Measurement of Phonated Intervals During Four Fluency-Inducing Conditions

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Purpose: Previous investigations of persons who stutter have demonstrated changes in vocalization variables during fluency-inducing conditions (FICs). A series of studies has also shown that a reduction in short intervals of phonation, those from 30 to 200 ms, is associated with decreased stuttering. The purpose of this study, therefore, was to test the hypothesis that the distribution of phonated intervals (PIs) should change during 4 of the most well-known FICs.
Method: A repeated-measures design was used to explore the relationship between PIs and stuttering during 4 FICs: chorus reading, prolonged speech, singing, and rhythmic stimulation. Most conditions were conducted at 2 different speech rates. The distribution of PIs was measured during these conditions and was compared with PI distributions obtained during control conditions.
Results: Overall PI distributions were significantly different during all 4 FICs, as compared with control conditions. PIs in the range of 30–150 ms were reduced across all FICs, at all speech rates.
Conclusion: These results provide further evidence of the importance of phonation variables to (a) our understanding of how FICs may operate and (b) the treatment of stuttering. These findings, along with previous studies that showed how purposefully reducing the number of short PIs resulted in the elimination of stuttering, suggest that treatment programs based on prolonged speech—or PIs, in particular—may benefit from emphasizing a reduction in the number of short PIs and a simultaneous increase in the number of longer PIs.

KEY WORDS: stuttering, phonation, fluency-inducing conditions

Stuttering is known to be markedly reduced under a number of "fluency-enhancing" or "fluency-inducing" conditions (FICs), with the most consistent decreases reported for rhythmic speech, singing, prolonged speech, and chorus reading (e.g., Andrews, Howie, Dozsa, & Guitar, 1982; Bloodstein, 1950; Johnson & Rosen, 1937; Wingate, 1969). Numerous explanations of these fluency-enhancing effects have been proposed, yet the hypothesis with the greatest theoretical influence on the stuttering literature was arguably the modified vocalization hypothesis (MVH; Wingate, 1969, 1970). Essentially, Wingate hypothesized that stuttering may be due to irregularities in the rhythm of one's speech and that melodic and prosodic changes during FICs stabilize these irregularities through inducing continuity in phonation.

Several investigators have since assessed this hypothesis by examining speech and voice pattern characteristics during various FICs. Packman, Onslow, and van Doorn (1994) and Robb, Lybolt, and Price (1985), for example, showed that vowel duration increased relative to

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baseline conditions during prolonged speech. Syllable duration has also been shown to increase during prolonged speech (Webster, Morgan, & Cannon, 1987). Median utterance duration (Healey, Mallard, & Adams, 1976), voicing duration (Colcord & Adams, 1979), and mean phonation duration (Andrews et al., 1982) have all been reported to increase during singing, whereas mean vowel duration (Brayton & Conture, 1978) and mean phonation duration (Andrews et al., 1982) have been reported to increase during rhythmic stimulation and chorus reading, respectively. Other reports provide counterevidence to the hypothesis of consistent lengthening or continuation of vocalization during these conditions: Vowel duration can decrease during chorus reading (Adams & Ramig, 1980), for example, and mean phonation duration has been demonstrated to decrease during rhythmic stimulation (Andrews et al., 1982). Nevertheless, the majority of the data suggest that increases in voicing duration occur during all of these conditions in a manner consistent with Wingate's (1969) original hypothesis.

The general purpose of many investigations of the MVH has been to identify the speech or voice variables that modulate under FICs, usually in an attempt to identify a change that is common to all experimental conditions and that may, therefore, be the means—or one of the means—by which fluency is obtained during these conditions. With respect to understanding important ways to reduce stuttering, the FICs provide a valuable experimental opportunity. If a common variable can be found in the numerous manners in which fluency is easily obtained, this variable may be important to our most basic understanding of the disorder itself. This possibility is similar to the rationale behind much of the work on the articulatory (e.g., Zimmerman, 1980), laryngeal (e.g., Smith, Denny, Shaffer, Kelly, & Hirano, 1996), and respiratory (e.g., Peters & Boves, 1988) dynamics of stuttering. In fact, research about speech motor control variables in stuttering has a substantial history of attempting to identify interactions among motor systems or attempting to explain the many known characteristics of stuttering within one larger framework (e.g., Smith & Kelly, 1997; Zimmermann, Smith, & Hanley, 1981). In addition, the current move toward brain imaging has led to examining "common features" of brain activity during more than one FIC (metronomic speech and singing; Stager, Jeffries, & Braun, 2003).

Despite the importance of such logic, however, there has actually been relatively little research that has attempted to identify, within a single study, a common speech variable that changes in the same parametric direction (i.e., longer vs. shorter, more vs. less) from a control condition to all four of the well-known FICs identified previously. In fact, the only investigation found in the literature that included all four of these conditions was reported by Andrews et al. (1982), who showed an increase in mean phonation duration of more than 2 *SD*s, compared with a control condition, for chorus reading, singing, and prolonged speech only. Andrews et al.'s (1982) definition and measurement of phonation duration were problematic, though, in that all pauses or nonphonated times shorter than 250 ms were ignored or were included in the measurement of the surrounding phonated times. In essence, their measure was a measure of "utterance or phrase length" (Andrews et al., 1982, p. 210). As such, there is no single experimental assessment of phonation-related variables that has included all four of the most effective FICs.

Phonated Intervals in Stuttering

A fifth less common FIC, the reduction of short phonated intervals (PIs) in the range of 30–200 ms, provides a parallel opportunity to obtain valuable information about the nature of stuttering. A PI is a measure of the duration of vibration measured from the surface of the throat in between breaks of 10 ms or more. These intervals are interpreted as an estimate of the duration of vocal fold vibration (i.e., a 50-ms PI refers to a 50-ms period during which the vocal folds were vibrating; Gow & Ingham, 1992; Ingham et al., 2001; Ingham, Montgomery, & Ulliana, 1983). Speakers produce a number of PIs of varying duration in a specified amount of speaking time. For participants in the present study, there was an average of 144 PIs in 1 min of speech during normal speaking tasks. In summary, a PI is a measure of vocal fold movement duration and can be understood as reflecting the voiced portions of a spectrogram.

Because the PI literature developed as an empirically grounded search to operationalize the characteristics of prolonged speech treatments (Ingham et al., 2001), PI research has the potential to provide information about the links between theoretically motivated studies of the nature of stuttering, on the one hand, and empirically and clinically motivated studies of the reduction of stuttering, on the other. Ingham et al. (1983) first assessed whether persons who stutter could establish control over the frequency of PIs and whether a correlation existed between the control of PIs and changes in stuttering frequency. In this early study, no specific instructions were provided to the participants about how to achieve the goal of controlling PIs. Two men who stuttered began by attempting to manipulate PIs with a duration of 50 ms or less (i.e., 10–50 ms), and subsequent increases of 50 ms were tested until the experimenters found the shortest range of phonation duration that participants could control (defined as the ability to increase and decrease PIs in this range by 50%). One participant exhibited control of PIs at 100 ms and the other at 150 ms. Fifty percent reductions in PIs shorter than these levels were accompanied by a decline in the frequency of stuttering (near 0% syllables stuttered), and 50% increases in PIs were affiliated with an increase in stuttering.

Ingham and Devan (1987) later demonstrated that 3 participants were also able to reduce PIs by 50% relative to their base rate in the range of 10–100 ms, 10–90 ms, and 10–130 ms, respectively, with concomitant reductions in stuttering frequency. Two of the participants also maintained their speaking rate and speech naturalness during the PI conditions. Finally, Gow and Ingham (1992) tested whether manipulating a specific PI range would have any effect on the frequency of stuttering in 2 adult men who stutter. The PI range was chosen by dividing PIs found during base rate into decile ranges, a different procedure from previous PI studies. The range manipulated by the participant was determined by beginning at the lowest decile range (10%) and identifying the smallest number of decile ranges in which a participant could reduce his base rate PIs by at least 50%. One participant achieved this goal by using a combination of his two lowest decile ranges (30–140 ms), and the other did so by using his three lowest (15–200 ms) (i.e., the PIs in the lower 20% and 30% of their PI distributions, respectively). Both participants were able to reduce their target PIs by more than 50% during spontaneous speech, with an accompanying reduction in stuttering frequency to near-zero syllables stuttered.

These PI findings were later incorporated into a therapeutic procedure called *Modifying Phonated Intervals* (MPI; Ingham et al., 2001). The PIs targeted for reduction were defined in terms of the shortest PIs that could be controlled by the client, identified in terms of deciles or quintiles of the client's own PI distribution. Participant-controllable PIs typically fell in bins ranging from approximately 30 ms to 200 ms. Treatment involves reducing the number of target-duration PIs in one's speech and completing a succession of within- and beyond-clinic speaking tasks. Data presented by Ingham et al. (2001) from participants 1 year into the maintenance program demonstrated zero or near-zero stuttering rates in intra- and extra-clinic speaking contexts.

The most recent PI investigation examined whether the distribution of PIs during spoken reading was similar in a group of persons who stuttered and a group of normally fluent controls (Godinho, Ingham, Davidow, & Cotton, 2006). PIs were divided into 20 separate duration bins that covered the entire possible range of PIs produced (30–1,000 ms). These authors found no difference in the overall distribution of PIs nor any difference in the percentage of PIs in any particular 50-ms PI range across the whole distribution when comparing the two groups of speakers. As Godinho et al. (2006) stated, these results suggest that abnormal production of PIs "is not part of the core problem of stuttering" (p. 168); however, the reduction of short PIs has been shown to reduce stuttering frequency with associated changes in brain regions that appear critical for fluency (Ingham, Ingham, Finn, & Fox, 2003). Therefore, further examination of the relationship between PIs and fluency changes may be a fruitful endeavor to continue gaining information about the nature and treatment of stuttering.

The present study was designed to examine the relationships between PIs and fluency by investigating the distribution of PIs during multiple FICs. It also served as an opportunity to assess the validity of the newer PI measurements and the MPI treatment's underlying assumptions. It was hypothesized that all four of the selected FICs would be associated with changes in the PI distribution. Specifically, it was hypothesized that PIs in the range of 30–200 ms would be reduced during these conditions. A reduction in PIs in this duration range (50–150 ms) has been previously shown to accompany a reduction in stuttering during prolonged speech (Packman et al., 1994).

In addition, our study was designed to address two issues arising from the methodology of the current MPI treatment program (Ingham et al., 2001). The use of the speaker's own shortest duration PIs (bottom decile or bottom quintile) and the requirement of a 50% reduction in target-range PIs have not been shown to be necessary, nor the most effective and efficient, for the elimination of stuttering. Thus, this study was also intended to provide information that could support or refute the continued use of the current form of the MPI treatment program by evaluating PI measurements in the context of multiple FICs.

Method

Participants

Seven men and 3 women who stuttered participated (M = 38.2 years, range = 19–61 years). Nine participants had previously received some form of therapy for their stuttering, but only 1 had received any therapy within the last year. That therapy, which was completed 5 months before his participation in this study, involved the modification of attitudes toward stuttering, not the alteration of his speech pattern, and analysis of his experimental data showed no differences from other participants. The remaining participants had received treatment for their stuttering an average of 12 years before participation (range = 1–37 years). Each participant was diagnosed as displaying developmental stuttering by two ASHA-certified clinicians using their own standard clinical diagnostic criteria. No participant reported any past or present neurological disorder, voice problems, oral–motor problems, or head or neck problems that could affect PI data.

Participants all completed a questionnaire documenting their experience with the four FICs that were used in this study, with such experience varying. No participant had previously been involved in an MPI treatment protocol.

Materials

Participants were seated in a room that contained the computer and audio–video recording equipment. The MPI system (Windows platform) consisted of a single-axis accelerometer (Measurement Specialists, Huntsville, AL; Model ACH-01-04), a signal conditioning amplifier, customized software, and related hardware. The accelerometer used to obtain the PIs was a piezo-electronic transducer with no sensitivity relative to the earth and a frequency response of 2 Hz to 20 kHz. The MPI system uses a Sound Blaster Live card (16-bit) with a frequency response of 10–44 kHz. The signal from the accelerometer is bandpass filtered at 80–300 Hz (7th order Butterworth). The system sets the digitization rate for the sound card at 12 kHz yet ignores 11 of each 12 samples, for an effective sampling rate of 1 kHz. Input signals were integrated and smoothed over a 10-ms window, after which only alternate values were kept, resulting in an effective sampling rate of 500 Hz for the conditioned signal. Before the start of each MPI session, the system noise floor was established by the user. System noise was typically between 62 and 75 mV of noise maxima. When the intensity of the incoming signal exceeded the noise floor by greater than 10%, the recording of a PI was initiated by the analog/digital (A/D) system.

PI Protocol

Informed consent procedures were first completed, as approved by the university's Institutional Review Board. The FIC questionnaire was administered next. Participants were then fitted with the accelerometer that was held by an elastic collar and worn comfortably around the neck such that the accelerometer was paralateral to midline and just inferior to the thyroid prominence. The MPI program was then engaged, sampling gain was adjusted, the background noise check was conducted, and movement artifact checks were completed (e.g., participants were asked to nod; if undesired signals were registered, the accelerometer was repositioned until head movements did not record a PI). Participants were instructed not to cough or clear their throats during data acquisition trials because these behaviors might register a PI.

Speaking Conditions

Six speaking conditions were studied, including two control conditions (control reading and control speaking) and four FICs (chorus reading, singing, rhythmic stimulation, and prolonged speech). Because rate is often associated with differences in phonation measurements (Andrews et al., 1982), three of the experimental conditions were performed at two different speech rates: 180 syllables per minute (SPM), which is within the typical range for nonstuttering adults, and 90 SPM, providing a clear and slower contrast.

Control conditions. Four 3-min normal speaking trials and four 3-min spoken reading trials, performed before the experimental conditions, were completed to obtain a baseline of stuttering frequency and PI distribution. During the control speaking condition, the participants produced monologues on self-selected topics or were provided with cue cards. For the control reading condition, participants read an excerpt from a high school–level textbook.

Chorus reading. This condition involved reading the same words simultaneously with a normally fluent adult man (the "accompanist") who was pre-recorded via a Hi-8 video recorder. The accompanist was trained to maintain rates of 90 SPM and 180 SPM prior to recording, and the experimenter (the first author) rechecked the accuracy of the accompanist's rate and found approximately 90 SPM and 180 SPM, respectively, on the tapes used during the investigation. Participants were told to start reading and to try to match their words with the speaker on the television screen. Participants read for two 3-min trials with the recorded accompanist for each speech rate, for a total of four chorus reading trials. These conditions are referred to as chorus reading 90 SPM and chorus reading 180 SPM. Some participants had great difficulty completing the 180 SPM chorus reading task. It was hypothesized that having a live chorus reader would allow for better task compliance, as both readers could adjust to each other rather than only 1 participant adjusting to the pre-recorded video. Therefore, the experimenter read along with the participant if the participant was unable to complete the 180-SPM chorus reading trial with the pre-recorded televised reader. To determine whether the experimenter's reading changed from participant to participant, a graduate student clinician rated the ability of the experimenter to read (during the chorus reading trials) identically to a previously recorded solo reading session. Using a 7-point scale (1 = *identical to solo reading,* 7 = *totally different from solo reading*), the graduate student clinician rated the perceptual quality of the chorus reading by the experimenter to be identical to a separate solo reading session by the experimenter (all scores of 1 on the scale). The graduate clinician was instructed to listen for changes in rate, intonation, vocal quality, and loudness.

Singing. During the singing condition, each participant sang one of seven simple traditional or popular songs. Words for these songs were provided if the participants were not familiar enough with the lyrics. Based on pilot trials, the decision was made not to control the rate of singing because it was too difficult or unnatural a task for participants to sing at prescribed rates. Comparisons between control speaking and singing, therefore, maintained the participant's normal or comfortable rate for both conditions.

Rhythmic stimulation. Rhythmic speech was entrained via a metronome (auditory) set at 184 beats per minute (BPM) and 92 BPM, similar to the rates used for chorus reading and allowing investigation of the influence of rate on phonation measurements (Andrews et al., 1982). Participants were instructed to produce one syllable per beat. During these conditions, referred to as rhythmic stimulation 92 BPM and rhythmic stimulation 184 BPM, participants read from a high school–level textbook. Reading was used for the rhythmic stimulation conditions because pilot testing revealed that participants were unable to perform the faster condition using self-generated speech.

Prolonged speech. Prior to this condition, the examiner demonstrated a pattern of prolonged speech similar to that described by Goldiamond (1965) at a rate of approximately 90 SPM. The experimenter's model consisted of elongating syllables and words in addition to continuous phonation across word and syllable articulatory boundaries. Participants practiced the modeled pattern for 5–10 min and until the examiner judged the participant's production to be adhering to the modeled pattern (see also the discussion of performance ratings in the *Dependent Variables* subsection). Rate was controlled by measuring the number of syllables spoken during the first 3-min trial of prolonged speech (after the experimenter's 90 SPM model) and then asking participants to "double that rate" (approximately 180 SPM) for the final two trials. Participants were cued by the experimenter to increase or decrease rate during the trial if they were not adhering to the prescribed rate. Participants spoke on self-selected or cue card topics for two 3-min trials for each rate. The two prolonged speech conditions are referred to as prolonged speech 90 SPM and prolonged speech 180 SPM.

Order of experimental conditions. The order of experimental conditions was counterbalanced. Of the four, rhythmic stimulation and prolonged speech have been suggested to be conditions in which the speaker may learn and maintain fluency-producing effects (Andrews et al., 1982). Singing and chorus reading, on the other hand, have not been suggested to produce carryover or sequencing effects. All participants therefore began with either chorus reading or singing, followed by the remaining two conditions. The third and fourth conditions for each participant were rhythmic stimulation and prolonged speech, with the order of these two conditions also counterbalanced across participants. To further control the possibility of carryover, rest periods of at least 2 min were placed between experimental conditions. During each rest period, the participant conversed with the experimenter on self-selected topics while the experimenter measured percent syllables stuttered (%SS). If baseline levels of stuttering (within 10% of baseline or greater) were reached during the first 2 min of speaking, the next condition was initiated. Otherwise, the experimenter and participant continued conversing in 2-min increments until baseline levels were reached. A 2- to 3-min period of silence between all conditions was also imposed while the experimenter prepared for the next condition.

Dependent Variables

Dependent variables included %SS, SPM, performance ratings, and duration of PIs. The %SS and SPM data were measured using the Stuttering Measurement System (SMS; Ingham, Bakker, Kilgo, & Moglia, 1999) software, which allows an observer using a computer mouse to count syllables spoken with and without stuttering and to obtain measurements of syllables spoken per minute and %SS. A perceptual definition (Martin & Haroldson, 1981) of stuttering was used, with the only instruction given to the independent rater that continuing attempts at the same syllable was one stuttering event. SPM data were obtained by the SMS program, which divided the number of syllables by the time elapsed during a trial (3 min in the present study). All %SS, SPM, and performance ratings data presented in this report represent the mean value from the two raters combined.

Performance ratings were gathered to ensure that the participants were complying with the parameters of the experimental conditions. The experimenter and an independent judge, both graduate student clinicians with expertise in stuttering, each separately rated whether the participant was properly singing, producing rhythmic speech, producing prolonged speech, or reading along with the chorus reader. "Properly" was based on each judge's own criteria. Performance ratings used a scale of 1 to 7 (1 = *definitely producing this condition correctly,* 7 = *definitely not producing this condition correctly*).

Finally, PIs were measured to determine if a change in PI distribution existed from control to experimental conditions. The primary dependent variable for this study was the distribution of PIs as determined by the percent of PIs that fell into 21 durational ranges (hereafter referred to as *bins*). The bins were divided in the following manner: one 20-ms bin from 30 to 50 ms; nineteen 50-ms bins between 51 and 1,000 ms; and one bin encompassing all PIs greater than 1,000 ms. The short durational increments for bin size were chosen in order to examine PI distributions in substantial detail. A single bin for PIs over 1,000 ms was chosen because very few PIs are produced above this duration during habitual speaking and reading. The entire speaking trial was used to obtain PI data because PI distributions containing stuttered speech and stutter-free speech have been shown to be similar (Godinho et al., 2006; Gow, 1998).

Data Analysis

Distribution analysis. There were two levels of analysis conducted on the PI data. The first was a set of Cochran-Mantel-Haenszel (CMH) tests, which are used to examine the direct relationship between two variables after controlling for a third variable (usually called the *stratified variable*). The null hypothesis of the CMH test is that there is no direct relationship between two variables, when the effects of the third variable are removed. To control the sensitivity of the CMH test and to determine if the null hypothesis can be rejected, critical values of 0.1, 0.05, and 0.01 are used most often, with 0.05 being most common. As such, 0.05 was used as the critical value in the present study.

CMH tests were used to determine whether different PI ranges are conditionally associated with different conditions (e.g., control reading vs. chorus reading 90 SPM, control reading vs. chorus reading 180 SPM, etc.) after controlling for the different participants. The CMH test is preferred over the log-linear chi-square analyses used in the Godinho et al. (2006) article. That publication examined the association between treatment group (persons who stutter vs. normally fluent controls) and PI distribution and provided a guide for the present article's analysis. The advantage of the CMH test used in the present analyses is that it allowed the determination of whether there was a direct association between the two variables in question (speaking condition and PI distribution), which cannot be determined by a log-linear chi-square analysis.

We were interested in whether the distributions for the control conditions and experimental conditions differed from one another; therefore, we conducted seven separate CMH tests of association using condition (control condition and one experimental condition) and PI bin duration as the variables of interest in each test. Control reading was used as the control condition for chorus reading (2 rates) and rhythmic stimulation (2 rates), and control speaking was used as the control condition for singing and prolonged speech (2 rates).

Individual bin analysis. Following the CMH tests, paired-sample t tests (experimental condition vs. control condition) with Bonferroni correction were completed to further isolate sources of variation. Following the method of Andrews et al. (1982), and given our hypotheses, obtained data structure, and goals of this study, effect sizes (experimental mean minus the baseline mean, all divided by the baseline *SD*) were also calculated to assess the differences between control and experimental conditions. The control speaking and control reading conditions were used as the baseline means, and the FICs were used as the experimental means, with the same comparisons performed here as were conducted during the CMH tests. We completed t tests for all bins in the 30- to 200-ms PI range. The t tests were only conducted in this region because it was previously found that a reduction of PIs in this range was associated with reductions in stuttering. In addition, this minimized the possibility of obtaining false negatives from conducting a large number of tests. Bonferroni correction was used for the total number of t tests, resulting in an alpha level of .0018 (.05/28).

Stuttering frequency and PI correlations. Pearson correlation coefficients were calculated to assess the relationship between stuttering frequency and the percentage of PIs in specific PI bins. Percent syllables stuttered values and the percentages of PIs in each 3-min trial during the control conditions were used for this analysis. The same range of 30–200 ms was targeted for this analysis.

Performance ratings. A performance rating of 3 or lower on the 7-point scale described previously was required for the participant's data to be included in our group analyses. This cutoff was considered the point at which the participants were still generally performing the task properly yet where too much data would not be eliminated. Although this criterion was rather lenient, it still produced unusable data; thus, group data reported on subsequent pages do not always involve all participants. In addition, because participants had difficulty performing prolonged speech at a rate of 180 SPM, prolonged speech trials were separated into two categories: trials exhibiting 75–110 SPM and those exhibiting 130–200 SPM, generally referred to hereafter as prolonged speech 90 SPM and prolonged speech 180 SPM, respectively. Prolonged speech trials with speech rates between 110 and 130 SPM were discarded.

Reliability

Reliability checks were performed for all four dependent variables and are presented in the Results section. Interjudge reliability was assessed for %SS and SPM by having the experimenter and one graduate clinician, who was previously trained on the SMS, each independently watch video recordings of the entire trial of all experimental and control conditions and count the number of stutters and SPM. Intrajudge reliability for %SS and SPM was completed by having both the experimenter and the independent rater re-judge one trial from each condition. Reliability of performance ratings was calculated similarly.

Reliability of PI duration measurements was also estimated. PI distributions from the second and third control trials for two randomly selected participants were compared. PI measures cannot be repeated for the same speech sample, but there should not be any significant difference between two control trials recorded immediately after one another.

The agreement of PI duration between the MPI system and an acoustic analysis program has been established previously in two other investigations, both of which reported similar findings. Godinho et al. (2006) used continuous speech and three-word utterances to compare the similarity of measurements. In that study, it was found that 81 of 100 intervals differed by 20 ms or less. For the remaining intervals, 7 differed by 22–28 ms and 12 differed by 31–40 ms. These values are comparable to the values obtained in another study, which reported that 22 of 29 intervals differed by 20.4 ms or less between the two systems (Ingham et al., 2001). These data demonstrate that PI values produced by the MPI system are consistent with phonation duration and that the differences are well within the 50-ms bin duration used in the present study.

Results

Performance Ratings

Out of a total of 145 FIC trials, 113 received an average performance rating of 3 or lower. Thus, data are included in the following analyses from 9 participants in the singing condition, with a mean performance rating of 1.25; 8 participants for chorus reading 90 SPM (2.13), 8 participants for chorus reading 180 SPM (2.10), 9 participants for prolonged speech 90 SPM (2.0), 4 participants for prolonged speech 180 SPM (1.92), 10 participants for rhythmic stimulation 92 BPM (1.48), and 9 participants for rhythmic stimulation 184 BPM (2.26).

Stuttering Frequency

As shown in Table 1, stuttering was reduced during all of the experimental conditions in comparison to the two control conditions (control speaking and control reading). Table 2 demonstrates that these effects cannot be attributed to carryover because participants tended to return to their base rate levels of stuttering between conditions. The exceptions were (a) 13 instances in which the averaged %SS scores approached but did not reach baseline (the online judgments by the experimenter always reached baseline, but the combined judgments by the raters, shown in Table 2, did not) and (b) Participant 9, who stated that she was feeling "very comfortable" in the testing situation.

For further assurance that carryover did not occur, the perceptual quality (regardless of stuttering frequency) of the 13 trials in which baseline levels were not reached during the rest periods was judged by two raters on a scale of 1 (*sounds identical to the control speaking trials*) to 9 (*sounds totally different than the control speaking trials*). All rest periods were scored as "1" by both judges, further decreasing the possibility that carryover effects were responsible for the data.

Speech Rate

Table 1 also provides SPM scores for all experimental conditions for those speakers who received an average performance rating of 3 or less. Slight deviations from the intended rates were expected because of factors such as normal disfluencies, normal reading errors, stutters, and actual time spent chorus reading with the live accompanist. On the whole, all participants were capable of closely matching our predetermined speech rates (except prolonged speech, as explained previously). Rhythmic stimulation 184 BPM deviated the most from the prescribed target rate. The participants stated that they paused momentarily when they felt out of sync with the metronome.

PI Data

Overall distribution of PIs. Figures 1–4 show the distribution of PIs across the 21 duration bins. Inspection of these figures reveals global differences in the distributions between the control and experimental conditions, particularly in the lower duration ranges. The results of the CMH tests, displayed in Table 3, support the conclusions from the graphic display that the PI distribution is dependent on the condition. All of the CMH tests were significant under the alpha level of .05. These results demonstrate that speaking during the experimental conditions produced a significantly different distribution of PIs than speaking in the control conditions. Examining the CMH test values allows us to gather further information regarding how similar the distributions were. In general, the lower the CMH value, the more similar the PI distributions. As can be seen, it appears that the faster rates produced distributions more similar to the control conditions, an issue that is explored further in the Discussion section.

PIs by duration range. The second level of analysis involved effect size calculations and paired-sample t tests comparing each of the seven experimental conditions to its respective control condition. The results of this analysis, displayed in Table 4, show effect sizes and mean percentage of PIs in selected bins by condition.

As discussed previously, the area of interest was between 30 and 200 ms. As can be seen by the negative effect sizes, there was a reduction in the percentage of PIs in all bins in all of the experimental conditions in this range except for the 151- to 200-ms bin (hereafter,

Table 1. Percent of syllables stuttered (%SS) and syllables per minute (SPM) for all fluency-inducing conditions.

Condition	Participant 1	2	3	4	5	6	7	8	9	10
Control speaking										
%SS	2.09	4.28	3.46	4.69	28.92	1.42	1.96	1.61	3.84	1.58
SPM	203.00	183.08	108.79	216.71	100.46	170.25	184.71	240.33	182.39	199.38
Control reading										
%SS	2.80	3.56	0.78	4.08	1.28	1.08	0.44	1.13	1.84	1.67
SPM	213.38	183.20	223.04	203.87	243.46	195.00	246.79	216.08	232.79	244.92
Singing										
%SS	0.52	0.58	0.22	0.00	0.00	0.06	0.00	0.10	0.12	—
SPM	134.17	147.17	139.92	117.67	110.26	126.44	134.01	156.93	127.01	—
Chorus reading 90 SPM										
%SS	0.10	0.00	—	—	0.00	0.00	0.00	0.00	0.09	0.00
SPM	91.09	92.00	—	—	96.85	93.01	94.26	91.34	93.17	93.07
Chorus reading 180 SPM										
%SS	0.09	0.00	—	—	0.00	0.00	0.00	0.00	0.00	0.00
SPM	181.42	181.25	—	—	200.34	199.12	187.17	197.19	196.61	189.42
Prolonged speech 90 SPM										
%SS	1.27	0.00	1.85	1.12	—	0.00	—	0.00	0.00	0.00
SPM	91.83	85.00	79.83	95.92	—	87.14	—	92.25	80.66	75.34
Prolonged speech 180 SPM										
%SS	0.93	0.36	—	0.06	0.47	—	—	—	—	—
SPM	146.09	138.50	—	136.08	165.50	—	—	—	—	—
Rhythmic stimulation 92 BPM										
%SS	0.28	0.00	0.10	0.10	0.00	0.00	0.11	0.00	0.00	0.00
SPM	87.67	91.00	87.25	88.50	82.51	91.08	89.66	88.57	90.00	89.57
Rhythmic stimulation 184 BPM										
%SS	0.43	0.00	0.60	0.00	—	0.00	0.00	0.00	0.00	0.04
SPM	165.75	183.42	130.33	174.50	—	171.65	173.33	187.15	178.40	182.99

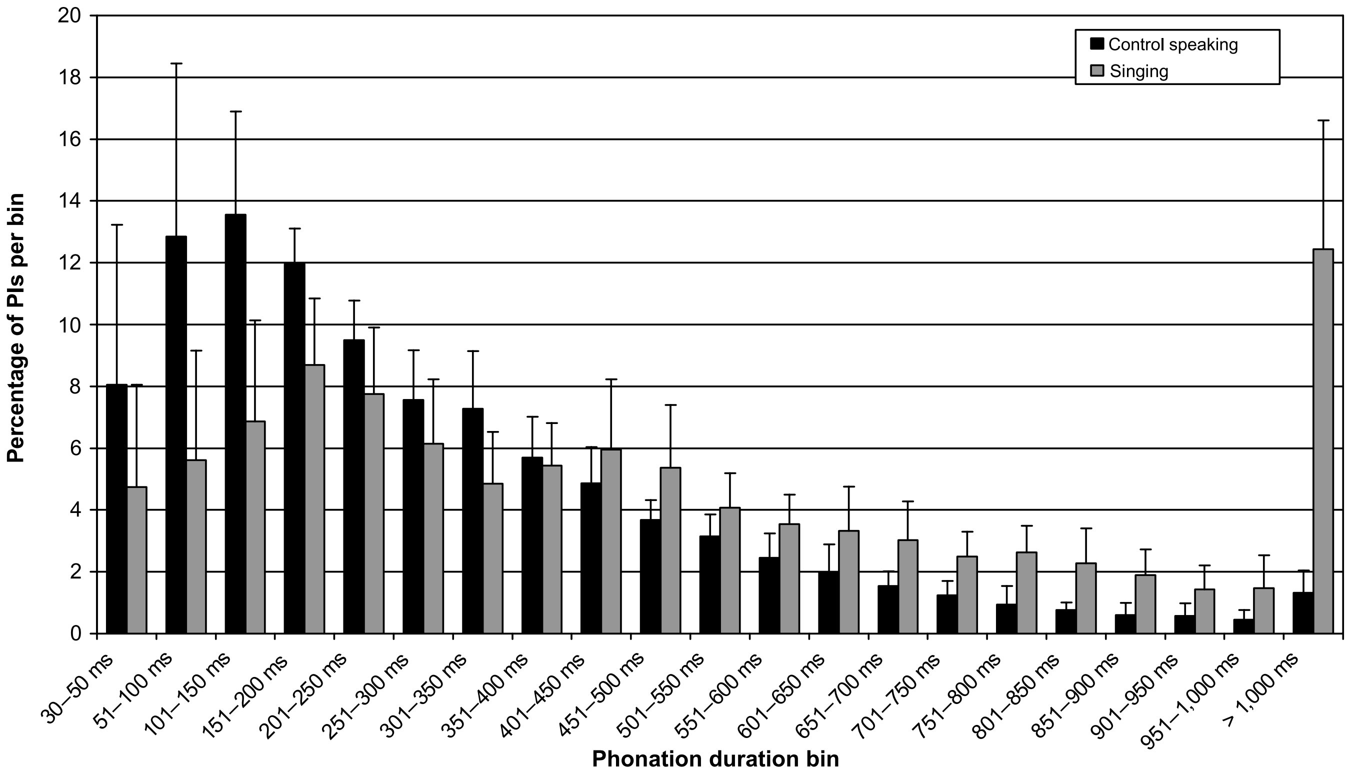
Note. Hyphen indicates performance ratings above 3 on both trials in that condition and, therefore, the elimination of data. BPM = beats per minute.

Table 2. %SS data for normal speaking during baseline and during 2-min rest periods between experimental conditions.

Condition	Participant 1	2	3	4	5	6	7	8	9	10
Baseline	2.09	4.28	3.46	4.69	28.92	1.42	1.96	1.61	3.84	1.58
Rest 1	3.00[a]	6.37	2.78	3.60	32.77	2.26	1.24	3.09	1.32[a]	0.74[a]
Rest 2	3.72	7.96	3.64	4.00	34.53	1.90[a]	1.51	3.58	1.45[a]	1.02
Rest 3	2.46	4.62[a]	16.73	3.70	23.87	1.95	1.86[a]	3.65[a]	1.01[a]	1.97[a]
Rest 4[b]				3.55	28.24[a]					

[a]Data from a second or third rest period were required to obtain online baseline stuttering levels. [b]Participants 4 and 5 have a fourth rest period because as a result of technical difficulties, they performed control reading last, prompting the need for returning to baseline stuttering before initiating the condition.

Figure 1. Phonated interval (PI) distributions across all 21 bins for control speaking and singing. Data are the average values across the group and reflect only those participants who performed the singing condition properly (cf. see Table 1). Error bars represent the standard deviation of the means.



"151-200 bin") during the chorus reading 180 SPM and rhythmic stimulation 184 BPM conditions. The 51–150 range showed the largest and most consistent change. Eight of the 14 t tests in this range showed statistically significant (α = .0018) reductions in the percentage of PIs. Four of the comparisons approached significance (control speaking vs. singing for 51–100 bin, $p = .002$; control speaking vs. prolonged speech 90 SPM for 51–100 bin, $p = .007$; control speaking vs. prolonged speech 180 SPM for 51–100 bin, $p = .004$; control reading vs. chorus reading 180 SPM for 101–150 bin, $p = .005$). These nonsignificant findings were likely due to the small alpha level used in the present study (.0018). Additionally, there was a significant reduction in the percentage of PIs in the 51–100 and/or 101–150 bin for each experimental condition, except for prolonged speech 180 SPM (for 51–100 bin, $p = .004$; for 101–150 bin, $p = .086$). This exception was likely the result of the limited number of participants in the prolonged speech 180 SPM comparison ($N = 4$).

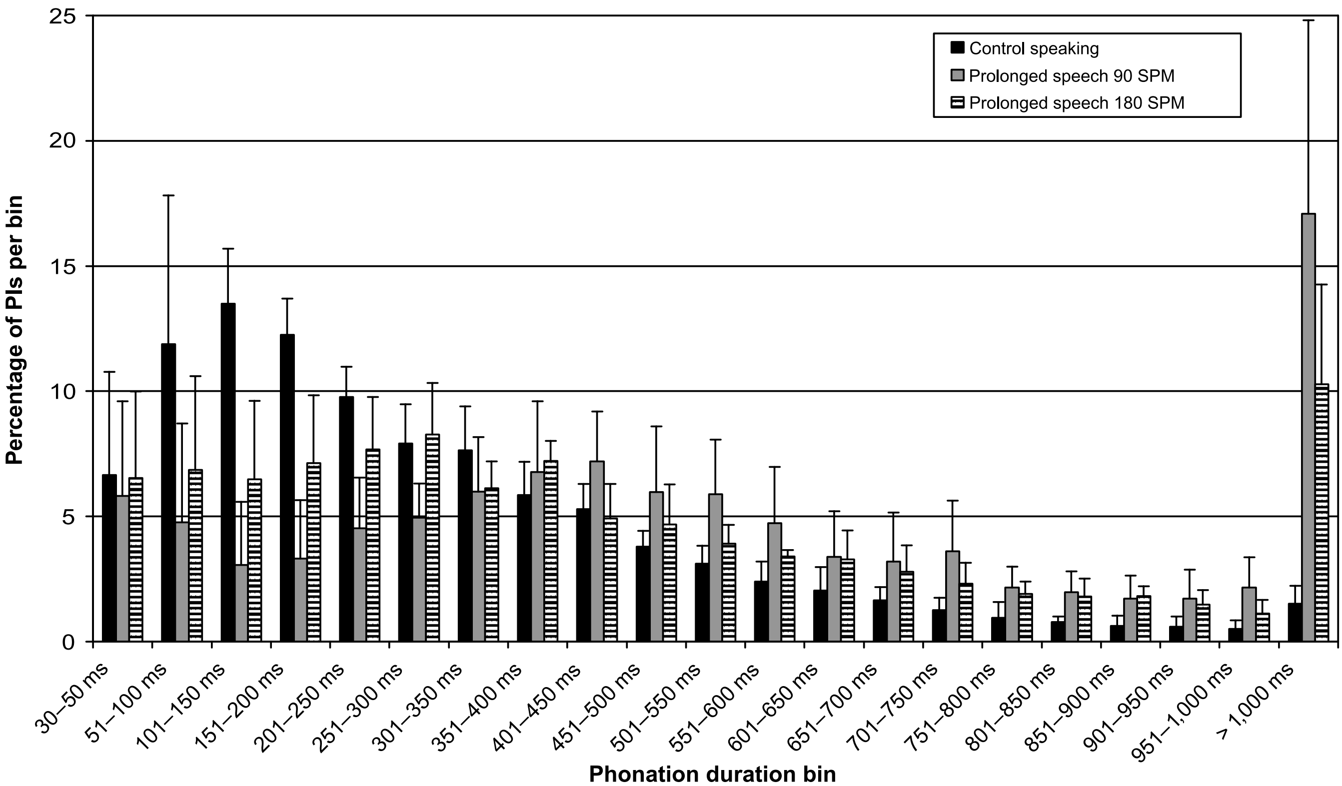
The reductions in short PIs are congruent with previous PI research showing that a reduction of PIs in this range is related to reductions in stuttering. It should also be noted that several conditions produced an increase in the percentage of PIs above 1,000 ms, as can be seen by the positive effect sizes in Table 4, suggesting that the fluency-inducing effects of some FICs may also be related to longer phonated segments, supporting Wingate's (1969, 1970) original hypothesis.

Table 5 displays the number of participants that showed reductions in PIs in the range of 30–150 ms. Every participant had a reduction in the percentage of PIs in at least one of the three bins encompassing this range in every experimental condition. In addition, only 2 participants did not have a reduction in two of these bins in every experimental condition. These instances were attributed to Participant 4 during rhythmic stimulation 92 BPM and to Participant 9 during prolonged speech 90 SPM.

Relationship Between Stuttering Frequency and Phonated Interval Bins

Pearson correlation coefficients were performed to assess the association between stuttering frequency and the percentage of PIs in the range of 30–200 ms. Table 6 shows three significant correlations. The first was a positive relationship for the 30–50 bin during control speaking ($r = .66$, $p < .001$). However, removing the data of Participant 5, a speaker with substantially more

Figure 2. PI distributions across all 21 bins for control speaking, prolonged speech 90 SPM, and prolonged speech 180 SPM. Data are the average values across the group. The control means are from all 8 of the participants who performed prolonged speech 90 SPM correctly, and the means for the fluency-inducing conditions (FICs) reflect only those participants who performed that condition properly (cf. see Table 1).



stuttering than any other participant, resulted in a nonsignificant correlation of –0.06 in this bin. The second significant correlation was for the 51–100 bin during control reading ($r = .35$, $p = .03$). Finally, there was a significant negative association for the 101–150 bin during control speaking ($r = –.52$, $p = .001$).

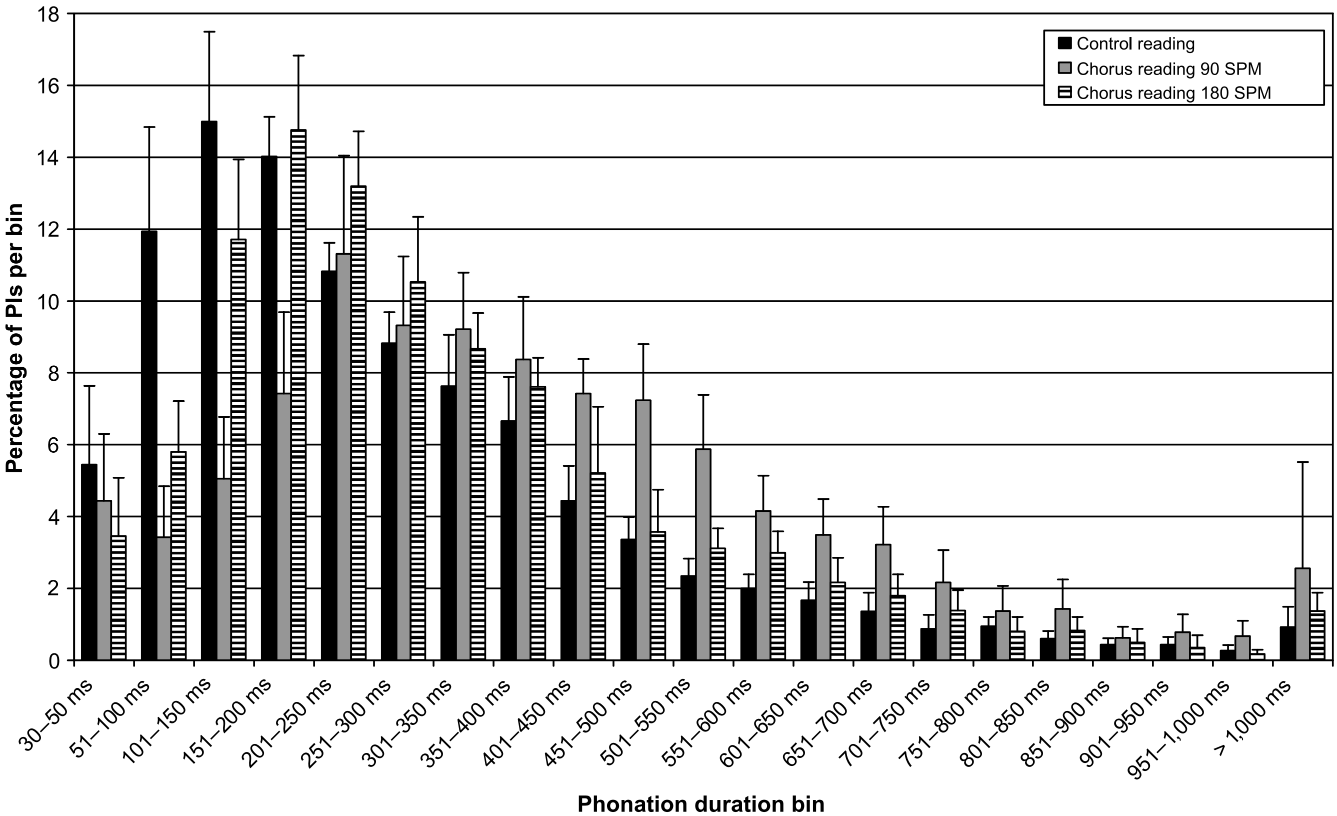
Reliability

Interjudge reliability. The raters differed by 1%SS or less on 199 (88.8%) of the 224 total trials (control and experimental). Of the remaining 25 trials, the raters differed by 1–2% 17 times, 2–3% 4 times, 3–4% 3 times, and 4–5% once. For speech rate ratings, 29 of 79 control trials and 118 of 145 experimental condition trials differed by 10 SPM or less. The remaining control trial SPM scores differed by 11–20 SPM on 20 trials, 21–30 SPM on 16 trials, and above 30 SPM on the remaining 14 control trials. For the remaining experimental conditions, SPM scores differed by 11–20 SPM on 16 trials, 21–30 SPM on 7 trials, and above 30 SPM on the remaining 4 trials. The most difficult experimental condition for counting syllables was chorus reading at 180 SPM, with only 15 of 25 trials receiving scores within 10 SPM of each other. These trials were also described as especially difficult by both raters due to the sound of both voices at the same time. Participants with speech rates above 200 SPM were responsible for most of the large discrepancies in SPM numbers during control conditions. However, as mentioned previously, the syllable counts by both raters were combined in an effort to reduce the effects of any error by an individual rater.

Performance ratings were also compared between raters. Of 145 possible trials, 120 (82.8%) received the same discrete scale value from both raters or differed by only one scale value (49 identical, 71 differing by one scale value). For the remaining trials, rating values differed by two scale units in 18 instances and 3 scale units in 7 instances.

Intrajudge reliability. Raters 1 and 2 showed rate–rerate differences of 1%SS or less in 59 and 57 of 60 possible trials, respectively. All other rate–rerate differences were less than 2%SS. For SPM data, Rater 1's two ratings were within 0 to 4.99 SPM on 48 trials, within 5 to 9.99 SPM on 6 trials, and differed by 10 SPM and above on 6 trials. Rater 2 differed by 0 to 4.99 SPM on 32 trials, 5 to 9.99 SPM on 12 trials, and 10 SPM and above on 16 trials. Previous reports found even lower agreement for judges counting syllables using the technique

Figure 3. PI distributions across all 21 bins for control reading, chorus reading 90 SPM, and chorus reading 180 SPM. Data are the average values across the group and reflect only those participants who performed the chorus reading conditions properly (cf. see Table 1).



in the present study (Onslow, Andrews, & Lincoln, 1994; Onslow, Costa, Andrews, Harrison, & Packman, 1996; Onslow, Costa, & Rue, 1990), and differences on the order of 5–10 SPM are not believed to interfere with interpreting the results of this study.

Both raters assigned the same performance rating in 23 of a possible 40 re-ratings. Most of the remaining trials were rated one value different on the scale from the first to second rating (16 times for Rater 1 and 14 times for Rater 2). The remaining trials for both raters were judged 2 scale points apart from the first to second rating.

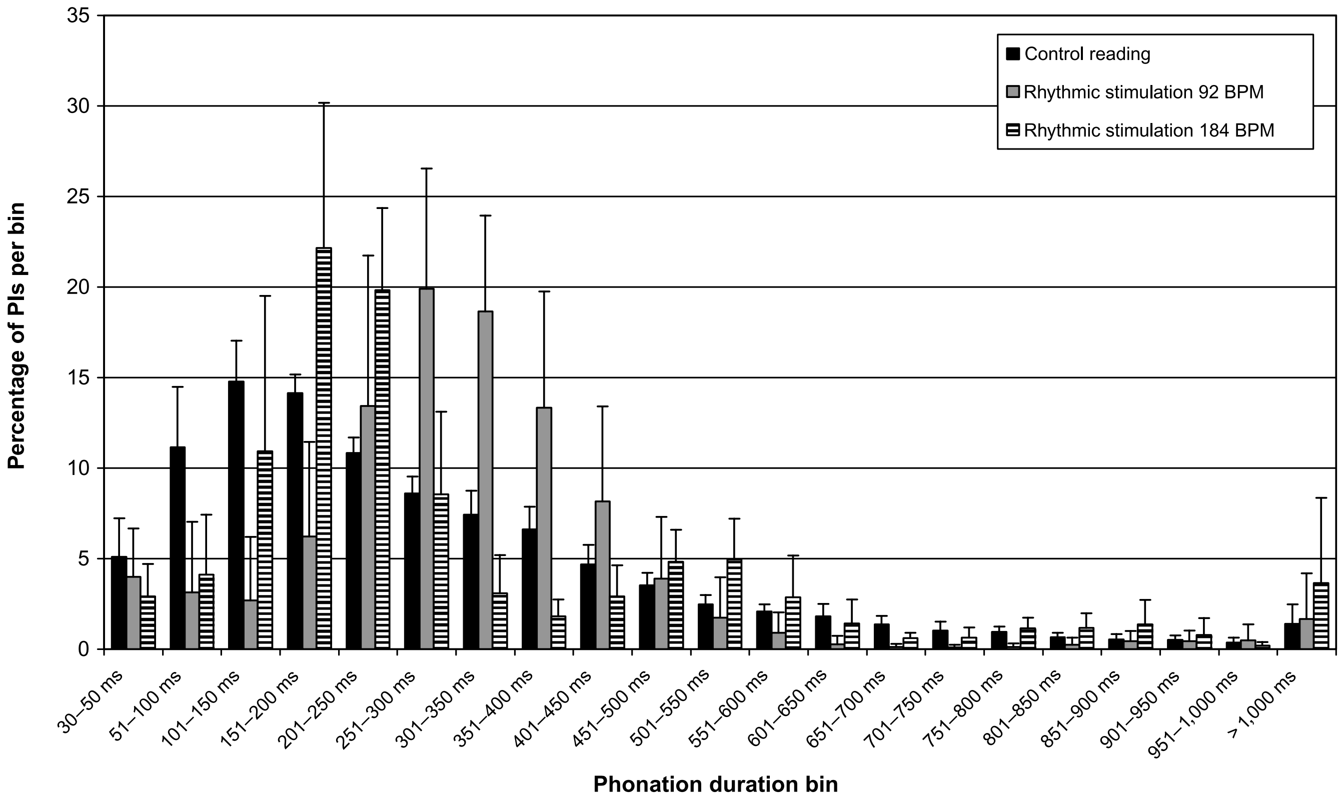
Reliability of PI measurements. The PI distributions from the second and third control trials for the 2 randomly selected participants revealed that, across both participants, there were only seven bins in which the percent of total PIs differed by more than 2%. Most of the remaining bins differed by less than 1%.

Discussion

The principal hypotheses of the present study were that the overall distribution of PIs would change from the control to experimental conditions and that the number of short intervals of phonation would be reduced during experimental conditions, as compared with control conditions. There was strong support for both of these hypotheses: Overall distributions were significantly different from the control condition when compared to *all* FICs, and PIs between 30 and 200 ms were significantly reduced across *all* FICs. To the best of the authors' knowledge, this is the first investigation to find a similar change from a control condition to all of the FICs studied here and a significant change in magnitude in a similar direction (a significant reduction in short-duration PIs) for all of the FICs in the present study. It appears that altering one's overall PI distribution may be important for the stuttering reductions during these FICs. Specifically, from the consistency found in the present study, reducing short-duration PIs (51–200 ms) may be the most critical alteration of the PI distribution.

One of the more interesting findings in this report is the lack of significant reductions in the 30–50 bin. One would hypothesize that if a reduction in the number of short PIs was critical to the reduction of stuttering during these FICs, the shortest duration PIs would have seen the largest reduction. Two reasons are suggested

Figure 4. PI distributions across all 21 bins for control reading, rhythmic stimulation 92 BPM, and rhythmic stimulation 184 BPM. The control means are from all 10 participants, and the means for the FICs reflect only those participants who performed that condition properly (cf. see Table 1).



for this unexpected finding. First, the lack of significance might be an artifact of the cutoff time boundaries for each bin. For example, using the bounds of 40 and 60 ms may have resulted in a significant reduction in that bin because a different percentage of PIs may have been placed into this new bin due to the new bounds. Of course, this suggestion can be said for all of the bounds used in all of the bins and suggests that the finding of no significant reduction of short PIs in the 101–150 bin for rhythmic stimulation 184 BPM, for example, does not diminish the importance of a reduction of PIs in this range for fluency. Using 86 ms and 135 ms instead of 101 and 150 as the bounds of a bin may have resulted in a significant reduction. It could be that the important reduction during rhythmic stimulation is only up to 135 ms.

A second reason for the lack of significant reductions in the 30–50 bin may be that it is very difficult to significantly reduce PIs of this duration in one's speech. Many participants using the MPI program have difficulty controlling PIs when focusing on their bottom decile range (see Introduction for explanation). The addition of longer PIs to their target range was needed when they

Table 3. Results of CMH tests examining whether there was an association between condition and phonated interval (PI) distribution.

Variable	Control reading and chorus reading 90 SPM	Control reading and chorus reading 180 SPM	Control reading and rhythm 92 BPM	Control reading and rhythm 184 BPM	Control speaking and singing	Control speaking and prolonged speech 90 SPM	Control speaking and prolonged speech 180 SPM
CMH test value	162.70	34.27	336.38	156.54	196.89	311.85	84.70
p value	< .0001	.0244	< .0001	< .0001	< .0001	< .0001	< .0001

Note. CMH = Cochran-Mantel-Haenszel.

Table 4. Mean percentage of PIs in each bin, for the PI ranges of 30–300 ms and >1,000 ms for all fluency-inducing conditions.

PI duration bin	Experimental condition						
	Singing (*n* = 9)	CR 90 SPM (*n* = 8)	CR 180 SPM (*n* = 8)	PS 90 SPM (*n* = 8)	PS 180 SPM (*n* = 4)	RS 92 BPM (*n* = 10)	RS 184 BPM (*n* = 9)
30–50 ms							
Effect size	−0.64	−0.46	−0.90*	−0.20	−0.48	−0.51	−0.98
Exp. mean	4.74	4.44	3.46	5.83	5.79	3.99	2.91
Cont. mean	8.05	5.45	5.45	6.66	8.80	5.09	5.13
51–100 ms							
Effect size	−1.29	−2.95*	−2.12*	−1.20	−2.95	−2.40*	−2.18*
Exp. mean	5.61	3.42	5.81	4.76	5.82	3.14	4.13
Cont. mean	12.85	11.94	11.94	11.88	14.20	11.15	11.47
101–150 ms							
Effect size	−2.01*	−3.98*	−1.32	−4.73*	−2.06	−5.33*	−1.80
Exp. mean	6.87	5.05	11.71	3.07	5.54	2.70	10.94
Cont. mean	13.56	15.00	15.00	13.49	12.80	14.77	15.02
151–200 ms							
Effect size	−2.86*	−6.01*	0.66	−6.17*	−4.54	−7.79*	7.78
Exp. mean	8.69	7.43	14.75	3.32	7.02	6.22	22.16
Cont. mean	11.98	14.03	14.03	12.26	12.17	14.15	14.26
201–250 ms							
Effect size	−1.35	0.61	3.00	−4.36	−1.14	3.02	9.90
Exp. mean	7.75	11.31	13.19	4.52	7.81	13.44	19.83
Cont. mean	9.49	10.82	10.82	9.77	9.38	10.83	10.80
251–300 ms							
Effect size	−0.88	0.57	1.98	−1.88	0.81	12.16	0.03
Exp. mean	6.15	9.32	10.53	4.96	9.05	19.90	8.56
Cont. mean	7.56	8.83	8.83	7.91	7.74	8.60	8.54
>1,000 ms							
Effect size	15.34	2.89	0.78	21.94	55.40	0.26	2.07
Exp. mean	12.44	2.55	1.37	17.08	10.90	1.68	3.66
Cont. mean	1.33	0.93	0.93	1.52	1.20	1.39	1.31

Note. Control (Cont.) means are beneath experimental (Exp.) means, recalculated to reflect only those participants who contributed data to the experimental condition. Asterisk indicates a significant *t* test result. CR = Chorus Reading; PS = Prolonged Speech; RS = Rhythmic Stimulation.

were unable to reach the 50% reduction target mentioned previously. It may be that PIs in this shortest bin are somewhat difficult to regulate voluntarily. Although it is possible to reduce their duration to a certain degree, as evidenced by the effect sizes in Table 4, it might not be possible for most speakers to reduce them significantly. If this is a valid conclusion, it might be unnecessary to include these shortest duration PIs in the "target range" of MPI users.

The findings of an alteration in PI distributions—and, specifically, a reduction in the percentage of short PIs—are consistent with previous reports that studied some subset of the conditions used in this study (Adams & Ramig, 1980; Andrews et al., 1982; Brayton & Conture, 1978; Colcord & Adams, 1979; Healey et al., 1976; Hutchinson & Navarre, 1977; Klich & May, 1982; Packman et al., 1994; Webster et al., 1987; Wingate, 1981). The most consistent finding in previous literature was that various aspects of phonation have been found to increase during the four FICs used here, and Figures 1–4 and Table 4 do reveal an increase in the number of longer PIs in specific bins in every condition. Although there is no consistent increase or decrease in the number of PIs across the four conditions in any one 50-ms bin above 200 ms, or in any systematic combination of bins, these data do not rule out the possibility that a significant number of longer PIs might be found if more speech were analyzed. Persons who stutter performing prolonged speech 90 SPM appear to be extending the reduction seen in the range of 51–150 ms to the range of 151–300 ms (and increasing the percentage of PIs above the 300-ms marker). During singing and prolonged speech 180 SPM,

Table 5. Number of participants showing changes in percentage of PIs in the three shortest PI bins.

Condition and PI bin	Number of participants: Decreased	Increased
Singing (n = 9)		
30–50 ms	7	2
51–100 ms	9	0
101–150 ms	9	0
Chorus reading 90 SPM (n = 8)		
30–50 ms	6	2
51–100 ms	8	0
101–150 ms	8	0
Chorus reading 180 SPM (n = 8)		
30–50 ms	8	0
51–100 ms	8	0
101–150 ms	8	0
Prolonged speech 90 SPM (n = 8)		
30–50 ms	5	3
51–100 ms	7	1
101–150 ms	8	0
Prolonged speech 180 SPM (n = 4)		
30–50 ms	3	1
51–100 ms	4	0
101–150 ms	3	1
Rhythmic stimulation 92 BPM (n = 10)		
30–50 ms	7	3
51–100 ms	9	1
101–150 ms	10	0
Rhythmic stimulation 184 BPM (n = 9)		
30–50 ms	8	1
51–100 ms	9	0
101–150 ms	6	3

an increase in longer PIs above 300 ms was also found. Those performing rhythmic stimulation 92 BPM and 184 BPM and chorus reading 180 SPM may be transferring the PIs from the range of 51–150 ms to specific bins in the range of 151–300 ms. These data show that an increase in longer PIs, in addition to a decrease in short PIs, may be responsible for the reductions in stuttering.

Using Modified PIs for Treatment

The results of this study are consistent with previous reports showing that a reduction in short-duration PIs is associated with reductions in stuttering (Gow & Ingham, 1992; Ingham & Devan, 1987; Ingham et al., 1983, 2001). Two questions remain, however: (a) whether the reductions in PIs found in the present study are necessary or associative and (b) whether they occur, and therefore, may contribute to the fluency obtained during other behavioral treatments or FICs. Having clients speak under the FICs while attempting not to change their PI distributions might provide further information about the importance of PI changes to the improvements in fluency that are associated with the FICs. Additionally, measuring PIs during and upon completion of different treatment techniques could inform us as to whether an altered PI distribution may be associated with fluency during treatments that do not focus on PIs.

As discussed in the Introduction, one treatment that has focused on a particular aspect of phonation, and that indirectly capitalizes on extended phonation, is the MPI treatment program (Ingham et al., 2001). The indirect nature of the MPI treatment stems from the fact that speakers work to reduce short PIs, as opposed to directly increasing longer PIs. Presently, this program has the speaker reduce PIs in the "lowest 20th percentile that the speaker could sufficiently reduce that was accompanied by the elimination of stuttering" (Ingham et al., 2001, p. 1233). This "target PI range" is developed individually for each speaker but is typically in the vicinity of 25–200 ms and can extend over the 200-ms marker. Interestingly, the present study found the 51- to 150-ms PI range to be reduced during all of the experimental conditions, providing support for the use of the reduction of short PIs in the remediation of stuttering, regardless of the complexities discussed previously in this article. The MPI program's emphasis on each speaker's first quintile of PIs, which often extends past 150 ms, might need to be reevaluated, however, in light of the present study's consistent reductions in the 51- to 150-ms range. In addition, if the MPI user cannot reduce the PIs in the first quintile, longer PIs are included in the target range, which makes the task of a 50% reduction in target range

Table 6. Correlations between stuttering frequency and the percentage of PIs in the four shortest PI bins.

Condition	Phonation duration bin: 30–50 ms	51–100 ms	101–150 ms	151–200 ms
Control speaking	0.66**	0.21	–0.52**	–0.17
Control reading	–0.10	0.35*	–0.10	–0.01

*Significant at the .05 alpha level. **Significant at the .01 alpha level.

PIs easier—that is, MPI users often have difficulty reaching the target 50% reduction goal while trying to reduce their shortest duration PIs, so including longer duration PIs in their target range simplifies the task. It may be more beneficial to force clients to practice until they can reduce shorter range PIs without including longer duration PIs. In fact, recent evidence in the neurorehabilitation literature has shown that forcing the nervous system to perform beyond its assumed limits can produce long-term neural and behavioral changes that are superior to those of more traditional treatment programs (Davidow, Richardson, Bothe, & Andreatta, 2006; Pulvermuller et al., 2001; Taub, Uswatte, & Elbert, 2002).

In addition to PI duration range, the exact number of PIs to reduce within a certain range also needs further study. It was mentioned earlier that the MPI program used by Ingham and colleagues (Gow & Ingham, 1992; Ingham & Devan, 1987; Ingham et al., 1983, 2001) used a 50% reduction in PIs to induce fluency, yet this number was chosen initially for a series of relatively unspecified reasons. It has been shown to be effective, but to investigate whether a particular percentage may be more effective, the amount of reduction from control speaking to chorus reading 180 SPM and from control speaking to rhythmic stimulation 184 SPM in the 51–100 bin was calculated. These two conditions were chosen because, as can be seen from Table 4, the number of PIs in this bin seems to depend on the rate of the experimental condition, and these rates are closer to habitual speech rates, which are the ultimate goals of the MPI program. Therefore, the use of these two conditions better reflects the necessary reduction.

The 51–100 bin was selected because it appears that it may be important in relation to fluency since it showed the most significant reductions in PIs, along with the most individual speaker reductions (see Table 5), during the FICs. There was an average drop of 57% for the group across these conditions, with a range of 41% to 72%. Therefore, if phonated intervals in this range are related to a reduction in fluency and the effect of these FICs, the 50% value used by Ingham and colleagues (Gow & Ingham, 1992; Ingham & Devan, 1987; Ingham et al., 1983, 2001) appears to be near the amount of reduction during the experimental conditions and may be the most appropriate target to achieve zero or near-zero stuttering. However, the variation (41%–72%) suggests that each person who stutters may benefit from a different target reduction percentage. Although only conjecture at this point, however, forcing an even greater reduction in short-duration PIs may allow for more prolonged behavioral changes. Future experimentation in which participants purposefully reduce differing percentages of PIs may help resolve this question.

In general, it appears that alterations to phonation may be critical to the reduction of stuttering, and researchers should continue to examine ways to include phonatory variables in stuttering therapies. Current prolonged speech therapies attempt to capitalize on this phenomenon by increasing the duration of phonation or making other changes that involve extended vocal tract gestures, but even one of the most well-known and well-respected prolonged speech programs resulted in only about 60% of persons who stutter reducing stuttering frequency to below 2%SS at 1 year postestablishment (Boberg & Kully, 1994). In addition, another very popular program, the Precision Fluency Shaping Program, has reported even fewer participants reaching this 2% stuttering standard at follow-up (Mallard & Kelley, 1982; Schwartz & Webster, 1977), with group data well above this value (De Nil & Kroll, 1995). If prolonged speech treatments or the MPI strategy are to improve their effectiveness, it may be better and more efficient to focus on a combination of reducing the proportion of short-duration PIs while simultaneously increasing the proportion of longer duration intervals.

One complexity with this recommendation, however, emerges from the Godinho et al. (2006) finding of no significant difference between the PI distributions of persons who stutter and those of normally fluent controls. The present study also found essentially no association between %SS scores and short-duration PIs and revealed relatively modest change in stuttering rates for 9/10 participants (due to relatively low control condition stuttering rates), with larger changes in PIs, both suggesting that an abnormal PI distribution is not necessarily associated with stuttering. It is possible that such methodological details as examining bins shorter than 50 ms, or different combinations of bins, may yet identify differences between the groups' distributions. Assuming that the mutually confirmatory findings of the present study and the Godinho et al. study are pointing to a solid result, however, then the difference between persons who stutter and those who do not may be found, as Godinho et al. discussed, in "affected speakers' ability to manage the production of short-duration PIs" (p. 168), and especially in the neurophysiological implications of reducing the use of short PIs.

Future Research

Several other issues raised by this investigation appear to deserve further discussion. Figures 2, 3, and 4 and Table 4 show that the same speaking condition at different speech rates produced different group PI distributions and effect sizes. Clearly, any future investigations of vocalization variables in stuttering speakers must test different speech rates during the FICs rather than depending on any one rate. The effect of a reduction in speech rate on the dependent variables versus the actual need for the variable's change for fluency cannot be determined, as phonation-related variables have been shown to be altered by simply changing speech rate (Allen & Miller, 1999; Gay, 1978; Kessinger & Blumstein, 1998), with the most common finding being an increase in phonation time as speech rate decreases.

Insight into this issue for PIs is obtained by examining the PI distributions of those speakers in the present study who had similar control and experimental condition SPM rates. Participants 2 and 6 produced similar rates of speech during control reading, chorus reading 180 SPM, and rhythmic stimulation 184 BPM. Participants 3 and 5 actually showed an increase in speech rate from control speaking to singing, unlike the other participants who all showed a reduction in SPM rate. In all cases, there were reductions in the percentage of PIs in the range of 30–150 ms. It appears from these data that there is a reduction of short PIs even when speaking rates are similar, making it less likely that a slowed speech rate is solely responsible for the findings. Further examination with more participants is needed to further confirm these preliminary data. We are presently exploring these and other issues by examining changes in several speech production variables during FICs at speech rates identical to control condition rates.

The present study also raises the issue of performance ratings. Previous studies have not presented such ratings or any other form of experimental fidelity data (Adams & Ramig, 1980; Andrews et al., 1982; Brayton & Conture, 1978; Colcord & Adams, 1979; Healey et al., 1976; Hutchinson & Navarre, 1977; Klich & May, 1982; Martin, Johnson, Siegel, & Haroldson, 1985; Packman et al., 1994; Stager, Denman, & Ludlow, 1997; Stager & Ludlow, 1993; Wingate, 1981). In the present study, there were several occasions when the experimenter restarted a trial because of the participant's performance regression with time. Thus, it also seems essential for any future research in this area to assess the performance of the speakers after the task to ensure that the data accurately reflect the performance requirements intended by the researchers.

In summary, these data suggest that the reduction of short PIs may be influential in our understanding of the fluency-inducing mechanisms underlying the most common FICs. Knowledge regarding these mechanisms may lead to the development of improved treatment programs. Purposefully altering PIs in specific duration ranges has resulted in fluent speech and appears to be associated with all commonly employed FICs. Additionally, reducing short PIs has been shown to be associated with changes in brain regions that appear critical for fluency (Ingham et al., 2003), suggesting that PI changes may be used to drive neural changes necessary for long-term behavioral improvement (Davidow et al., 2006; Taub et al., 2002). These findings taken together suggest that PI alteration may be a powerful means to instate and maintain fluency in persons who stutter. Future research in this area will help further our understanding of the importance of this variable to stuttering and fluency treatments.

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