stage I on the ordinate of Figure 2 above the “5-minute trials” line. (The PI counts in the duration ranges that appear below this line were derived by the Monte Carlo analysis and are discussed later). There were no obvious trends in most decile ranges during the A, B− (30–100) or B− (30–140) phases. However, the 30–100- and 100–140-msec Pls were reduced in the Stage I phases (see Figures 1 and 2). Thus T.B. evidenced some control over the frequency of PI counts within a discrete duration range (30–140 msec) and without changing his PI counts in other decile ranges.

Stage II. Initially, base-rate or A conditions were reintroduced in order to test for the effect of removing the preceding B− (30–140) phase conditions. Figure 1 shows that T.B.’s 30–140-msec Pls immediately returned to Stage I A phase levels, accompanied by increases in stuttering frequency, speech rate, and speech naturalness ratings (i.e., towards more unnatural-sounding speech).

The next four phases of Stage II assessed the effect of instructing T.B. to decrease (B− phases) and then increase (B+ phases) 30–140-msec PI counts. In the B− phases, the criterion was the same as in the Stage I B− (30–140) phase: T.B. was instructed to speak with no more than five 30–140-msec PI counts per 30-sec interval for the three consecutive trials. Figure 1 shows that in the first B− phase of Stage II, T.B. immediately reduced his target range PI counts (reaching criterion performance by the eighth trial), and his stuttering frequency was concomitantly reduced. There was also a decrease in speech rate, but no alteration in speech naturalness ratings.

In the subsequent B+ (30–140) phase, T.B. was instructed to increase his target range PI counts by 50% above their base-rate frequency. This meant that T.B. was to produce a minimum of 160 target range PI counts per trial, i.e., 16 per 30-sec interval. Figure 1 shows that T.B. could not achieve this goal; he only managed to increase his target range PI counts to base-rate frequency levels. His stuttering frequency did increase during this phase, but only to base-rate levels, which was also true for his speech rate. There was a slight increase in his mean speech naturalness ratings (towards more unnatural-sounding speech) across this phase, but this increase was not distinguishable from the preceding B− phase data trend.

In the final B− and B+ phases of Stage II, T.B. produced almost identical data trends to those in the first B− and B+ phases. This trend replication also occurred in T.B.’s stuttering frequency and speech rate data. In these last two phases, however, T.B.’s speech naturalness appeared to improve during B− and then worsen during B+.

The results of Stage II of T.B.’s experiment are relatively straightforward. They show that T.B. could reduce the frequency of his target range PI counts, but not increase them above base-rate levels. They also show that decreases in these PI counts were consistently associated with reductions in stuttering frequency and decreases in speech rate. Hence, any reductions in T.B.’s stuttering frequency during Stage II could be due to either reductions in his speech rate or reductions in his 30–140-msec PI counts.

In an attempt to resolve the apparent confound between changes in PI frequencies and speech rate, a modified replication of the Stage II experimental procedure was planned for Stage IV. However, it may also have been the
case that the data trends in Stage II were due to changes in PI counts in other duration ranges (i.e., within or beyond the 30–140-msec range). The Stage II PI data in the upper part of Figure 2 show that this was not the case; whereas changes occurred in T.B.'s 30–140-msec range, his PI counts in most other decile ranges remained relatively stable. Nevertheless, there were some signs that the PI data trends in the adjacent 140–200-msec range varied in the same direction as the target range. Thus, the changes in T.B.'s 30–140-msec PI counts may have either affected, or been produced by, changes in some other PI counts.

The Monte Carlo sampling analysis (see Method) was applied to the PI data from the two B− and two B+ phases of Stage II. The Monte Carlo analysis identified the duration ranges in which the maximum differences occurred in the PI counts from B− and B+ phases and then ranked the ranges from those showing most to those showing least differences in PI frequencies. The 30–210-msec range showed most differences between these data sets (p < 0.05) and became the Monte Carlo Range investigated in Stage III.

A post hoc verification of the Monte Carlo Range was made by reconfiguring the Stage I and II data. The PEAP divided the PIs for each trial in those phases that were less than 260 msec (the boundary of the fourth decile range) into two duration ranges: the Monte Carlo Range (30–210) and the remainder (210–260). The resulting data trends are displayed in Figure 2 below the “5-minute trials” line.

The consistency of changes in the Monte Carlo Range is emphasized by comparing the PI trends and those in the adjacent 210–260-msec range, where there was no evidence of related changes. Hence, the Monte Carlo Range PI data not only were consistent with the experimental phase changes, but they also served to verify the effectiveness of the Monte Carlo analysis.

Stage III. This stage evaluated whether T.B. could directly control and then modify the frequency of the Monte Carlo Range (30–210) PI counts. T.B. was required to reduce his 30–140-msec PIs to the B− criterion level (i.e., the same level he achieved during the B− phases in Stage II) However, throughout the B− phase, T.B.'s 30–210-msec PI
counts were monitored to identify his mean 30–210-msec PIs in that phase. In the immediately following C(30–210) phase, therefore, T.B. was merely required to sustain the frequency of 30–210-msec PI counts at the same level as occurred during the preceding phase. The difference between these two phases, therefore, was the PI range on which feedback was made contingent. That is, in the B–(30–140) phase, feedback was provided for PIs in the 30–140-msec range. In the subsequent phase, C(30–210), the feedback was given for 30–210-msec PIs, the PI range that appeared to be functional during the B– conditions. The rationale for this procedure was that if T.B. was expected to reduce 30–210-msec PIs (in a subsequent C– phase), then, at the very least, he should have been able to maintain the frequency of 30–210-msec PIs he produced in the B– phases when given feedback for occurrences of these PIs. The mean number of 30–210-msec PIs that T.B. produced during the B– phase trials of Stage II was 83. Hence, T.B. was instructed to ensure that his 30–210-msec PIs did not exceed eight per 30-sec interval during C(30–210) phase trials.

The results of Stage III, as shown in Figure 1, reveal that T.B. could not consistently maintain the criterion level 30–210-msec PI count in the C phase. However, Figure 1 shows that T.B.’s 30–140-msec PI counts did remain at the B–(30–140) phase levels during the C phase. It is also apparent that his stuttering frequency showed increased variability across this phase. In the following B–(30–140) phase, T.B. again demonstrated that he could achieve criterion level 30–140-msec PI counts (i.e., with feedback for 30–140-msec PIs rather than 30–210-msec PIs), and his stuttering frequency returned to the B– levels after the second trial. Hence, T.B. failed to control the frequency of his Monte Carlo Range PI counts even though their rate of occurrence was controlled when he received 30–140-msec PI count feedback.

The data trends across Stage III for the remaining speech performance measures (Figures 1 and 2) show the following: T.B.’s speech rate remained stable and at levels similar to the B– phases of Stage II; his speech naturalness ratings in the B– phases resembled those produced during the Stage II B– phases, though they did not decrease during the C phase; and his PI counts in the eight other decile ranges (Figure 2) showed no evidence of change in either trend or level.

In summary, the Stage III findings show that T.B. was not able to control directly the frequency of his Monte Carlo Range PIs despite evidence that he could indirectly control that range when modifying his 30–140-msec PI counts.

Stage IV. An obvious finding from the first three stages of T.B.’s experiment was that whenever the target range PI counts were modified, there were concomitant changes in his speech rate. Consequently, the final stage of T.B.’s experiment sought to test whether his reduced speech rate during B– conditions was necessary for him to control his 30–140-msec PI counts and reduce his stuttering frequency. Hence, Stage IV was a rate control (RC) phase change experiment (B–/RC/B–/RC) in which T.B. was required to speak at a rate close to the mean SPM rate that he used in the final B–(30–140) phase of Stage III.

In the initial B– phase of this stage, T.B. was required to reduce his 30–140-msec PIs to the previously established criterion levels for the B–(30–140) phases. However, through this phase, speech rate data were added to T.B.’s VDT display. During the last 5 sec of each 30-sec interval, the RTP tallied the number of syllables spoken (from Judge 1’s button-press counts) during the previous interval and displayed the total on the VDT for the next 30 sec. At the end of each 5-min trial, the total number of syllables spoken was displayed. No additional instructions were provided for this phase. T.B. was simply informed that the numeric display referred to his speech rate while he attempted to reduce his 30–140-msec PIs. Figure 1 shows that in the first B–(30–140) condition of Stage IV T.B. reduced his 30–140-msec PI counts, but with virtually no change to the speech rate he displayed during the Stage III B– phases. His stuttering frequency in this phase also resembled levels achieved in the previous B– phases. Hence the effect of adding speech rate information did not appear to influence T.B.’s speech performance during B– conditions. Consequently, the speech rate feedback procedure was identical in all four phases of Stage IV.

In the following RC phase, the subject’s VDT displayed only the number of syllables spoken per 30-sec interval and the elapsed trial time. No PI data were displayed nor PI feedback signalled. T.B. was told the mean number of syllables that he had spoken, per 30-sec interval, during B– phase trials. He was then instructed to maintain this rate by speaking so that the number of syllables per 30-sec interval was within plus or minus 5% of the mean number. The mean number of syllables and the plus or minus 5% range were clearly displayed in writing above the VDT. It was hypothesized that if T.B.’s speech rate was responsible for controlling his 30–140-msec PIs and stuttering frequency data during B– phase trials of his experiment, then his 30–140-msec PIs and stuttering should remain reduced whenever T.B.’s speech rate was similar to the rate he used during the B–(30–140) phase levels.

The data for Stage IV in Figure 1 show that T.B. maintained a relatively constant speaking rate during both RC phases. There were essentially no marked differences between SPM data trends across the B–/RC/B–/RC phases. In the initial RC phase, his SPM data marginally exceeded his previous B– phase level, but in the second RC phase his SPM data were generally the same as in the two previous B– phases. It was also clear that the data trends for T.B.’s 30–140-msec PIs in the RC phases were generally higher than they were in the B– phases. Similarly, T.B.’s stuttering frequency increased and became more variable in the RC phases than it was in the B– phases.

In summary, the reduced speech rate that T.B. maintained in the RC phases was not sufficient to maintain reductions in his stuttering and target range PI counts. It follows, therefore, that reductions in T.B.’s 30–140-msec PIs in the B– phases did not depend on reductions in his speaking rate. Furthermore, T.B.’s stuttering frequency during Stage IV once again covaried with changes in his target range PI counts. It is noteworthy that T.B.’s 30–140-msec PI counts overlapped the levels that were observed in the A and B+(30–140) phases of Stage II, but his stuttering frequency in the RC phases did not approach the levels they displayed in those Stage II phases. This suggests that variations in T.B.’s 30–140-msec PI counts were not entirely responsible for variations in his stuttering frequency.
A supplementary analysis determined whether T.B. also continued to alter PI counts in the Monte Carlo Range during Stage IV. Thus Figure 2 also shows his 30–210-msec and 210–260-msec range data and confirms that whenever T.B. modified his 30–140-msec PI frequencies, similar changes occurred in the Monte Carlo Range. This result suggests that T.B. could modify his 30–140-msec PI frequency only by also changing PI counts beyond that range.

Reliability

Figure 3 shows the reliability data for subject T.B. The figure compares the original experimental data, using randomly selected trials within each phase, with data obtained from the two independent judges who scored recordings of those trials. The data trends for stuttering frequency and speech rate data trends and levels in T.B.'s experiment appear to be reliable.

The reliability of the original speech naturiness ratings appears to be less satisfactory. In Stages I and IV, the data trends appear to be relatively similar. However, in Stages II and III, there were some discrepancies between Judge 2 and the second independent judge's ratings. When T.B. alternately decreased and increased his PI counts in the target range (B+/B+/B+/B+), it appears that Judge 2 and the independent judge may have based their ratings on different aspects of speech quality; their data trends moved in opposite directions across some trials in the B− and B+ phases. In Stage III, the independent judge consistently rated T.B.'s speech as more unnatural sounding; however, the two sets of data did differ by more than one rating point (Martin, Haroldson, & Triden, 1984).

In general, however, the reliability data for T.B.'s experiment show that the original experimental trends were reproduced by the two independent judges.

Subject J.P.

The data for J.P.'s experiment are presented in Figures 4 and 5. The four stages of J.P.'s experiment were completed
in 13 sessions and included 112 five-minute speaking trials with a variable number of trials per session. The results of J.P.’s experiment were similar to T.B.’s, and are summarized accordingly.

**Stage I.** The first phase (A) in Figure 4 shows J.P.’s base-rate data. Over the six A phase trials, J.P.’s speech naturalness ratings consistently increased from 6.0 to 7.9, that is, towards more unnatural-sounding speech. This very likely occurred because his stuttering frequency gradually increased from 18.3 to 29.8 %SS and his speech rate gradually increased from 72.2 to 103.8 SPM.

After the sixth base-rate trial, the PEAP divided J.P.’s entire base-rate PI frequency distribution into decile ranges. The three lowest decile ranges were 15–80, 80–140, and 140–200 msec. When combined, the two lowest decile ranges formed the lowest 20% of the distribution (15–140 msec), and the three lowest decile ranges together formed the lowest 30% of the distribution (15–200 msec). The number of PI counts produced in the lowest decile and the next two combinations of decile ranges for each trial are shown in the A phase of Figure 4. The mean number of PIs across the A phase trials was 39.8 for the 15–80-msec decile range; 81.5 for the 15–140-msec range; and 122.0 for the 15–200-msec range. These ranges and their PI frequency counts are also displayed in Figure 5 (above the “5-minute trials” line) along with the remaining eight decile ranges and the PI counts in those ranges for each trial.

The principal data trends, shown in Figure 4, indicate that J.P.’s 15–80-msec PIs were relatively stable throughout the A phase. However, J.P.’s 15–140- and 15–200-msec PIs tended to decrease. The A phase of Figure 5 shows that the 140–200- and 200–260-msec PIs also decreased and the data in the 640–960-msec decile range increased. There were no systematic data trends in the remaining decile ranges.

In the following B–(15–60) phase, J.P. was instructed to try to reduce the frequency of PI counts in the lowest decile range (15–80 msec) by 50% of the mean base-rate frequency. The criterion for a 50% reduction was nineteen 15–80-msec PIs per trial (i.e., no more than 2 per 30-sec interval). Figure 4 shows that J.P. was unable to reduce his PI frequency counts below base-rate levels by the sixth trial.

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**Figure 4.** Speech performance measures for each 5-min speaking trial for the four Stages (I–IV) of J.P.’s experiment. The top row shows mean speech naturalness ratings (1 = highly natural- and 9 = highly unnatural-sounding speech). The second row shows the mean number of syllables spoken per minute. The third row shows percent syllables stuttered. The lowest row shows the number of phonation intervals (PIs) that were within the target decile ranges: 15–80 msec (A), 15–140 msec (B), 15–200 msec (C), and 75–210 msec (D). The phases are labelled with symbols to identify the target PI range. Note that all phase changes occurred within, rather than between, the 13 speaking sessions.
However, there was a marked reduction in his stuttering frequency and speech naturalness ratings (towards more natural-sounding speech), plus a slight increase in speech rate. Figure 5 shows that these changes in stuttering were unrelated to changes in other PI decile ranges except for an increase in the 80–140- and 140–200-msec PIs. These data trends were not in the expected direction.

In the next phase, B–(15–140), J.P. was instructed to reduce 15–140-msec PIs. J.P.’s A and B–(15–80) phase PI data trends in the 15–140-msec range (see Figure 4) were relatively unchanged. The criterion for a 50% reduction in his PIs was forty 15–140-msec PIs per trial, that is, no more than 4 PIs per 30-sec interval.

The data in the B–(15–140) phase show that J.P. reduced his 15–140-msec PIs to the criterion level by the fourth trial and that this reduced his stuttering frequency. However, during the fourth trial, it became obvious to the experimenter that J.P. had adopted a rhythmic speech pattern in order to reach the PI criterion level. The effect of this unnatural speech pattern is reflected in J.P.’s stuttering frequency (it reached zero), his speech rate (it dropped to 70 SPM), and his speech naturalness ratings (they increased sharply). We chose to prevent the subject from completing the experiment using this well-known speech pattern: We simply asked him to try to meet the criterion without using rhythmic speech. The data for the remaining B–(15–140) trials show that J.P. slightly reduced his 15–140-msec PI counts, but not to criterion level; they also show he complied with this request.

For these trials his stuttering frequency and speech rate were relatively unchanged and his speech naturalness ratings increased slightly.

Figure 4 shows that although J.P.’s 15–140-msec PIs failed to reach the criterion level in the B–(15–140) phase, his stuttering frequency was obviously reduced well below the levels observed in the A and B–(15–80) phases. To test whether some variation in J.P.’s 15–140-msec PI counts might functionally control his stuttering frequency, a B+(15–140) phase was introduced. In the B+(15–140) phase, J.P. was instructed to increase 15–140-msec PIs by 50% above their base-rate frequency (i.e., 120 per trial). The data for B+(15–140) show that J.P. again failed to reach the criterion level by the sixth trial but did increase his PI counts relative to his B–(15–140) phase levels. At the same time, J.P.’s stuttering frequency increased, whereas his speech naturalness ratings and speech rate remained essentially unchanged relative to the B–(15–140) phase.

In the subsequent B–(15–140) phase, however, J.P. failed to reduce 15–140-msec PIs to either the criterion level or even below A and B–(15–80) phase levels. Figure 5 shows data trends in the remaining eight decile ranges were not distinctive across these three phases. Therefore, despite some covariation in stuttering and 15–140-msec PIs, the overall data trends did not show experimental control.

The next phase of Stage I investigated attempts to reduce PI counts in the three lower decile ranges, that is, 15–200 msec. An A phase, reintroduced to identify a 15–200-msec PI
base-rate, showed J.P.’s stuttering frequency, speech rate, and speech naturalness returned to levels found in the B+(15–140) phase. In the following B–(15–200) phase, J.P. was instructed to reduce 15–200-msec PIs by 50% to no more than 60 PIs per 5-min speaking trial or 6 per 30-sec interval; and met this control criterion by the fourth trial. His stuttering frequency was reduced to essentially zero %SS, and his speech naturalness ratings showed a slight decrease. A slight decrease in speech rate was also observed. (N.B. In Figure 5, the scaling for PIs in the 15–200-msec target range changes in the last two phases of Stage I and is different from other decile ranges). Hence, the 15–200-msec PIs became the target PI range for the next stage of J.P.’s experiment.

Stage II. The first phase of this stage (A) actually completed an A/B–/A sequence (the last two phases of Stage I and first in Stage II). The data trends in Figure 4 show that J.P.’s 15–200-msec PIs returned to almost the initial A phase levels of Stage I, with concomitant increases in his stuttering frequency and speech naturalness ratings. There was some evidence, though, that his speech rate did decrease.

The next four phases of Stage II (B–/B+/B–/B+) assessed the effect of instructing J.P. to decrease (B– phases) and then increase (B+ phases) 15–200-msec PIs. As in the previous B–(15–200) phase of Stage I, J.P.’s PI criterion was no more than six 15–200-msec PIs per 30-sec interval for three consecutive speaking trials. Figure 4 shows that J.P. immediately met this criterion. His stuttering frequency was reduced to near-zero levels, and his speech was rated as relatively more natural sounding. However, J.P.’s speech rate continued to decline as it had throughout the preceding A phase.

In the subsequent B+(15–200) phase, J.P. tried to increase his 15–200-msec PIs to a minimum of 183 per trial or 18 per 30-sec interval. Figure 4 shows that he increased his PI counts to near base-rate levels, but not to the higher criterion level. There were concomitant increases in his stuttering frequency and his speech naturalness ratings, but they overlapped the levels he had achieved in his A phase when no feedback was provided. There was, however, a slight but distinguishable increase in his speech rate.

The repeated B–(15–200) and B+(15–200) phases that completed Stage II virtually replicated the effects that J.P. produced during the initial B– and B+ phases in this stage. In the B–(15–200) phase, J.P.’s PI counts met the criterion by the seventh trial, but in the subsequent B+(15–200) phase he failed to increase his 15–200-msec PIs to the criterion level, although they exceeded the level produced in the previous B–(15–200) phase. His stuttering frequency and speech rate did vary as in the initial B–/B+ phases, while his speech naturalness ratings were unaffected by the phase changes.

The results of Stage II show that J.P. consistently altered the frequency of his 15–200-msec PIs and, like T.B.‘s, his stuttering frequency and speech rate varied with these changes. J.P.’s speech naturalness ratings did seem to covary across the A/B–/A phase change sequence that overlapped Stage I and II, but they were virtually unchanged in the rest of Stage II. Hence, as for T.B., variations in J.P.’s speech rate may have controlled his stuttering frequency and target PIs, so the resolution to this confound was reserved for Stage IV. J.P.’s PI counts in the 15–200-msec and seven remaining decile ranges for Stage II are shown in the upper part of Figure 5. It is not immediately obvious from this figure that the changes observed in his 15–200-msec PIs were reflected in other decile ranges. A Monte Carlo analysis performed with the PI data from the two B– and two B+ phases sought the duration range that reflected the most substantial PI changes across the Stage II experimental conditions. This analysis showed that the maximum changes in PIs occurred in the 75–210-msec range (p < 0.05). Consequently, the effect of feedback of PIs in this Monte Carlo Range (75–210 msec) was investigated in Stage III.

The PEAP’s reconfiguring of the Stage I and II PI data displayed in the panels below the “5-minute trials” line of Figure 5 show the Monte Carlo Range (75–210 msec) and the 210–260-msec PIs. The Monte Carlo Range PI data in Stage I did show some evidence of change in the same direction as the 15–140-msec PIs, and these changes were more pronounced in Stage II. By contrast, the adjacent ranges (15–75 and 210–260 msec) show relatively stable trends in PIs across Stages I and II.

Stage III. Using a B–/C/B– phase change experiment, J.P. first reduced his 15–200-msec PIs to the B–(15–200) criterion level (i.e., the same level achieved during B–(15–200) conditions in Stage II). Concurrently, his 75–210-msec PIs were monitored to identify their mean frequency. Hence, in the following C(75–210) phase, J.P. was only instructed to continue to control the frequency of 75–210-msec PI counts to the same level he achieved during the B–(15–200) phases, but with feedback contingent on the Monte Carlo Range.

Figure 4 shows that J.P. could not maintain 75–210-msec PI counts at the criterion level. His 15–200-msec PIs slightly exceeded the levels that were produced in the previous B–(15–200) phases. When the B–(15–200) phase was reintroduced, he was still able to reduce his 15–200-msec and Monte Carlo Range PIs despite the absence of feedback for PIs in the latter range.

Figure 4 shows that throughout the B–/C/B– phase changes, J.P.’s stuttering frequency, speech rate, and naturalness ratings remained close to the levels he produced in all B–(15–200) conditions. Figure 5 shows that J.P.’s PI counts in the seven remaining decile ranges were relatively stable throughout Stage III.

In summary, like subject T.B., J.P. failed to control directly the frequency of PIs in the Monte Carlo Range, but they were indirectly controlled when he held his 15–200-msec PIs to the criterion level frequency.

Stage IV. As in T.B.’s experiment, Stage IV sought to determine whether J.P.’s 15–200 msec PIs covaried with his speech rate. The rate control experimental design (B–/RC/ B–/RC) was identical to that used with T.B. Figure 4 shows that J.P. maintained a relatively constant speaking rate across all Stage IV phases. In the RC phases, when 15–200-msec PI feedback was removed, J.P.’s stuttering frequency was more variable than in the B–(15–200) phases. The variations in J.P.’s stuttering frequency were closely related to variations in his 15–200 msec PI counts, and these changes were unrelated to variations in his speech rate.
The lower panels of Figure 5 show that J.P.'s Monte Carlo Range PI counts also varied with changes in his 15–200-msec PIs. Furthermore, these changes were not reflected in the adjacent ranges. Hence, the changes in the Monte Carlo Range PIs were associated with changes in J.P.'s 15–200-msec PIs and not because of alterations to his speech rate.

Reliability

Figure 6 shows the reliability data for J.P. The data trends for stuttering frequency and speech rate show that, in general, the independent judge's scores closely follow the original judge's (Judge 1) scores for all phases of J.P.'s experiment.

A comparison of the second independent judge's speech naturalness ratings with those produced by Judge 2 shows that the trends were similar in most phases of the experiment, but they show a less precise relationship in Stages III and IV. However, it should be recalled that there was little evidence of a systematic change in speech naturalness ratings across the entire experiment.

In general, therefore, the original experimental trends were reproduced by the two independent judges (with the exception of Judge 2's Stage III and IV speech naturalness ratings). The other speech performance measures produced during Stages I, II, and IV gave a reliable account of J.P.'s actual performance. The trends observed in J.P.'s speech naturalness ratings, however, were not quite as conclusive.

Discussion

The two single-subject experiments demonstrated that an adolescent and an adult who stutter could modify the frequency of prescribed PIs during spontaneous speech and that these modifications influenced their stuttering frequency. The method used to measure the distribution of PIs and feedback-prescribed target range PIs during these experiments revealed that both subjects concomitantly changed the frequency of PIs outside the target PI range. The PI range in which these changes were most prominent was identified by a Monte Carlo analysis, although it was found that neither subject could directly control PIs within that range. However, for both subjects, the effect of modifying target range PIs on stuttering frequency was independent of changes in speaking rate and did not seriously disrupt speech naturalness ratings. The experiments' data trends for stuttering frequency and speech rate were essentially reproduced by independent judges. The independent judge's speech naturalness ratings, however, were not always consistent with those produced by the original judge.

Generally, the findings are consistent with those reported by Ingham, Montgomery, and Ulliana (1983) and Ingham and Devan (1987). In these studies, all subjects demonstrated that, with feedback, they could modify PIs within a 0–200-msec range. It was also demonstrated that when these target PIs were reduced by 50% (or more) during spontaneous speech, then stuttering, regardless of its frequency, was reduced to almost zero. Both the Ingham et al. (1983) and the

![Figure 6](http://jslhr.pubs.asha.org/) Subject J.P.'s original and independent judges' data for speech naturalness ratings, syllables per minute, and percent syllables stuttered. Each of the randomly selected 5-min trials in the four stages (I–IV) of the experiment was rater by the independent judges (○). The original judges' scores are also shown (●).
present studies demonstrate that the experimental effects do not depend on changes in speech rate. There was considerable variation in speech quality because only 1 of the 4 subjects across these studies appeared to achieve completely normal-sounding speech. Another similarity was that all subjects showed a lack of carryover of any treatment effect in withdrawal phases.

The present findings did differ from the other studies in some rather important ways. In the present study, subjects failed to increase the frequency of target range PIs to 50% above their base-rate frequencies. On the other hand, the present study provides a much more extensive description of the effect of manipulating target range PIs on the subject's entire PI distribution, plus the effect of these manipulations on speech naturalness ratings. The present study also incorporated some unique features that may explain these differences: the method used to select target range PIs as the independent variable (i.e., from a decile distribution), the use of an EGG (rather than an accelerometer) to measure phonation duration, and the measurement of speech naturalness. The most pertinent issues arising from this study are discussed below.

Selection of the Independent Variable

In this study, the shortest PI range that the subjects could reduce (and concomitantly reduce stuttering) was identified by a stepwise procedure; that is, by incremental increases in the size of the target PI range, beginning with the shortest range. The incremental steps in the size of the target range were based on decile divisions of each subject's entire base-rate PI distribution. Hence, the first step was the range occupied by the lowest 10% of the subject's PI distribution. Perhaps other effects might have occurred if the subjects had attempted to decrease or increase PI counts within ranges of much longer duration, maybe starting with the longest decile range.

The decision to modify short-duration PIs stemmed from the clinical orientation in the Ingham et al. (1983) study. These authors argued that the use of extended intervals of phonation was probably the most common feature among stuttering treatment procedures that employ prolonged speech (Goldiamond, 1965; Perkins, 1973). They concluded, therefore, that the proportion of short-duration PIs in the speech of a person who stutters should result in the use of longer phonation intervals. Ingham et al. (1983) recognized that it was not clear just how much phonation extension was both necessary and sufficient in order to modify stuttering. By identifying this interval size, they argued, it might be possible to control stuttering without producing unnatural-sounding speech. In the present study, therefore, it was of interest that both subjects did alter the frequency of PIs in slightly longer duration ranges when they modified their target range PIs, although this was not a consistent effect. The present study did not determine whether directly modifying PIs in relatively longer ranges might produce similar effects.

A related issue concerns the possible contribution to these findings of variation in pauses or, more particularly, NPIs. Although NPIs were not investigated in these experiments, the subjects' control over their target range PIs may actually have been produced by modifications to NPIs. Ingham and Devan (1987) provided some evidence that this could be the case. They found that changes in short-duration PIs may reflect changes in the NPI distribution. Hence, in the present experiments, the subjects may have also reduced the frequency of their target range PIs by altering the frequency distribution of NPIs. Relevant to this issue are data showing that the stutter-free speech of persons who stutter may contain significantly more short pauses than is the case in the speech of persons who do not stutter (Love & Jeffress, 1971). Future research will determine whether persons who stutter are able to reduce the frequency of such pauses, and whether this produces functional control of stuttering.

Another issue of interest was the nature of the relationship between changes in PI frequencies within the selected ranges and stuttering frequency. The findings of the most relevant previous studies (Ingham et al., 1983; Ingham & Devan, 1987) suggested that there is a strong relationship between changes in certain PIs and changes in stuttering. The results of the present study were not as compelling. Both subjects reduced their stuttering when target range PIs were reduced, but their stuttering did not always increase when target range PIs increased. Interestingly, neither subject could increase his target range PIs above base-rate (A phase) levels, which means they might not have achieved satisfactory control over their target range PIs. In the present study, control meant that subjects could speak with PI counts between 50% above and below base-rate PI frequencies. The fact that the subjects could not manipulate their target range PIs beyond a criterion level may, of course, mean that the criterion level was a critical factor. The criterion may have been stringent, but it was essentially an arbitrary criterion. Further research may determine the amount of variation in PI counts that is necessary to modify stuttering.

Speech Rate Factors

The interpretation of the experimental effects in the present study may be clouded by the way speech rate was measured. Speech rate is an extremely complex phenomenon (Starkweather, 1985) and, as yet, there is no standard procedure for measuring it validly. In the present experiments, for instance, the SPM data included occurrences of stuttering and pauses of unspecified length, variables that interact with speech rate measurement. This interaction might have been important when subjects displayed relatively more stuttering. However, if the SPM data had been adjusted to exclude stutterings then, in all probability, this would have actually exaggerated some of the observed changes in speech rate. During Stage II, for example, when speech rate appeared to decrease and increase, with concomitant changes in PI counts, then these changes might have been even more apparent.

What is more important, though, is that during the rate control experiments (Stage IV), a relatively constant speech rate was claimed to have been present across phases when stuttering increased and decreased. If stuttering had been omitted from these intervals, then it is possible that both
subjects might not have displayed a stable speaking rate across the Stage IV phases. It is the case, though, that both subjects showed relatively little stuttering across the RC phases. Consequently, if their speech rate data had excluded stutterings, the omission would have had little impact on their SPM data. It is worth noting, incidentally, that when Ingham et al. (1983) recalculated their SPM data so that they excluded moments of stuttering they found that their original treatment effects were unchanged.

Changes in the Monte Carlo Range

A notable finding was that neither subject could directly control the frequency of his Monte Carlo Range Pls despite reliable evidence that this was the PI range that changed when subjects modified their target range Pls. There are a number of possible explanations for this finding. Perhaps the most obvious explanation relates to the phase changes that subjects experienced during Stage III. Prior to that stage, they had to reduce their Monte Carlo Range Pls, but in Stage III they simply had to maintain a range that they had been producing during other treatment conditions. In retrospect, perhaps this experiment might have yielded an even more conclusive result if the subjects had been required to manipulate, rather than maintain, their Monte Carlo Range Pls.

Another explanation for the experimental noneffect in Stage III is that the Monte Carlo analysis of each subject’s Stage II PI data did not identify the controlling variable. For instance, the concomitant changes in the subjects’ NPI distributions may have yielded a more accurate Monte Carlo Range. The fact that a PI range shows change, does not, of course, mean that that range is always responsible for changes in stuttering frequency.

Additional Considerations

An issue that emerged during the course of subject J.P.’s experiment relates to his Stage I B—(15–140) phase data (see Figure 4). During this phase J.P. was instructed to reduce his 15–140-msec PI counts, and in one trial he began to use rhythmic speech. The experimenters then decided not to allow J.P. to continue with this speech pattern, although if he had persisted with this pattern he may have ultimately produced a normally fluent speech pattern. However, the experimenters decided to see whether J.P. could achieve stutter-free speech without adopting any obviously unusual speech pattern. The same decision, incidentally, would have been made if the subject had decided to sing, count, use prolonged voicing, or whisper so as to reduce PI counts.

This incident serves to highlight the need for an independent method for verifying that the subject’s manner of speech is appropriate for a particular experiment. That method should also be capable of identifying speech patterns such as singing and counting. In the present case such a method is needed so as to recognize patterns that lack the features necessary to achieve normal speech. The speech naturalness ratings may, at least, provide some indication of departures from natural-sounding speech.

One of the more innovative features of this study was the application of computer-assisted feedback to the modification of phonatory behavior. The use of the EGG and the computer system made it possible, for virtually the first time, to investigate the changes that might occur in a subject’s PI and NPI distribution. That system also made it possible to isolate the precise changes that occur in a subject’s PI distribution during experimental conditions.

Conclusion

It has often been reported that stuttering may be reduced when persons who stutter extend their customary phonated intervals during speech. Manipulations to phonation have also been implicated as the mechanisms responsible for the fluency-inducing effects of rhythmic speech, masking, singing, chorus-reading, shadowing and prolonged speech and its variants (Ingham, 1984). However, very few studies have endeavored to investigate systematically the precise variables responsible for these effects. This study makes a contribution by reporting an attempt to identify a precise controlling variable at the level of phonation interval frequencies. With some qualifications, the findings do demonstrate that stuttering can be brought under control by modifying a durational feature of phonation. They show that it is possible to modify a component of the surface structure of the speech motor control system, a component that may be a necessary, even sufficient, condition of phonatory behavior in the speech motor control systems of persons who stutter.

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References


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