

Factors Influencing the Effects of Delayed Auditory Feedback on Dysarthric Speech Associated with Parkinson's Disease

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Abstract

Purpose: The present study examined the effects of Delayed Auditory Feedback (DAF) as a rate control intervention for dysarthric speakers with Parkinson's disease. Adverse reactions to relatively long delay intervals are often observed during clinical use of DAF, and may result from improper "matching" of the delayed signal. To facilitate optimal use of DAF, clinicians may need to provide instruction, modeling, and feedback. Therefore, the primary purpose of this study was to evaluate the impact of clinician instruction on the effectiveness of DAF in treating speech deficits. A related purpose was to compare the effects of different delay intervals on speech behaviors.

Method: Three males with Parkinson's disease and an associated dysarthria served as participants in this single-subject study. The A phases consisted of a sentence reading task using DAF; the B phases incorporated clinician instruction. During each of the 16 experimental sessions, speakers read with four different delay intervals (0 ms, 50 ms, 100 ms, and 150 ms). During the B phases, the experimenter provided verbal feedback and modeling pertaining to how precisely the speaker matched the delayed signal. Dependent variables were speech rate, percent intelligible syllables, and percent disfluencies.

Results: Results indicated that for all three speakers, DAF significantly reduced reading rate and produced significant improvements in either intelligibility (Speaker 3) or fluency (Speakers 1 and 2). A delay interval of 150 ms produced the greatest reductions in reading rates for all speakers, although any DAF setting used was sufficient to produce significant improvements in either intelligibility or fluency. Additionally, supplementing DAF with clinician instruction resulted in significantly enhanced gain achieved with DAF.

Conclusions: These findings demonstrated the effectiveness of various intervals of DAF in improving speech deficits associated with Parkinson's disease; particularly when patients are provided with instruction, modeling and feedback by the clinician.

Keywords: Parkinson's disease; Dysarthria; Delayed auditory feedback

Introduction

Hypokinetic dysarthria is a motor speech disorder resulting from disturbances in muscular control secondary to neurological damage [1,2]. This type of dysarthria was dubbed "hypokinetic" based on the view that its physiological basis involved a reduction in the range of movements needed for speech production. Parkinson's disease is the prototypic disease associated with hypokinetic dysarthria, accounting for most of the cases seen in speech-language pathology practices [2]. Due to motor symptoms such as tremor, rigidity and akinesia, Parkinson's disease patients exhibit a high prevalence of speech and voice deficits [3-5].

Perceptual features of hypokinetic dysarthria typically include imprecise consonant articulation, reduced variability of pitch and loudness, variable speech rate, short rushes of speech, and inappropriate or excessive silences [3,2]. In fact, hypokinetic dysarthria is the only type of dysarthria in which rapid rate is often a

prominent and distinctive perceptual feature. Syllables are typically produced in an accelerating manner, with a reduced range of articulatory excursions. Perceptually, syllables may sound "blurred" or seem to "run together" [2]. Additionally, fluency deficits impacting rate and intelligibility often include sound or syllable repetitions, difficulty initiating phonation, and palilalia (i.e., involuntary repetition of words or phrases) [6].

Many patients with hypokinetic dysarthria benefit from intervention that reduces speech rate, as a -0.78 correlation between speech rate and intelligibility has been reported [1]. Moreover, it is often easier for dysarthric speakers to learn to control their rates than to achieve other motor goals. In fact, speech rate may be the single most behaviorally modifiable variable for improving intelligibility [7,8]. Rarely in clinical treatment of speech production can such dramatic a change be brought about by the manipulation of one variable [9].

Therefore, the present study investigated the effects of a rate control intervention using Delayed Auditory Feedback (DAF). Essentially, this technique involves delaying the auditory feedback of the person's

speech, which requires him or her to prolong each syllable until the feedback "catches up" to the speech production. Ideally, DAF induces a relatively slow, fluent speech pattern characterized by prolonged syllabic nuclei (i.e., vowels), smooth transitions between syllables, and relatively stable syllable durations [10-12]. Evidence from a number of published reports, as well as anecdotal clinical evidence, suggests that DAF offers several benefits as a method of rate reduction including substantial reductions in rate, increased articulatory precision, increased speech fluency, and improved intelligibility [3].

Although individual responses to DAF vary considerably [11], the delayed signal typically induces reduced speech rate, prolonged vowels, and/or repetition of word-final and sentence-final sounds in an "echo-like" manner [13]. The delayed speech signal seems to lead to the erroneous perception that speech production is not as far along as it actually is. This may cause the speaker to continue a speech gesture, resulting in the prolongation of a sound. Alternatively, the delayed signal may indicate that the last sequence of gestures should not have been terminated, resulting in the speaker repeating the production of speech segments. These two phenomena may account for the variability of responses to DAF; some speakers produce sound/syllable repetitions, whereas others prolong vowels [13].

These speech responses are modified depending upon the speaker's level of attention paid to the delayed signal [11] and can be manipulated by instruction [13]. Instruction to listen to their voices while speaking with DAF reportedly resulted in normal speakers greatly reducing their speech rates, compared to instructions to ignore the signal. This finding has important implications for the clinical use of DAF and will be discussed later in further detail. Thus, an important aspect of Goldiamond's findings was the controlling effects of paying attention to the delayed signal, often referred to as "matching" the signal.

Following the use of DAF with adults who stutter [14-19], researchers examined its use with dysarthric speakers [20-22,23,24]. Results were generally mixed, but suggested positive effects of DAF on speech rate, intelligibility, and fluency for appropriate speakers [25-28]. Delay intervals ranging from 50 ms [21] to 150 ms [22] were used effectively, whereas delays in excess of 150 ms were reported to yield no further gains in rate or intelligibility [9]. In fact, such delays reportedly produced "disastrous" effects on the speech of some individuals [29,24].

Unfortunately, there is a paucity of studies experimentally demonstrating the effects of extended use of multiple delay intervals. As a result, differential responses of individual speakers to various delay times have not been documented experimentally. Adverse reactions to relatively long delay times are commonly observed during clinical use of DAF, and seem to result from imprecise matching of the delayed signal. This has been documented with persons who stutter [10], dysarthric speakers [29,24], and even normal speakers [30,31].

To facilitate optimal use of DAF, therefore, clinicians may need to provide instruction, modeling, and feedback. Clinician feedback is routinely used in speech-language therapy, but has not been evaluated empirically with DAF-based interventions. Rosenbek and LaPointe [29] suggested that the clinician should be as active in DAF training as in any other form of therapy, stating that carry-over of treatment gains can only be achieved if the clinician provides feedback regarding the speaker's performance. Unfortunately, most reports of DAF-based interventions have not clearly delineated instructions or modeling procedures used by clinicians.

What are currently lacking in the literature are studies that experimentally demonstrate the effects of clinician instruction pertaining specifically to how precisely speakers match the delayed signal. The primary goal in this line of inquiry is not to demonstrate that DAF benefits some patients under some conditions, but rather which task parameters (e.g., clinician instructions, delay interval) contribute to its success or failure. Such information could later be used to "fine-tune" the DAF procedure in order to maximize its efficacy and efficiency. Toward that end, the purpose of the present study was to evaluate the relative contributions of clinician instruction and delay interval on the effectiveness of DAF in treating speech rate, intelligibility, and fluency deficits in adults with dysarthria secondary to Parkinson's disease. Specific research questions were as follows:

Does delayed DAF reduce reading rate in speakers with Parkinson's disease?

Does DAF improve intelligibility and/or fluency?

Are there differential effects of various delay intervals on speech behaviors?

Are there differential effects of clinician instruction on speech behaviors?

Materials and Methods

Participants

Three adult males with Parkinson's disease and an associated dysarthria participated in the study (see Table 1 for relevant characteristics). All participants met the following inclusion criteria:

- 1) A neurologist's diagnosis of Parkinson's disease [32].
- 2) Disease severity of at least Stage 1 level on the Hoehn and Yahr severity scale [33].
- 3) A passing score of 24/30 on the Mini-Mental State Examination [34] to rule out the presence of dementia.
- 4) Self-reported native speakers of English.
- 5) Normal or corrected vision.
- 6) Pure-tone hearing thresholds at or below 50 dB HL for 0.5, 1.0, and 2.0 kHz.
- 7) Presenting complaint of two or more of the following speech symptoms, verified by the experimenter using a dysarthria checklist: excessive speech rate, imprecise articulation, poor intelligibility, disfluencies (e.g., sound, syllable, word, or phrase repetitions; interjections; revisions).
- 8) No history of reading difficulties.

Stimuli

A sentence-reading task was used throughout the study in all experimental conditions and during all phases. Sentences were obtained from the Speech Perception in Noise (SPIN) test [35], and consisted of six to nine syllables each. The sentences were typed out in relatively large font (i.e., 16-point Times New Roman style) and presented to speakers on sheets of paper for reading ease.

Instrumentation

Delayed auditory feedback was generated using the Pocket Fluency System (Casa Futura Technologies), a portable unit capable of producing delay intervals of up to 250 ms in duration. All speakers wore a head-mounted microphone/headphone assembly (Labtec, model C-324). This assembly was connected to the DAF unit, and an additional microphone was clipped onto the speaker's shirt and connected to a portable cassette tape recorder (Sony, model WM-D6C). This procedure permitted audio recordings that were later used for reliability checks. All sessions were recorded onto TDK D60 audiocassette tapes.

	Speaker 1	Speaker 2	Speaker 3
Age in years	64	36	74
Years since diagnosis	23	7	16
Overt physical signs	Shuffling gait, resting tremor, involuntary arm movements	Festinating gait, postural instability, use of walker	Non-ambulatory, rigidity in limbs, limited arm and hand movement
Speech characteristics	Rapid rate, imprecise consonant articulation, disfluencies	Rapid rate, imprecise consonant articulation, frequent disfluencies	Variable rate, soft intensity, fatigue of oral musculature, vowel distortions, imprecise consonant articulation, difficulty initiating phonation
Primary types of disfluencies	Sound and syllable repetitions	Sound repetitions, word revisions	Interjections (e.g., extraneous vocalizations), phrase repetitions
Medication	Sinemet	Sinemet, Mirapex	Sinemet CR, Tasmart, Mirapex, Eldepryl

Table 1: Descriptive characteristics of the three speakers with Parkinson's disease.

The experimenter also wore a microphone/headphone assembly (Labtec, model C-324), attached to a second pair of jacks on the DAF unit, in order to hear the speaker's delayed speech signal. This allowed the experimenter to evaluate how precisely the speaker "matched" the delayed signal, as well as providing modeling of accurate matching. For each speaker, delay intervals of 0 ms, 50 ms, 100 ms, and 150 ms were presented in a randomized sequence during each of the 16 sessions. Intensity levels were set at comfortable listening levels for each speaker.

Data collection

The first author served as experimenter during all 16 sessions. The three dependent variables measured throughout the study were speech rate (in syllables per second), intelligibility (i.e., percentage of intelligible syllables), and percent disfluencies (i.e., the number of disfluent events per hundred syllables). Unintelligible syllables were defined as those that the experimenter was unable to identify. Disfluencies tallied included sound, syllable, word, and phrase

repetitions, interjections (e.g., "um," "uh," as well as extraneous vocalizations), and revisions (e.g., "She went to *he went* to the store.").

Following each session, reading rate, intelligibility, and disfluency were calculated for each 20 sentence DAF condition (i.e., 0 ms, 50 ms, 100 ms, and 150 ms). Rate was calculated by dividing the total number of syllables in each sentence by the total number of seconds elapsed during production of that sentence. Dividing the number of intelligible syllables in each sentence by the total number of syllables in that sentence; and multiplying by 100 calculated intelligibility. Dividing the total number of disfluent events in each sentence by total syllables in that sentence, and multiplying by 100 calculated disfluency. Mean values for all three dependent measures were computed for each interval condition in every session. For each of the 16 sessions, reading rate, intelligibility, and disfluency were plotted for each of the interval conditions (i.e., 0 ms, 50 ms, 100 ms, and 150 ms) on separate graphs for each speaker.

Procedures

An A-B-A-B, alternating-treatments design was utilized for each of the three participants [36]. The A phases (four sessions each) consisted of a sentence reading task using DAF alone, whereas the B phases (four sessions each) incorporated experimenter instruction/modeling into the DAF protocol. During each of the 16 experimental sessions, speakers were exposed to four different DAF intervals (i.e., 0 ms, 50 ms, 100 ms, and 150 ms). The order of presentation of the delay intervals was randomized to control for sequence effects. Each participant performed exactly the same experimental protocol.

During each of the two A phases (i.e., DAF alone), each speaker read 20 sentences using each of four DAF intervals, for a total of 80 sentences per session. The speaker wore the microphone/headphone assembly throughout the entire session, and the loudness of the delayed feedback was adjusted to a comfortable listening level. During each condition, the speaker read the sentences from sheets of paper placed in front of him. After 20 sentences were read, the experimenter adjusted the delay setting on the DAF unit (e.g., from 50 ms to 150 ms), and began the next delay interval condition.

During each of the two B phases (i.e., DAF + instruction), procedures were similar to those followed during the A phases. However, following each sentence production by the speaker, the experimenter provided verbal feedback specifically pertaining to how precisely the speaker matched the delayed signal throughout production of the sentence. "Matching" the delayed signal was defined as the speaker prolonging (i.e., "stretching") each spoken syllable until he heard that syllable through the headphones, and then beginning production of the next syllable in the sentence. It was expected that this manner of speech production, when performed accurately, would result in the elimination of an audible repetition of the syllable (or an "echo"). In effect, the speaker would be allowing the delayed signal to "catch up," temporally, to his production of the syllable before proceeding with production of the next syllable. This typically results in a "synchronization" of the speaker's direct speech signal with the delayed signal, preventing a potentially distracting and aversive auditory stimulus. Precise matching of the delay also ensures maximal speech rate reduction from that particular delay interval.

As described above, the experimenter listened to each sentence production through headphones in order to monitor matching accuracy. Following each sentence production, the experimenter provided the speaker with verbal feedback about how precisely he

matched the delayed signal. Whenever deemed necessary (i.e., when audible echoes were perceived), the experimenter briefly instructed the speaker on how to improve matching accuracy (e.g., "Wait until you hear the syllable through the headphones before you start the next syllable," or "Stretch out your syllables a little longer, I'm still hearing an echo.").

Following this verbal feedback, the experimenter demonstrated precise matching by orally producing the same sentence at the appropriate rate with each syllable adequately elongated. Following this demonstration, the experimenter prompted the speaker to read the next sentence on the list while matching as precisely as possible. For production of sentences judged to be accurately matched, the experimenter responded with verbal praise (e.g., "Good.") and instructed the speaker to proceed with the next sentence in the list. This procedure was followed for every session during each of the two B phases.

Data analysis

The dependent variables (i.e., reading rate, intelligibility, and disfluency) were plotted on separate graphs for each speaker following each of the 16 sessions. Descriptive statistics computed included mean values for each of the four delay settings (i.e., 0 ms, 50 ms, 100 ms, 150 ms) during the A phases (i.e., A1 + A2) and B phases (i.e., B1 + B2), as well as across all four phases. Likewise, mean values for the A and B phases were calculated across interval conditions. Standard Deviation (SD) was used as the measure of variability.

Visual inspection of these data was supplemented with statistical analysis. For each speaker, three 2x4 Analyses of Variance (ANOVAs) were performed (one on each of the three dependent variables) to test for main effects of DAF interval and experimental phase (i.e., DAF vs. DAF + instruction), as well as interactions between these two factors. Following all main effects of DAF interval, Bonferroni tests were used to make pair-wise comparisons among the four DAF interval conditions across experimental phases.

Intrajudge reliability

Agreement between the experimenter's calculations of each of the three dependent variables was computed using five percent of the sentences produced by each speaker during each session (i.e., 64 sentences per each speaker, for a total of 192 sentences). Intrajudge reliability was calculated using Pearson product moment correlations to evaluate the relationships between the two sets of values (i.e., TIME 1 and TIME 2) for each dependent variable. Table 2 provides a summary of the intrajudge reliability data.

	Mean and SD for TIME 1	Mean and SD for TIME 2	Correlation and significance
Reading rate in syllables second	2.31 (.88)	2.34 (.89)	r=.981 p=.000
Percent intelligible syllables	96.55 (10.63)	97.77 (8.94)	r=.617 p=.000
Percent disfluency	2.58 (6.27)	3.01 (6.91)	r=.891 p=.000

Table 2: Summary of intrajudge reliability data for the three dependent variables.

Interjudge reliability

A graduate student in Communication Sciences and Disorders served as reliability judge. Following a brief training period, this student calculated reading rate, intelligibility, and disfluency for five percent of the sentences produced by each speaker during each session (i.e., 64 sentences for each speaker). Interjudge reliability was calculated using Pearson product moment correlations to evaluate the relationships between the two sets of values for each dependent variable. Table 3 provides a summary of the interjudge reliability data. As indicated in the table, interjudge reliability was generally high. However, the relatively low (but significant) correlation between the two sets of intelligibility values (r=.303) suggests the presence of a ceiling effect for intelligibility during sentence reading. That is, because of the restricted range of values for this measure (i.e., speakers were generally intelligible during this task), values varied only slightly either above or below the mean. For example, JUDGE 2's calculation for a particular sentence was typically slightly higher or slightly lower than JUDGE 1's calculation for that same sentence (hence, a relatively low correlation between the two sets of values).

	Mean and SD for JUDGE 1	Mean and SD for JUDGE 2	Correlation and significance
Reading rate in syllables second	2.31 (.88)	2.50 (1.07)	r=.982 p=.000
Percent intelligible syllables	96.55 (10.63)	94.98 (14.01)	r=.303 p=.000
Percent disfluency	2.58 (6.27)	4.90 (7.22)	r=.512 p=.000

Table 3: Summary of interjudge reliability data for the three dependent variables.

Results

Speaker 1

Figures 1 and 2 display Speaker 1's speech rate and disfluency across the 16 experimental sessions. Intelligibility data are not presented, as this speaker maintained nearly 100% intelligibility during the relatively simple sentence task utilized during the experiment. The four lines plotted on each graph represent the four DAF conditions utilized during each session (i.e., 0 ms, 50 ms, 100 ms, and 150 ms). Each graph is divided into four sections, which display data for the four phases of the experiment (i.e., A1, B1, A2, and B2). During each A phase, each participant read the sentences while using DAF without instruction and modeling from the experimenter. The experimenter provided instruction in conjunction with the use of DAF during the two B phases.

Speech rate

Figure 1 displays Speaker 1's speech rate (in syllables per second) across all 16 sessions. A 2x4 Analysis of Variance (ANOVA) yielded main effects for phase [F (1, 63)=51.766, p<.000] and interval [F (3, 63)=5.720, p=.000], but no interaction effect [F (3, 63)=2.013, p<.123]. In addition, a one-way ANOVA yielded a main effect of phase for the 0 ms condition [F (1, 15)=5.756, p<.031]. A Bonferroni test was performed to determine the differential effects of the four delay

intervals on speech rate. Results indicated that Speaker 1's reading rate during the 0 ms DAF condition was significantly higher than during each of the three remaining DAF conditions ($p < .0001$), and that 50 ms DAF yielded a significantly higher rate than did 100 ms DAF ($p < .0001$) or 150 ms DAF ($p < .0001$). However, 100 ms DAF and 150 ms DAF did not produce significantly different speech rates ($p < .089$). In sum, statistical analyses revealed that Speaker 1's speech rate was significantly reduced during the B phases (i.e., DAF + instruction), including during the 0 ms (i.e., no DAF) condition. Additionally, with the exception of 150 ms, each DAF interval produced a significantly lower rate than the next shortest delay interval across phases.

These statistical results are highlighted by visual inspection of the data. The no DAF condition consistently yielded the highest speaking rates ($M = 4.04$ SPS, $SD = .25$), with no overlap with values for any of the three DAF settings. In fact, there were no overlapping values among any of the DAF conditions. As expected, 150 ms DAF yielded the lowest speech rates in every session ($M = 1.87$ SPS, $SD = .52$), most markedly during the second B phase. As stated above, however, the mean difference in speech rate between this condition and the 100 ms DAF condition ($M = 2.16$ SPS, $SD = .53$) across the four phases was not statistically significant. These results indicate that each successive increase in the delay interval resulted in a further decrease in Speaker 1's reading rate. By the final session, he read at a rate of over four syllables per second without the use of DAF but approximately 1.5 syllables per second with 150 ms DAF.

Examination of changes in speech rate between the four phases of the experiment revealed an immediate downward shift in rate for all four intervals at the beginning of the first B phase (i.e., session 5). This change in level during phase B1 was much greater in magnitude for the three levels of DAF than for the no DAF condition (i.e., 0 ms DAF), and illustrates the effectiveness of clinician instruction in increasing the efficacy of DAF as a rate control intervention. The beginning of phase A2 (i.e., withdrawal of experimenter instruction) resulted in an immediate increase in rate during all interval conditions (including the 0 ms DAF condition), as well as a slight upward trend for 100 ms DAF.

Re-instating the experimenter instruction at phase B2 (session 13) resulted in immediate downward shift in speech rate for all conditions with the exception of 50 ms DAF, which also produced a rate decrease by session 15. Throughout the remainder of this last phase (i.e., B2), performance stabilized during use of the two longest delay intervals (i.e., 100 ms and 150 ms), but showed slightly more variability without the use of DAF (i.e., 0 ms), as well as with the use of 50 ms DAF. In general, these results reveal that Speaker 1 experienced the most dramatic (and consistent) rate reductions by using the two longest delay intervals, particularly in conjunction with matching instruction from the experimenter. However, speech rate without the use of DAF was also significantly lower during the B phases (i.e., DAF + instruction) than during the A phases (DAF alone), suggesting within-session generalization of DAF effects.

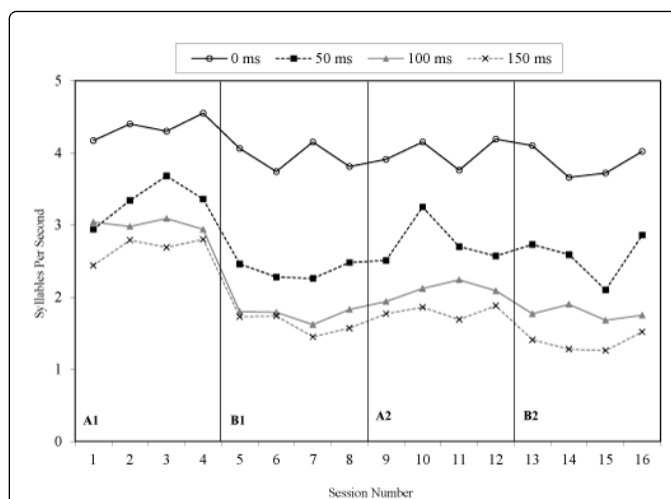
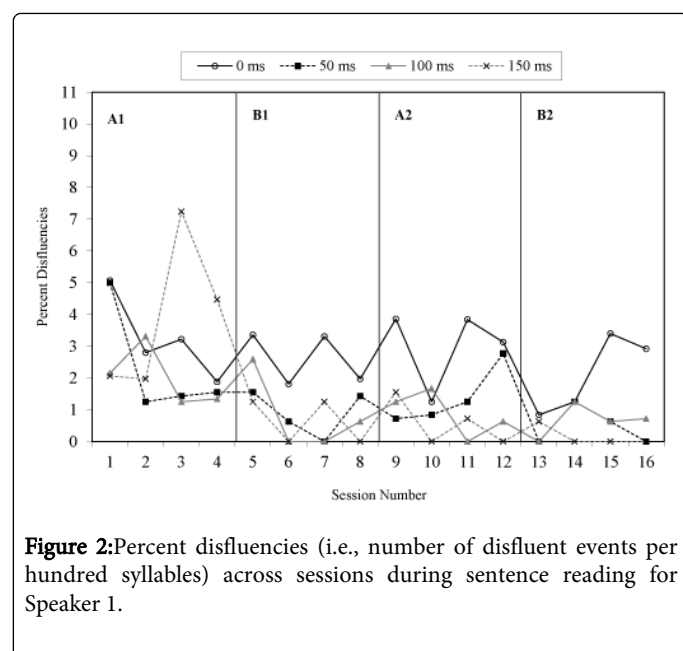


Figure 1: Reading rate (syllables per second) across sessions during sentence reading for Speaker 1.

Disfluency

Figure 2 displays Speaker 1's percentage of disfluency across sessions. A 2x4 Analysis of Variance (ANOVA) yielded main effects for phase [$F(1, 63) = 12.469$, $p < .001$] and interval [$F(3, 63) = 5.720$, $p < .002$], but no interaction effect [$F(3, 63) = .673$, $p < .572$]. In addition, a one-way ANOVA failed to yield a main effect of phase for the 0 ms condition [$F(1, 15) = 1.937$, $p < .186$]. A Bonferroni test was performed to evaluate the differential effects of the four delay intervals on Speaker 1's speech fluency. Results indicated that his percentage of disfluency during the no DAF condition was significantly higher than with each of the three DAF settings ($p < .011$, $p < .003$, $p < .016$), none of which yielded significantly different results from one another. Thus, statistical analyses revealed that Speaker 1's percentage of disfluency was significantly reduced during the B phases (i.e., DAF + instruction) relative to the A phases (i.e., DAF alone), but not during the 0 ms condition. Also, all three DAF settings (i.e., 50 ms, 100 ms, and 150 ms) significantly reduced disfluency compared to the 0 DAF condition.

Visual inspection of these data reveals some interesting patterns not readily apparent through statistical evaluation (see Figure 2). Throughout most of the experiment, the 0 ms DAF condition yielded the highest percentages of disfluency ($M = 2.74\%$, $SD = 1.15$), with little overlap with values for either the 50 ms DAF ($M = 1.27\%$, $SD = 1.23$) or 100 ms DAF conditions ($M = 1.09\%$, $SD = .98$). During the first phase, however, the highest disfluency levels (exceeding seven percent) resulted from use of 150 ms DAF (see data points for sessions 3 and 4). However, immediately following the introduction of experimenter instruction (session 5), disfluency during the 150 ms DAF condition decreased dramatically to less than one percent. From that point on, this delay interval produced relatively low disfluency rates ($M = 1.32\%$, $SD = 1.98$) comparable to those produced by 50 ms and 100 ms DAF. Speaker 1 evidently responded well to 150 ms DAF, but only after the introduction of matching instruction. It is also noteworthy that 50 ms DAF produced consistent, albeit slight, upward trends during both A phases that were quickly reversed during the B phases. In general, results illustrated that after initial instruction, all three settings of DAF were effective in decreasing Speaker 1's disfluencies.



Speaker 2

Figure 3 and 4 display Speaker 2's performance on each of the two dependent measures across experimental sessions. The graphs depict data for speech rate (Figure 3) and disfluency (Figure 4). As with Speaker 1, intelligibility data for Speaker 2 are not presented, as he maintained nearly 100% intelligibility during the relatively simple sentence task utilized during the experiment.

Speech rate

Figure 3 displays Speaker 2's speech rate across all 16 sessions. A 2x4 Analysis of Variance (ANOVA) yielded main effects for phase [$F(1, 63) = 64.752, p < .000$] and interval [$F(3, 63) = 196.708, p < .000$], as well as an interaction effect [$F(3, 63) = 2.013, p < .038$]. In addition, a one-way ANOVA failed to yield a main effect of phase for the 0 ms condition [$F(1, 15) = 2.778, p < .118$].

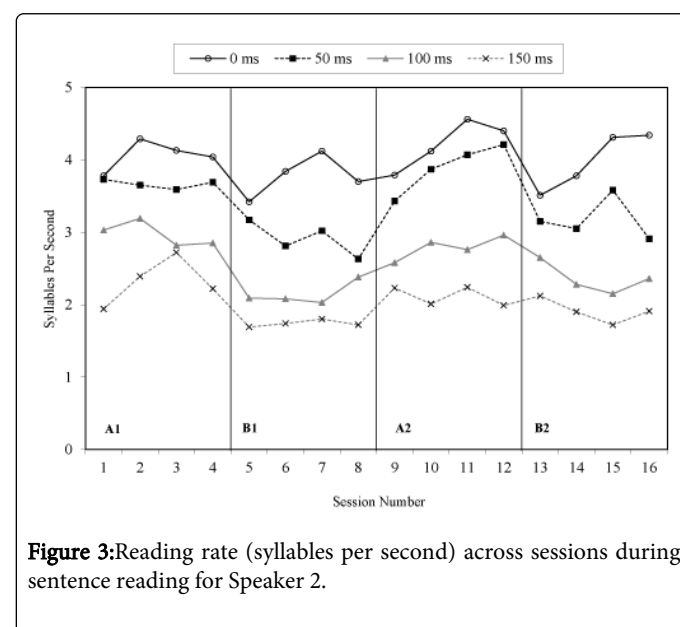
A Bonferroni test was performed to determine the differential effects of the four DAF intervals on speech rate. Results revealed that all six pairs of intervals were significantly different in terms of their effects on reading rate ($p < .0001$). That is, across the four phases of the experiment, each delay interval resulted in a significantly lower speech rate than the next shortest interval (e.g., 100 ms versus 50 ms). In sum, statistical analysis revealed that Speaker 2's reading rate was significantly reduced during the B phases (i.e., DAF + instruction), but not without the use of DAF (i.e., the 0 ms condition). Also, all six pairs of interval conditions produced significantly different rates across phases. Lastly, the interaction effect suggests that the impact of phase change (i.e., shifting from DAF alone to DAF + instruction) was more pronounced for particular DAF intervals than for others.

This interaction effect becomes more evident through visual inspection of the data in Figure 4. The separation between the data points and absence of overlapping values reveals the differences in speech rate produced by the four DAF intervals, regardless of phase (i.e., whether DAF was used alone or supplemented by instruction). However, the relative differences in speech rate among the four intervals were somewhat idiosyncratic. That is, performance at

each delay interval was affected somewhat differently by changes in phase (e.g., proceeding from the use of DAF alone to DAF plus instruction).

Close examination of speech rate changes between the four phases of the experiment reveals an immediate downward shift in rate for all four interval conditions at the beginning of the first B phase (i.e., session 5). However, this change in level was maintained throughout phase B1 for all three levels of DAF, but not for the 0 ms DAF condition (i.e., no DAF). Reading rate at 0 ms DAF returned to baseline levels (i.e., with the use of DAF alone), confirming the effectiveness of adding experimenter instruction to the DAF intervention. Withdrawal of instruction at phase A2 resulted in an immediate increase in speech rate during all interval conditions, as well as a marked upward trend for the 50 ms DAF condition. It became clear by phase A2 that 50 ms DAF produced relatively little rate reduction (in comparison to no DAF) when used without the benefit of experimenter instruction.

Re-instating the instruction at phase B2 (session 13) resulted in another immediate downward shift in reading during all interval conditions. Again, this decrease in rate was maintained at all three levels of DAF, but not at 0 ms DAF. As in phase B1, reading rate without the use of DAF returned to baseline levels (i.e., with the use of DAF alone), confirming the effectiveness of adding instruction to the DAF intervention. Thus, all three DAF settings were more effective when experimenter instruction was added to the protocol. This was particularly true for 50 ms DAF, which appeared to be most effective in reducing Speaker 2's rate when supplemented by verbal instruction and modeling.



Disfluency

Figure 4 displays Speaker 2's percentage of disfluency across sessions. A 2x4 Analysis of Variance (ANOVA) yielded significant main effects for phase [$F(1, 63) = 25.517, p < .0001$] and interval [$F(3, 63) = 8.843, p < .0001$], as well as an interaction effect [$F(3, 63) = 2.995, p < .038$]. In addition, a one-way ANOVA yielded a significant main effect of phase for the 0 ms condition [$F(1, 15) = 12.233, p < .004$].

suggesting generalization of DAF effects to sentence reading without the use of DAF.

A Bonferroni test was conducted to evaluate the differential effects of the four delay intervals on Speaker 2's percentage of disfluency. Results indicated that his percentage of disfluency during the no DAF condition ($M=4.86\%$, $SD=2.85$) was significantly higher than during each of the three remaining DAF intervals ($p<.001$, $p<.001$, $p<.000$), none of which yielded significantly different results from one another. Thus, statistical analysis indicated that Speaker 2's disfluency was significantly reduced during the B phases (i.e., DAF + instruction), including during reading without the use of DAF. Also, all three DAF settings significantly reduced disfluency (as compared to no DAF) across phases. Lastly, the interaction effect suggests that the significantly higher percentage of disfluency exhibited during the 0 ms DAF condition was more marked during the A phases than during the B phases.

This latter finding is confirmed by visual inspection of the data in Figure 4. The separation between the data points and absence of overlapping values during both A phases illustrate the higher levels of disfluency exhibited without the use of DAF. However, during the B phases, percentage of disfluency during 0 ms DAF was at times lower than during the three DAF conditions, suggesting generalization of DAF-induced fluency improvements. Alternatively, this may be due in part to the relatively high standard deviations attained for percentage of disfluency both during the A phases ($M=4.11\%$, $SD=2.19$) and the B phases ($M=2.12\%$, $SD=1.58$) across all delay intervals.

Examination of changes in disfluency between the four phases of the experiment reveals an immediate downward shift for all four interval conditions at the beginning of the first B phase. However, performance during phase B1 was marked by variability during three of the four interval conditions (i.e., 0 ms, 100 ms, and 150 ms), with frequent overlap with baseline values (i.e., those obtained during phase A1, which used DAF alone). The 50 ms DAF condition, however, produced consistently fewer disfluent events during B1 than during A1, as was expected. Withdrawal of experimenter instruction at phase A2 resulted in an immediate increase in disfluency during the no DAF condition and an upward trend for the 50 ms DAF condition, which was reversed by session 12. This low percentage of disfluency at session 12 may have reflected Speaker 2's ability to accurately match 50 ms of DAF without feedback from the experimenter.

Interestingly, performance with 100 ms and 150 ms DAF stabilized to relatively low levels throughout phase A2, although values were at times higher than those obtained during phase B1 (particularly for 150 ms DAF). This stabilization would be expected, and confirms the particular effectiveness of these relatively long DAF intervals in reducing the frequency of speech disfluencies, particularly when supplemented by clinician instruction. That is, longer delay intervals usually result in slower speech rates, which were expected to increase speech fluency.

Re-instating the experimenter instruction during phase B2 resulted in observably lower mean disfluency values for all four interval conditions, though with varying latencies of change. This relatively low level of disfluency was maintained for all four interval conditions, including the 0 ms DAF condition. However, the reduced variability during phase B2 for the three DAF settings (i.e., 50 ms, 100 ms, and 150 ms) suggests not only the effectiveness of DAF in stabilizing speech fluency, but also Speaker 2's improved ability to consistently

respond to the experimenter's matching instruction in order to maintain low levels of disfluency.

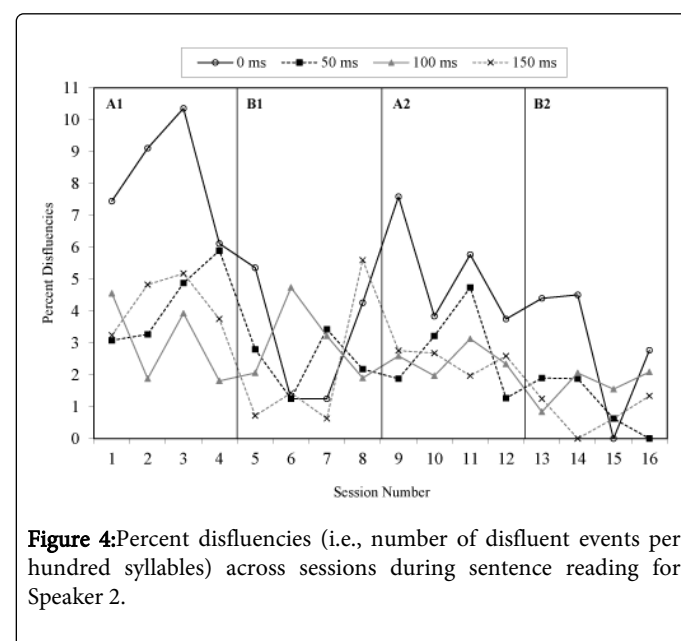


Figure 4: Percent disfluencies (i.e., number of disfluent events per hundred syllables) across sessions during sentence reading for Speaker 2.

Speaker 3

Figures 5 and 6 display Speaker 3's performance on each of the two dependent measures (plotted on the y-axes) across sessions (plotted on the x-axes). The graphs depict data for speech rate (Figure 5) and intelligibility (Figure 6). For this speaker, fluency data are not presented, as he exhibited relatively few sound, syllable, or word repetitions during the sentence reading task (i.e., a floor effect).

Speech rate

Figure 5 displays Speaker 3's mean speech rate (in syllables per second) during each of the four conditions across the 16 sessions. A 2x4 Analysis of Variance (ANOVA) was performed to evaluate the effects of phase and delay interval on speech rate. Results of the ANOVA yielded main effects for phase [$F(1, 63)=23.617$, $p<.0001$] and interval [$F(3, 63)=39.956$, $p<.0001$], but no phase-by-interval interaction [$F(3, 63)=1.195$, $p<.899$]. In addition, a one-way ANOVA failed to yield a main effect of phase for the 0 ms condition [$F(1, 15)=3.446$, $p<.085$].

Potential differences among the interval conditions were evaluated via a Bonferroni test. Results revealed that Speaker 3's rate during the 0 ms DAF condition was significantly higher than during each of the three remaining DAF conditions ($p<.000$), and that the 50 ms DAF condition yielded significantly higher speech rates than did the 150 ms DAF condition ($p<.003$). In sum, statistical analysis revealed that Speaker 3's reading rate was significantly reduced during the B phases (i.e., DAF + instruction), but not without the use of DAF (i.e., 0 ms). Also, all three DAF settings significantly reduced his speech rate (as compared with no DAF) across phases, while 150 ms DAF yielded a significantly slower rate than did 50 ms DAF.

These statistical results are corroborated by visual inspection of the data in Figure 7. The no DAF condition consistently yielded the highest speaking rates ($M=2.34$ SPS, $SD=.39$), with no overlap of values with any of the three DAF settings. Conversely, 150 ms DAF yielded the

lowest speech rate in nearly every session ($M=1.43$ SPS, $SD=.26$). As stated above, however, the mean difference in speech rate between this condition and the 100 ms condition ($M=1.58$ SPS, $SD=.22$) was not statistically significant.

Examination of changes in speech rate between the four phases of the experiment in Figure 5 reveals an upward trend by the end of phase A1 for all four conditions that was immediately reversed at the beginning of the first B phase. This downward shift supports the hypothesis that the treatment applied in phase B1 would be effective in reducing reading rate. Rates during all interval conditions increased slightly at session 6 before stabilizing throughout phase B1. The withdrawal of instruction in A2 produced an immediate increase in rate during all interval conditions, as well as a slight upward trend throughout the A phase for all conditions, again confirming the effectiveness of the experimenter instruction. Re-instating instruction in conjunction with DAF in B2 resulted in a second immediate decrease in speech rate during all interval conditions. Throughout the remainder of B2 performance stabilized during all DAF conditions with the exception of the 0 ms DAF condition, which produced less consistent reading rates.

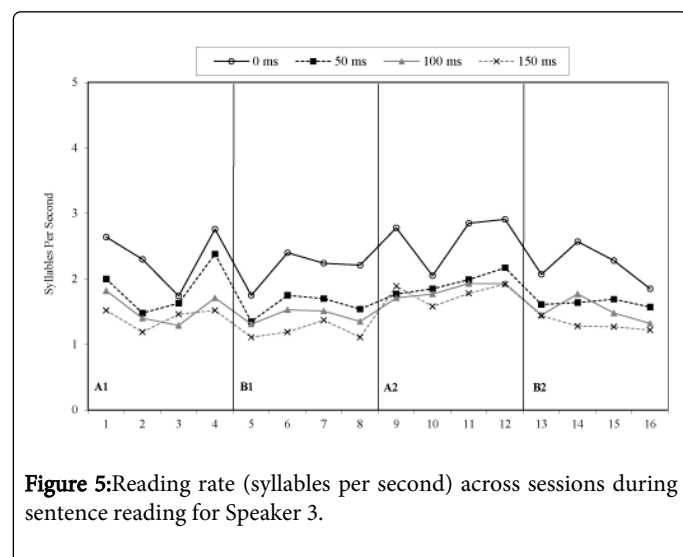


Figure 5: Reading rate (syllables per second) across sessions during sentence reading for Speaker 3.

Intelligibility

Figure 6 displays Speaker 3's percentage of intelligibility across all 16 sessions. A 2x4 Analysis of Variance (ANOVA) yielded main effects for phase [$F(1, 63)=24.396$, $p<.0001$] and interval [$F(3, 63)=4.614$, $p<.006$], but no interaction effect [$F(3, 63)=.075$, $p<.973$]. In addition, a one-way ANOVA failed to yield a main effect of phase for the 0 ms condition [$F(1, 15)=3.919$, $p<.068$].

A Bonferroni test was conducted to determine the differential effects of the four DAF intervals on Speaker 3's intelligibility. Results revealed that his intelligibility during the 0 ms condition was significantly lower than during each of the three remaining intervals conditions ($p<.024$, $p<.023$, $p<.018$), none of which differed significantly from one another. In sum, statistical analysis revealed that Speaker 3's intelligibility was significantly higher during the B phases than during the A phases, but not without the use of DAF. Also, all three intervals of DAF significantly increased his intelligibility relative to 0 ms DAF across phases.

Visual inspection of Speaker 3's intelligibility data in Figure 6 illustrates the improved intelligibility that resulted from using either 50 ms ($M=89.83\%$, $SD=7.46$), 100 ms ($M=89.86\%$, $SD=6.16$), or 150 ms DAF ($M=90.06\%$, $SD=6.16$), as opposed to no DAF ($M=82.66\%$, $SD=10.01$). The standard deviation of 10.01% in the 0 ms DAF condition, compared to the standard deviations in the other three DAF conditions (i.e., 6.16-7.46%), highlights the variability in Speaker 3's intelligibility when reading without the use of DAF. Figure 6 illustrates that while his intelligibility occasionally approached 100% with DAF (particularly during the second B phase), it deteriorated to less than 70% during both A phases without DAF (i.e., the 0 ms DAF condition). Although no DAF setting was clearly superior in improving Speaker 3's intelligibility, all three intervals yielded over 90% intelligibility throughout the final phase (i.e., B2).

Visual inspection of changes in intelligibility throughout the four experimental phases reveals that a slight upward trend at the end of phase A1 was extended during phase B1 for all DAF intervals except 0 ms. Thus, it is not clear that that addition of experimenter instruction in the first B phase was responsible for the observed increases in Speaker 3's intelligibility. With the exception of 100 ms DAF, performance at all delay intervals was characterized by variability during phase B1. However, withdrawal of instruction in session 9 produced an immediate downward trend in intelligibility during each delay condition except for 0 ms DAF. This shift suggests that the DAF + instruction were effective in increasing intelligibility relative to DAF alone. In addition, re-instating the instruction in B2 resulted in an immediate upward shift in performance during all four interval conditions, again indicating the effectiveness of the instruction. Throughout the remainder of this B2 performance stabilized during all interval conditions, but remained consistently lowest during the 0 ms DAF condition (i.e., no DAF).

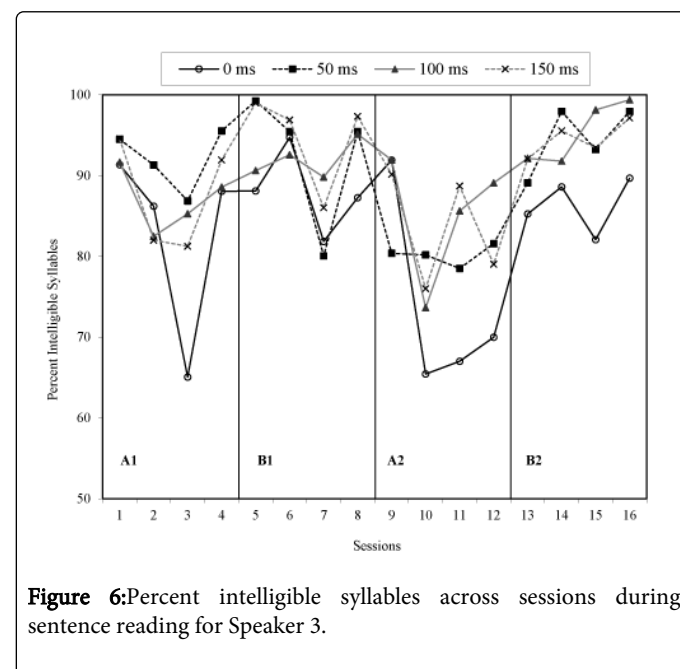


Figure 6: Percent intelligible syllables across sessions during sentence reading for Speaker 3.

Discussion

The present study evaluated the efficacy and efficiency of providing verbal instructions and using different delay rates in a DAF-based rate control intervention for dysarthric speakers with Parkinson's disease.

In the following sections, each of the research questions will be addressed individually.

Question 1: Does DAF reduce reading rate in speakers with Parkinson's disease?

Results indicated that for all three speakers with Parkinson's disease, DAF was effective in producing reductions in speech rate which were statistically significant and relatively stable across the 16 sessions. Regardless of age, disease severity, and specific speech characteristics, all participants exhibited maximum rate reductions of over 50% in comparison to their habitual sentence reading rates. Even Speaker 3, who exhibited habitual sentence rates below the normative mean of 4.7 syllables per second [37], demonstrated the ability to produce significantly slower speech rates while using DAF. The fact that his intelligibility improved significantly following an even further reduction in speech rate supports the rationale for attempting a rate control intervention with similar patients.

Question 2: Does DAF improve intelligibility and fluency?

In addition to documenting session-by-session changes in speech rate as a function of DAF, the present study also documented corresponding changes in either intelligibility or speech fluency. The use of DAF led to statistically significant improvements in intelligibility for Speaker 3, and fluency for Speakers 1 and 2. The specific speech parameters positively affected by DAF corresponded with the primary speech deficit exhibited by each individual participant.

Improvements in intelligibility

The increased intelligibility exhibited by Speaker 3, who presented the lowest habitual intelligibility, confirms previous findings that speech rate is an important behaviorally modifiable variable for improving intelligibility [2] that often correlates with intelligibility [1]. The fact that Speaker 3 exhibited the slowest reading rates of all three participants, as well as the lowest intelligibility percentages, confirms previous findings that speakers with slower rates sometimes exhibit poorer intelligibility than those who produce "more appropriate" rates [38].

In general, speech rate is thought to be "excessive" for a particular individual when it is beyond the capabilities of the person's neuromuscular control system. As was the case for Speaker 3, a patient with Parkinson's disease may actually be speaking more slowly than unimpaired speakers, but may still be speaking at an excessive rate given his or her neuromotor impairment. Appropriate intervention, such as the use of DAF, may result in an even further rate reduction, as was the case with Speaker 3. In such cases, however, the primary goal is not a "normal" speech rate, but "compensated intelligibility." That is, the primary concern is not how the speaker's rate compares to normative values, but whether his or her speech can be made more intelligible by reducing its rate [9].

Improvements in fluency

Speakers 1 and 2 exhibited statistically significant reductions in the frequency of disfluent events while reading with DAF feedback (with any of the three interval settings). The effects of DAF on this measure of speech fluency in dysarthric speakers have not been reported previously. However, the present results are consistent with findings of studies examining the effects of DAF on the speech of developmental

stutterers [10-12]. That is, persons who stutter exhibit a tendency to prolong syllables to overcome the "disruptive" effects of DAF, such as sound and syllable repetitions. Thus, speakers who do things to "beat" the DAF are incidentally doing things that are likely to improve speech fluency as well [12]. This was evidently the case for Speakers 1 and 2, as evidenced by greatly reduced reading rates during the DAF conditions (Figures 1 and 2). That is, these individuals demonstrated the ability to "beat" the DAF in order to significantly reduce their reading rates and improve their speech fluency.

Question 3: Are there differential effects of various DAF intervals?

One of the primary purposes of the present study was to experimentally evaluate the effects of three different delay intervals (i.e., 50 ms, 100 ms, and 150 ms) on speech behaviors. The goal of this manipulation was to determine whether each participant found one or more delay interval "optimal" in improving speech performance. Results revealed that all three participants experienced the greatest degree of rate reduction during use of 150 ms DAF. This was expected, as the longer the duration of the delay interval, the longer the "time lag" between production of a syllable and its perception.

In other words, the speakers were required to prolong each syllable longer while reading with 150 ms DAF than with either 50 ms DAF or 100 ms DAF, resulting in a slower speech rate. However, although 150 ms produced the slowest reading rates for all three speakers, this did not lead to any differential effects on either intelligibility (Speaker 3) or fluency (Speakers 1 and 2). That is, none of the speakers found any particular delay interval "optimal" for reducing their particular speech deficits. Using any of the DAF settings was sufficient to obtain significant improvements in either intelligibility or fluency. Close examination of the data in Figures 2 and 4 reveals that, for both Speakers 1 and 2, reading with 150 ms DAF reduced disfluencies to the greatest extent during several sessions and virtually eliminated all disfluencies in the case of Speaker 1. However, the differences among the three DAF settings were not significant. Thus, for both speakers, all three delay intervals used were effective in reducing the frequency of disfluent events to low levels. Similarly, Speaker 3 exhibited over 90% intelligibility throughout the final phase of the study with all three DAF settings.

Benefits of using multiple delay intervals

Using multiple delay intervals in clinical practice offers the speaker more specific treatment options, which may prove beneficial at some point during the course of intervention. Results of the present study indicated that all three participants found 150 ms DAF to be an optimal delay interval for rate reduction, but not significantly more effective than 50 ms DAF or 100 ms DAF in improving intelligibility or fluency. However, documentation of the superior rate control capabilities of 150 ms provides useful information for future investigators and clinicians.

First, some Parkinson's disease patients may respond more favorably to, or may simply prefer, one particular DAF setting. The three participants in the present study demonstrated the ability to modify their reading rates differentially in response to every alteration in delay time made by the experimenter, and did not verbally express any particular preferences regarding delay intervals. However, when working with similar patients achieving substantial speech benefits

with three different levels of DAF, clinicians are afforded the option of utilizing the setting that the individual speaker prefers or responds most favorably to.

Secondly, early treatment is widely encouraged in Parkinson's disease to slow the inevitable degeneration of function [29]. Many patients with Parkinson's disease experience a gradual deterioration of communicative abilities as the disease progresses [23]. At such time, a longer DAF interval, which would yield a slower speech rate, may be needed to maintain the level of intelligibility and/or fluency previously achieved with a shorter interval (e.g., 50 ms). Extended use of multiple delay intervals during each treatment session would allow the patient the opportunity to gain practice with longer intervals, which he or she may need to use during a later stage of the disease. This may be especially important for relatively young PD patients (such as Speaker 2, who was 36 years of age at the time of data collection), who may eventually experience substantial increases in disease severity.

Lastly, the use of delay intervals yielding speech rates slower than needed to achieve significant speech gains is advantageous when increasing the demands of tasks used during treatment. For example, the present study used sentence reading as the sole speech during intervention (i.e., the use of DAF, both with and without experimenter instruction). This relatively simple speech-language activity was utilized in order to maximize the internal validity of the study, and to provide a replicable DAF protocol that could be used easily and effectively by clinicians working with Parkinson's disease patients. Previous authors observed that some Parkinson's disease patients perform better on more structured tasks, such as reading, than on spontaneous speech tasks [6,26]. The inclusion of more complex tasks, such as picture description and spontaneous speech, may have accounted for the limited effectiveness of DAF previously reported [9,24].

Such findings are certainly not surprising, as spontaneous speech often places increased motor, linguistic, cognitive, and social demands on the speaker [39]. Reading also facilitates a more rhythmic speech pattern with relatively equal duration between stressed syllables, or "isochrony" [40]. Clinical evidence suggests that this enhances the use of the DAF signal to predict when the next syllable should be produced [12]. Based on these observations, as well as the findings of the present study, clinicians might consider using reading as the sole speech task, at least until stable responding to the DAF has been obtained. However, further studies are needed to evaluate the speech effects of DAF using other tasks (e.g., picture description, monologue, etc.), perhaps by conducting systematic replications of the present experiment [36].

Question 4: Does Clinician Instruction Enhance the Speech Effects of DAF?

As expected, the addition of experimenter instruction during the B phases of the present study resulted in significantly slower sentence reading rates for all three participants. In addition, instruction significantly improved intelligibility and speech fluency. In other words, every speech measure positively affected by the use of DAF alone was further enhanced by clinician instruction to a statistically significant degree.

A delay interval of 150 ms is relatively difficult to match, but yields significantly slower speech rates than either 50 ms or 100 ms, as was confirmed by the present findings. For example, Speaker 1 actually produced the greatest number of speech disfluencies during phase A1

while reading with 150 ms DAF, although this delay interval produced the slowest reading rates. His response to the longest delay interval used was similar to that of many normal speakers [30,31]. That is, the delayed signal may indicate that the last sequence of speech gestures should not have been terminated, inducing the speaker to repeat production of the speech segments. As illustrated in Figure 3, however, the introduction of experimenter instruction in phase B1 virtually eliminated Speaker 1's disfluencies during the 150 ms DAF condition.

This enhancement of DAF effects by clinician instruction suggests that the initial stage of a DAF-based rate control intervention may not be the best time to determine an individual speaker's "optimal delay," as is often observed in the published literature [20,22,23]. For example, examination of the disfluency data for Speaker 1 (see Figure 2) suggests that, had experimenter instruction not been introduced in session 5, the high percent disfluency exhibited with 150 ms DAF during phase A1 (i.e., DAF alone) would have continued during phase B1. The addition of instruction, therefore, resulted in maximal speech improvement for Speaker 1 using the longest delay interval offered to him.

The ability of all three participants to modify their reading rates using three different delay intervals, to a significantly greater degree when given feedback and modeling from the experimenter, confirms the effectiveness of attending to (and matching) the delayed signal. The literature confirms the long-standing clinical observation that Parkinson's disease patients exhibit wide variability in speech rate (both intra- and inter-speaker), and have difficulty modifying their speech rates when instructed to do so [1,41]. However, results of the present study suggest that when given clear, consistent, and specific instructions, Parkinson's disease speakers are able to modify their speech rates, at least during a relatively simple speech-language activity.

As highlighted by Duffy [2], overt instruction improves performance, as most patients do not improve simply by talking. Likewise, Rosenbek and LaPointe [29] asserted that few patients can modify rate without careful, systematic instruction. Feedback is essential to motor learning, especially during the initial stages, and should be immediate and precise relative to the treatment goals [9,42]. Such feedback can be instrumental (e.g., a DAF unit) or administered by the clinician (e.g., instructions and demonstration on how to most effectively use the unit). As Rosenbek and LaPointe [29] suggested, the clinician should be as active in DAF training as in any other form of treatment, as generalization can only be achieved if the clinician provides feedback regarding the speaker's performance.

Thus, the present findings provide a "model" protocol to be used by future investigators and clinicians endeavoring to further explore and refine the use of DAF as a rate control intervention for speakers with Parkinson's disease. However, generalization studies are needed to develop efficient methods of transferring speech improvements achieved during a DAF-based intervention. For example, studies examining the efficacy of the proposed DAF protocol during more complex speech-language activities (e.g., monologue, conversation) are especially needed.

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