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THE EFFECT OF RATE CONTROL ON THE INTELLIGIBILITY AND NATURALNESS OF DYSARTHRIC SPEECH

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Speaking rates of individuals with severe ataxic dysarthria (n = 4) and severe hypokinetic dysarthria (n = 4) were reduced to 60% and 80% of habitual rates using four different pacing strategies (Additive Metered, Additive Rhythmic, Cued Metered, and Cued Rhythmic). Effects of rate control on sentence and phoneme intelligibility and speech naturalness were examined. Sentence intelligibility improved for both groups, with metered pacing conditions associated with the largest improvement in scores. Similar improvements as speaking rates were reduced were not seen for the phoneme intelligibility task; however, one must recognize that sentence and phoneme intelligibility tasks are different. Slowing the rate of dysarthric speakers did not have as marked an impact on speech naturalness as it did for normal speakers whose naturalness decreased at slowed rates. Metered rate control strategies were associated with the lowest ratings of naturalness for all subject groups. A potential explanation for the discrepancies between the findings for sentence and phoneme intelligibility is offered.

KEY WORDS: communication, dysarthria, speaking rate, intelligibility, naturalness

Improved intelligibility is arguably the primary goal of speech intervention for individuals with severe dysarthria. Slowing the speaking rate of some dysarthric individuals has a beneficial effect on overall understandability of their speech (Rosenbek & LaPointe, 1985; Yorkston & Beukelman, 1981; Yorkston, Beukelman, & Bell, 1988). Many techniques have been suggested. Some rigid rate control techniques impose a one-word-at-a-time style upon the speaker and are usually reserved for the most severely involved speakers. These rigid techniques often involve some form of external pacing such as pacing boards (Helm, 1979) or alphabet supplementation (Beukelman & Yorkston, 1978; Crow & Enderby, 1989). Other techniques are not as disruptive to speech naturalness. These include devices that provide delayed auditory feedback to slow speaking rates (Hanson & Metter, 1980, 1983) or speaker training with specific feedback such as acoustic displays on oscilloscopic screens (Berry & Goshorn, 1983).

Two groups of dysarthric individuals appear to benefit more than others from a reduction in speaking rate. The first are those with Parkinson's disease with hypokinetic dysarthria whose habitual speaking rate is excessively rapid. This is the only type of dysarthria in which habitual speaking rates are more rapid than those of normal speakers. The speech patterns of these individuals have been likened to the festinating gait pattern also exhibited by some individuals with Parkinsonism. In a recent study involving kinematic, acoustic, and perceptual analyses, the speech of individuals with Parkinsonism is characterized by a general lack of articulatory movement, reduced duration of vocalic segments, and reduced formant transitions (Forrest, Weismer, & Turner, 1989). The second group of individuals who may benefit from rate control are individuals with ataxic dysarthria. Unlike individuals with Parkinson's disease, persons with severe ataxic dysarthria speak more slowly than normal individuals. Their failure to achieve articulatory targets is the result of uncoordinated movements rather than lack of movement.

The purpose of this study was to document the effect of controlling speaking rate on several perceptual aspects of speech, specifically sentence and phoneme intelligibility and naturalness of speech. A number of questions will be addressed. Do slowed speaking rates result in improved sentence intelligibility for hypokinetic and ataxic dysarthric speakers? If so, are some strategies of rate control more effective than others in improving sentence intelligibility? Are there parallel changes in phoneme intelligibility when speaking rates are slowed? In other words, does sentence intelligibility change because speakers produce speech sounds more adequately? Finally, because maintenance of speech naturalness is also an important objective of intervention, how does slowing a speaker's rate affect perceptual ratings of naturalness?

METHOD

Subjects

Dysarthric subjects. Eight dysarthric individuals whose habitual sentence intelligibility was less than 90%

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(Yorkston, Beukelman, & Traynor, 1984) served as subjects. All had sufficient language, visual, and reading abilities to perform the experimental tasks. All were native speakers of English. Relevant clinical information for the dysarthric subjects is presented in Table 1. Note that the subjects included 6 men and 2 women with ages ranging from 30 to 70 years. Judgments regarding type of dysarthria were based on perceptual patterns of deviant dimensions (Darley, Aronson, & Brown, 1975). Yorkston and Beukelman judged 4 subjects to have hypokinetic dysarthria, 2 to have ataxic dysarthria, and 2 to have mixed dysarthria with a component of ataxic dysarthria. Etiologies included Parkinson's disease (n = 3), traumatic brain injury (n = 2), cerebral palsy (n = 1), tumor resection (n = 1), and cerebellar degeneration (n = 1). All subjects were at least 2 years postonset.

Normal subjects. Four individuals with no history of neurologic disorder served as control subjects for the ratings of speech naturalness. Control subjects were matched for age and gender to dysarthric subjects H1, H4, A2, and A4.

Speech Samples

Sentence intelligibility. Sentence intelligibility was measured using samples randomly generated from the Computerized Intelligibility of Dysarthric Speech (Yorkston et al., 1984). Because of the length of the recording protocol, an attempt was made to reduce the number of stimulus items by recording 1 sentence from each sentence length (5 words–15 words). Thus, the total sentence sample for each task was 11 sentences and 110 words. A different random sample was generated and audio recorded for each speaking condition. See Appendix A for an example of a sentence intelligibility sample. Three judges orthographically transcribed each audio recorded sample. Scores are reported in percentage of words correctly transcribed, averaged across judges. Judges for the sentence and phoneme intelligibility samples were graduate students in the Department of Speech and Hearing Sciences who had judged a series of training tapes of other dysarthric speakers for both the sentence and phoneme intelligibility tasks prior to judging the experimental sample.

Phoneme intelligibility. Phoneme intelligibility was measured using a Phoneme Identification Task (Yorkston, Beukelman, Honsinger, & Mitsuda, 1989; Yorkston, Beukelman, & Traynor, 1988; Yorkston, Honsinger, Beukelman, & Taylor, 1989). In this task, subjects read 19 sentences in which words containing a total of 57 vowels and singleton consonants were embedded. A different random sample was generated and recorded for each speaking condition. See Appendix B for an example. The score sheets contained the sentence and word frames with the target phoneme deleted. Judges were asked to identify the missing sound. Scores, averaged across three judges, were reported as the percentage of consonants and vowels correctly identified.

Speech naturalness. In addition to the 8 dysarthric speakers, 4 nonimpaired speakers served as normal controls for this phase of the project. Each subject read a paragraph (see Appendix C) at habitual and slowed rates. The paragraph was constructed for this investigation and included sentences of varying lengths and stress or intonational patterns. A three-sentence segment from the midportion of the paragraph served as the speech sample and was dubbed onto a judging tape. One judging tape was created for each subject at each rate. The judging tape contained six samples: one segment was dubbed from the habitual production, and one from each rate control strategy for each targeted rate (80% or 60% of habitual). Habitual productions, which were included on both tapes, served as reliability items. The presentation order of the individual speech samples was randomized within each tape. The order in which the tapes were judged was also randomized. Judges were naïve to the recording conditions of the samples they were judging.

Natural speech was defined for this study as conventional in terms of intonation, voice quality, rate, rhythm, or intensity adjustments. Unnatural or bizarre speech, on the other hand, was defined as markedly deviating from the expected or conventional pattern. Naturalness, or lack of it, is a multidimensional phenomenon whose features

TABLE 1. Characteristics of the dysarthric subjects.

Subject	*Gender/ Age*	*Dysarthria Type*	*Etiology*	*Years Postonset*
H1	M/56	Hypokinetic	Parkinson's disease	6
H2	M/65	Hypokinetic	Parkinson's disease	6
H3	M/70	Hypokinetic	Parkinson's disease	8
H4	F/30	Hypokinetic	Cerebral palsy with dystonic posturing[a]	29
A1[b]	F/56	Ataxic	Cerebellar degeneration	4
A2	M/38	Ataxic/Spastic	Traumatic brain injury (TBI)	3
A3	M/40	Ataxic/Flaccid	Tumor resection	4
A4	M/35	Ataxic	TBI	17

[a]Although it is somewhat unusual for individuals with cerebral palsy to exhibit hypokinetic dysarthria, this subject's speech was characterized by rapid rushes, inappropriate silences, monopitch, monoloudness, and little articulatory excursion. All of these features are consistent with hypokinetic dysarthria. [b]Only sentence intelligibility and paragraph samples were obtained from this subject because a change in medical status prevented completion of the entire protocol.

vary from one dysarthric speaker to another. Ratings of naturalness were made using a 7-point, equal-appearing interval scale as described by Darley et al. (1975). Because the focus of this project was a comparison of a number of speaking conditions within subjects, a single naturalness judgment tape was constructed for each subject and rate. Thus, judges were comparing the naturalness of one subject across a number of speaking conditions. Nine judges, who were generally familiar with dysarthric speakers but not with the specific subjects in this investigation, served as raters. All judges were either certified speech-language pathologists or graduate students in the Department of Speech and Hearing Sciences. Judges were instructed to listen to the entire judging tape once prior to rating each sample in order to familiarize themselves with the range of samples on each tape. Scores reported are mean scale scores averaged across the nine judges.

Rate Control Conditions

Speaking rates were controlled via software developed for an Apple IIe microcomputer. Each speech sample (sentence intelligibility, phoneme intelligibility, and speech naturalness paragraph) was recorded under nine experimental conditions (one habitual production and four rate control strategies at two speaking rates). Subjects were audio-taped in a sound-treated room using a TEAC A-2300SX reel-to-reel recorder and a Sony ECM-50PS electret condenser microphone. The microphone was mounted in a headgear device to keep the microphone at a constant lip-to-microphone distance of 10 cm despite head movements by some subjects. Each recording session lasted no more than 2 hr. Because of the large number of samples required, several recording sessions were usually needed to complete the entire experimental protocol. The majority of the subjects completed the protocol in three 2-hr sessions.

Speaking rates. Subjects were recorded at three speaking rates: habitual, 80%, and 60% of habitual. The habitual rate was defined in this project as the rate at which subjects read stimulus passages when given no instructions regarding speaking rate. The 80% of habitual speaking rate was chosen because it represented a rate that was not excessively slow even for those individuals with ataxic dysarthria whose habitual rate was less than half of a normal speaking rate. Sixty percent of habitual was selected to represent a noticeable change in speaking rate even for individuals with hypokinetic dysarthria whose habitual rates exceeded that of normal speakers. Recordings at habitual speaking rates were obtained first, followed by paced samples at 80% and 60% of habitual rate. A randomly ordered recording sequence for the rate-controlled conditions was selected for each subject.

Rate control strategies. Because the effect of rate control may differ depending on the strategy used to slow the subject's speech, both presentation style and timing relationships were varied. Rate control strategies included both additive and cued presentation styles, which are described below. These two styles represented different types of prompting. It was felt that the additive style would be most useful for those individuals who needed a rigid, powerful prompt to control their speaking rate and that the cued style would be more appropriate for those for whom a less rigid strategy was adequate. Rate control strategies also included both metered and rhythmic pacing. Both were included because many pacing techniques, such as metronomes or pacing boards, encourage metered pacing strategy, yet many clinicians believe that maintaining the rhythmic characteristics of speech is important for naturalness. Varying presentation style and timing relationships resulted in the following four strategies.

1. Additive Metered (AM): A speech sample was displayed in its entirety on a computer monitor so that subjects could familiarize themselves with the passage. Activation of a control switch by the examiner cleared the screen, and the passage was presented by adding one word at a time at the rate selected by the examiner. During this condition, each word was presented on the screen with equal duration.
2. Additive Rhythmic (AR): This strategy was similar to the Additive Metered, except that the passage was presented on the screen with timing patterns simulating normal speech rather than equal durations for each word. Rhythmic characteristics were assigned to all experimental samples via a program in which a trained technician, following the natural rhythm of an audio recording of a nonimpaired speaker, tapped out the relative durational relationships of the sentence. The program then assigned a relative durational value to each word of the sentence. These values were used to slow speaking rates while preserving a normal relative durational pattern. More recently, computer software has been developed that automates specifying rhythmic patterns by having a program assign relative durational relationships by estimating the number of syllables in a word (Beukelman, Yorkston, & Tice, 1988).
3. Cued Metered (CM): In this strategy, the entire stimulus passage was presented on the screen for subject familiarization. Activation of a switch initiated the underlining of the passage, cuing the production of each word. Each word was cued with an equal duration at a rate selected by the examiner.
4. Cued Rhythmic (CR): This strategy was similar to Cued Metered, except that the words of the passage were cued with timing patterns that simulate normal speech.

Verification of Aspects of the Experiment

Before proceeding with the presentation and discussion of results, the adequacy of a number of aspects of this experiment need to be verified. Of particular concern is how well the pacing program actually controlled the speaking rates of both the neurologically impaired and nonimpaired subjects. Also of concern is the reliability of the various perceptual judgments.

Achievement of target speaking rates. All of the non-impaired and 6 of the 8 dysarthric subjects were able to perform the pacing task successfully at both 80% and 60% of their habitual speaking rate. One of the dysarthric subjects who could be paced at only one of the reduced rates was a hypokinetic dysarthric speaker (H3) whose habitual speaking rate was excessively rapid (240 words per minute). For him, the 80% condition was ineffective in changing his habitual rate. Note that 80% of 240 is 192 words per minute (wpm). Thus, even this "slowed" rate was close to the 190 wpm mean speaking rate of normal subjects on this task. The other dysarthric subject who could be paced at only a single slowed rate was A2, a traumatically brain-injured individual with ataxic dysarthria. He was unable to tolerate the extremely slow rate of 49 wpm, which was the target rate when his speech was paced at 60% of habitual.

The durations of all habitual and paced samples were measured, and actual speaking rates were computed. The actual speaking rates for the sentence intelligibility tasks were determined using the timing function within the software program (Yorkston et al., 1984). The phoneme intelligibility and paragraph tasks were timed using a stopwatch. In this analysis, intersentence pause times were eliminated for the sentence and phoneme intelligibility task, but not for the paragraph task. The three-sentence segment used for the naturalness judgments was timed to determine actual speaking rates for that task. Speaking rates for each task were computed in wpm. Because speakers with hypokinetic dysarthria tend to have speaking rates so different from those with ataxic dysarthria, subjects were grouped by type of dysarthria. Figures 1A, 1B, and 1C illustrate mean speaking rates averaged across subjects for the sentence and phoneme intelligibility and naturalness judgment tasks. Data are presented for habitual, 80%, and 60% conditions. For the slowed conditions, data are averaged across the four pacing strategies for each rate. Also illustrated are the target rates for each of the slowed rate conditions.

A review of Figure 1A suggests that the average habitual speaking rate for the sentence intelligibility task produced by the ataxic group was 70 wpm and by the hypokinetic group was 201 wpm, as compared with a normal speaking rate for this task of 190 wpm. An examination of individual subject data under rate control suggested that in all cases, the actual speaking rate achieved was within 10% of the target rate. The greatest discrepancy between actual and target rate occurred in the hypokinetic group at 80% of habitual, where the average target rate was 161 wpm and the average actual rate was 143 wpm. Thus, when the target rate was 80% of habitual, the actual rate was 71% of habitual.

A similar pattern is seen when reviewing the data from the Phoneme Intelligibility Task (Figure 1B) with average habitual rates of 66 wpm and 167 wpm for the ataxic and hypokinetic group, respectively. The largest discrepancy between actual and target rates was found in the ataxic group at 60% of habitual. Although the actual rate was 71% of habitual rather than the targeted 60%, this represents a difference of only 7 wpm. Figure 1C illustrates the actual and target speaking rates for the naturalness judgment task. Note that for the normal subjects, actual speaking rates were slightly higher than target rate. For hypokinetic subjects, actual speaking rates were slightly slower than targets; and for ataxic subjects, target and actual rates were nearly identical. Thus, for all subject groups, speaking rate was effectively paced by the computer software.

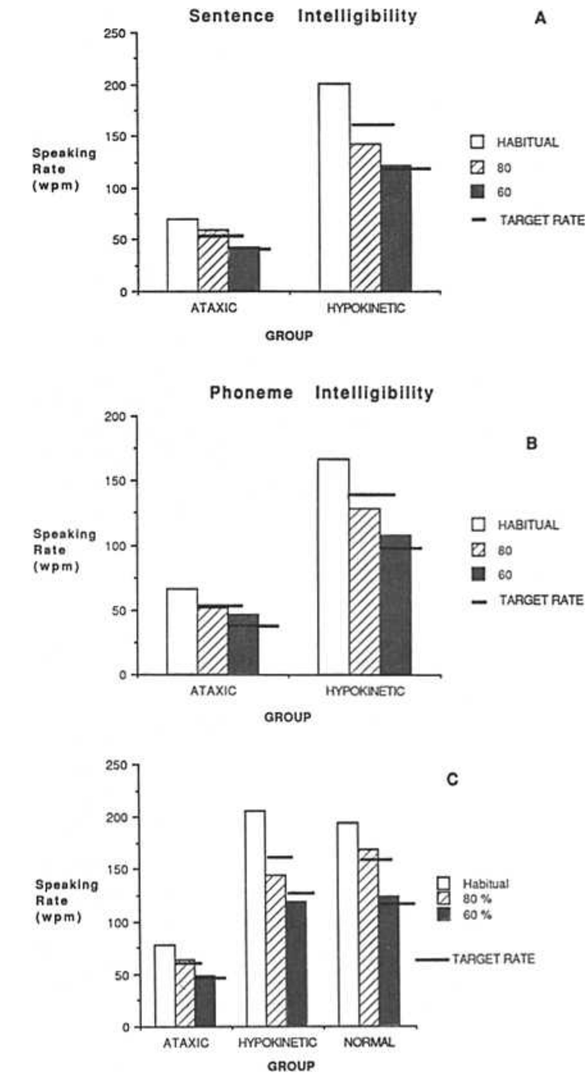

FIGURE 1. Speaking rates in words per minute (wpm) for the sentence intelligibility (A), phoneme intelligibility (B), and naturalness judgment (C) tasks for ataxic and hypokinetic dysarthria groups at habitual speaking rate and when paced at 80% and 60% of habitual. Also included in C are data from the normal control group. Columns indicate actual speaking rates. Target rates for the slowed conditions are shown.

Reliability. Because of the length of the recording protocol, an effort was made to reduce the impact of fatigue by recording a shortened version of Computerized Assessment of Intelligibility of Dysarthric Speech. In this shortened version, one rather than two sentences of each word length was recorded. In order to verify that the scores of the shortened version were similar to those of the standard version, transcripts of 30 previously judged samples were reviewed. The differences between scores generated from the shortened sample (11 sentences) and scores from the total sample (22 sentences) were computed. Results of this analysis indicated that the difference between the shortened and total sample averaged 3.2% with a standard deviation of 2.8%. A simple t-test comparison indicated that the shortened samples were not different from the total sample, with $p > .01$.

Reliability of the Phoneme Intelligibility Task (Yorkston et al., 1988) and Computerized Assessment of Intelligibility of Dysarthric Speech (Yorkston, Beukelman, & Traynor, 1984) is reported elsewhere. Because the Computerized Assessment of Intelligibility of Dysarthric Speech was shortened, a measure of the dispersion of judges' scores was obtained. Average range from the highest score to the lowest across speakers, tasks, and rates was calculated. Results indicate an average range of 8.9% with a standard deviation of 6.4%. A similar measure of dispersion of judges' scores was obtained for consonant and vowel intelligibility for the phoneme intelligibility task. The average range of judges' scores for consonant and vowel intelligibility was 9.6% (SD = 9.3) and 17.9% (SD = 14.9), respectively.

In order to examine the intrajudge reliability of the naturalness judgments, 10% of the samples were judged a second time. A comparison of first versus second judgments indicated that responses were the same or one scaled score different 88%, 91%, and 89% of the time for the ataxic, hypokinetic, and normal groups, respectively. A measure of interjudge reliability was obtained by computing the average standard deviation across the nine judges for each of the samples rated. Results of this computation indicate that the mean standard deviation was 0.97 scale points.

RESULTS AND DISCUSSION

The Effect of Rate Control on Sentence Intelligibility

Our first question was "Do slowed speaking rates result in improved sentence intelligibility for the two groups of dysarthric speakers studied in this project?" In order to answer this question, sentence intelligibility scores were averaged across judges and tasks for each speaking rate (habitual and 80% and 60% of habitual). Results of this analysis are presented in Figure 2. Note that for both groups mean sentence intelligibility increased as speaking rate was reduced. For the ataxic group, mean sentence intelligibility improved from 40.9% at habitual rates to 73.7% at 60% of habitual. For the hypokinetic group, mean sentence intelligibility improved from 60.7% at habitual speaking rates to 81.2% at 60% of habitual.

Data presented in Figure 2 represent the mean scores across subjects. Because subject groups are diverse, an examination of individual performance was also undertaken in an effort to verify the consistency of the overall

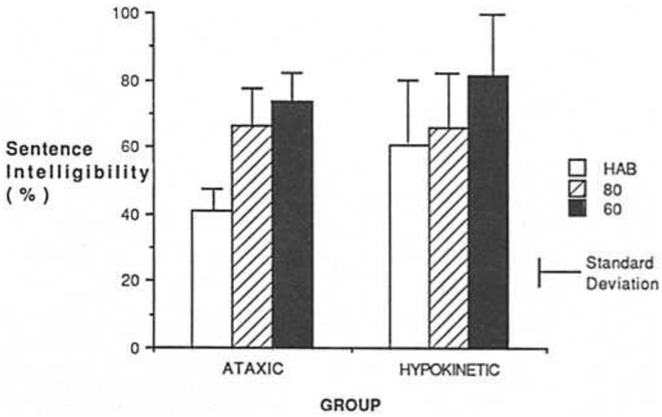

FIGURE 2. Sentence intelligibility at habitual and slowed speaking rates for ataxic and hypokinetic dysarthric speakers. Data for the slowed speaking rates were averaged across rate control strategies.

trend. Figure 3 illustrates the relationship between actual speaking rate (averaged across all tasks for a given speaking rate) and sentence intelligibility. A review of the figure suggests a highly consistent pattern. Sentence intelligibility scores of all subjects increased as speaking rates decreased.

Thus far, our data suggest a strong rate effect for sentence intelligibility. Our next question related to whether certain rate control strategies resulted in more improvement in sentence intelligibility than did others. In order to identify possible differences among the various rate control strategies, data from the 60% condition were averaged across subjects in the ataxic and hypokinetic dysarthria groups. Data from the 60% condition were selected for this analysis because the largest changes in intelligibility scores were noted for this condition. Results of this analysis are displayed in Figure 4. Note that the metered conditions produced higher mean sentence intelligibility scores for both groups of subjects than did the rhythmic conditions.

In order to examine the consistency of this trend across subjects, the sentence intelligibility scores for each subject and speaking rate were rank ordered across the four strategies, Additive Metered (AM), Additive Rhythmic (AR), Cued Metered (CM), and Cued Rhythmic (CR). In other words, the proportion of time that each strategy produced the highest sentence intelligibility score, the next highest score, and so on was computed. Results of this rank ordering are presented in Table 2. Of particular interest is the comparison of the Cued Metered with the Cued Rhythmic Strategy. Note that over half the time (54%), the Cued Metered strategy resulted in the highest sentence intelligibility scores. Compare this with the Cued Rhythmic strategy that never resulted in the highest or the next to highest rank.

The Effect of Rate Control on Phoneme Intelligibility

One potential explanation for the improved sentence intelligibility noted at reduced speaking rates is that

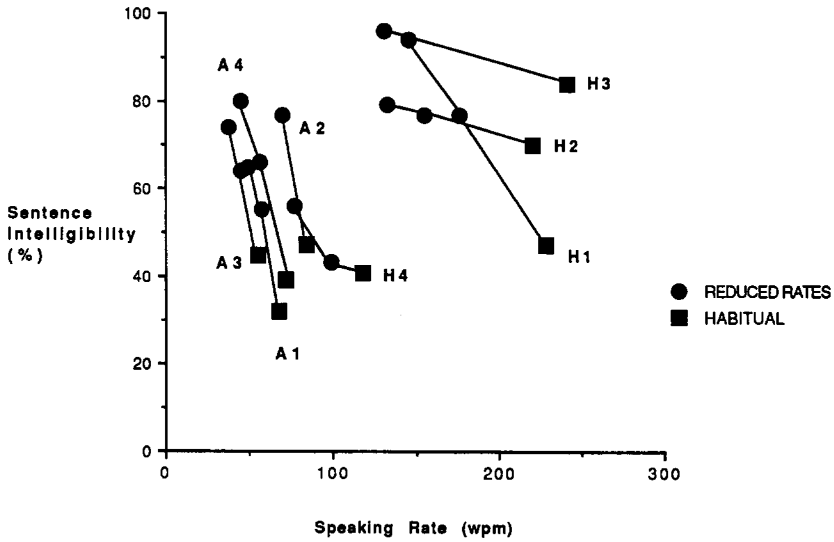

FIGURE 3. A plot of sentence intelligibility as a function of speaking rate for 4 hypokinetic and 4 ataxic dysarthric speakers. Data for the slowed speaking rates were averaged across rate control strategies. Readers should note that for 2 of the subjects (A2 and H3) data are presented for only one rate controlled condition.

slowing speech improves the speakers' ability to achieve precise articulatory targets. If this is the case, then one would expect to see an improvement in phoneme intelligibility at slowed rates. In order to explore the relationship between speaking rate and phoneme intelligibility, consonant and vowel intelligibility scores were averaged across judges (n = 3) and tasks (n = 4) for each speaking rate. Results of this analysis are presented in Figures 5A and 5B. Note that reduced speaking rates were not associated with improved consonant or vowel intelligibility. In fact, mean phoneme intelligibility scores change little as a function of slowed speaking rates. In no case were mean consonant or vowel intelligibility scores more than 5% different for habitual versus 60% condition. An examination of individual data (Figures 6A and 6B) suggests that individual responses to slowed rate are quite variable. For some subjects, phoneme intelligibility decreased at slowed speaking rates. This was the case for Subject A4 for both consonants and vowels. For others, phoneme intelligibility increased at slowed rates as was the case for Subject A3. It is interesting to note that vowel intelligibility decreased more than 10% for over half of the subjects at slowed rates. For Subject A4, vowel intelligibility decreased by more than 25% at the slowed

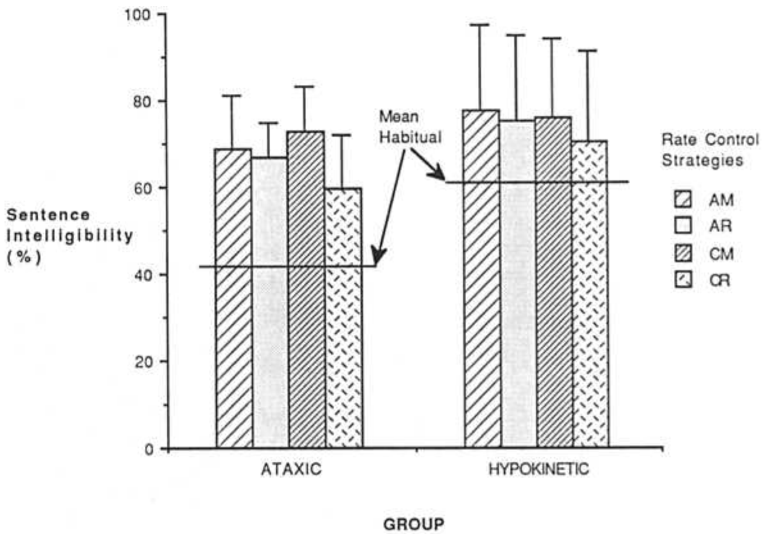

FIGURE 4. Sentence intelligibility scores averaged across slowed rates for the rate control strategies: Additive Metered (AM), Additive Rhythmic (AR), Cued Metered (CM), and Cued Rhythmic (CR). Also indicated are the mean habitual speaking rates for subjects in the ataxic and hypokinetic dysarthria groups.

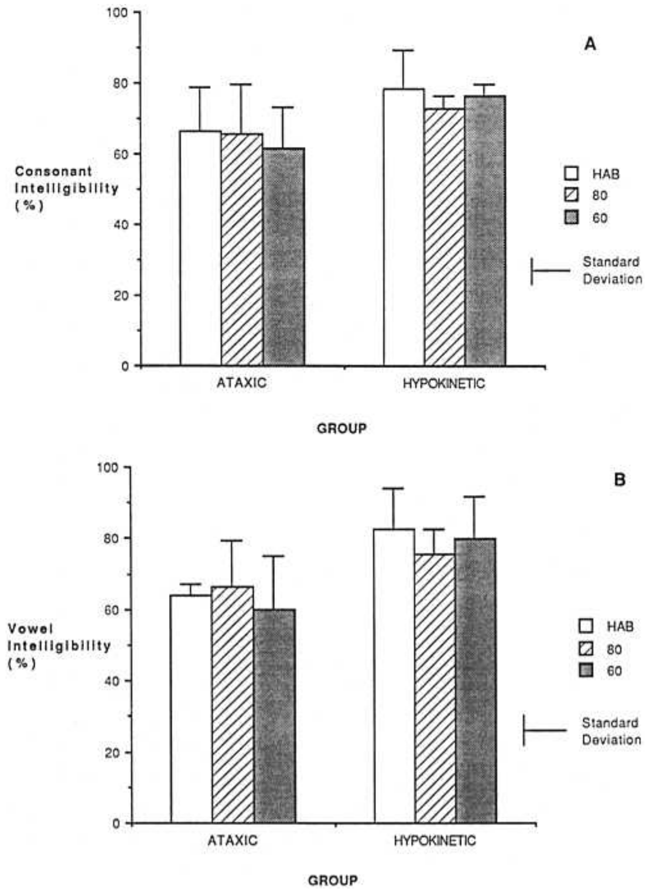

FIGURE 5. Consonant (A) and vowel (B) intelligibility at habitual and slowed speaking rates for ataxic and hypokinetic dysarthric speakers. Data for the slowed speaking rates were averaged across rate control strategies.

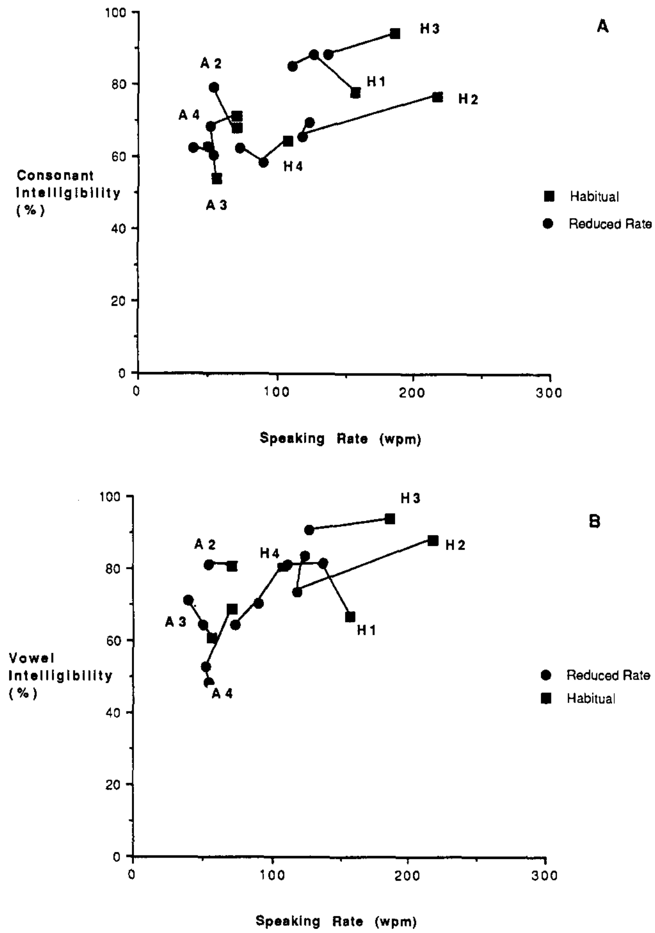

FIGURE 6. A plot of consonant (A) and vowel (B) intelligibility as a function of speaking rate for 4 hypokinetic and 3 ataxic dysarthric speakers. Data for the slowed speaking rates were averaged across rate control strategies.

rate. A review of this ataxic dysarthric speaker's audio recording and judges' responses suggested the judges heard more diphthongs at the slowed as compared to habitual rates. Because no consistent rate effect for phoneme intelligibility was found, further analysis of data for the various control strategies was not undertaken.

TABLE 2. Each cell indicates the percentage of time that a particular rate control strategy resulted in highest to lowest rank ordering of sentence intelligibility scores.

		Rank order of sentence intelligibility scores			
		Highest	—	—	*Lowest*
Strategy	Additive Metered	31%	54%	15%	0
	Additive Rhythmic	15%	23%	39%	23%
	Cued Metered	54%	31%	8%	8%
	Cued Rhythmic	0	0	54%	46%

The Effect of Rate Control on Speech Naturalness

Our next research question relates to the issue of rate control and speech naturalness. Specifically, how does slowing a speaker's rate influence naturalness? In addition to the two groups of dysarthric speakers, a normal control group was added for this task. Figure 7 illustrates the mean naturalness ratings across judges, subjects, and rate control strategies. An examination of the figure suggests that the ataxic group was judged to be the least natural, followed by the hypokinetic dysarthria group and the normal control group. When speaking rates were controlled, the greatest reduction in naturalness was seen in the normal group where mean naturalness ratings decreased from 1.8 (habitual rate) to 2.7 (60% condition). The hypokinetic dysarthria group showed a similar trend, but the difference between habitual and 60% was only 0.2 scaled points with mean naturalness scores of 4.3 for habitual and 4.5 for the 60% condition. The greatest difference between habitual naturalness and the slowed condition for the ataxic group was also small (from 5.0 for the 80% condition to 5.3 for the habitual production).

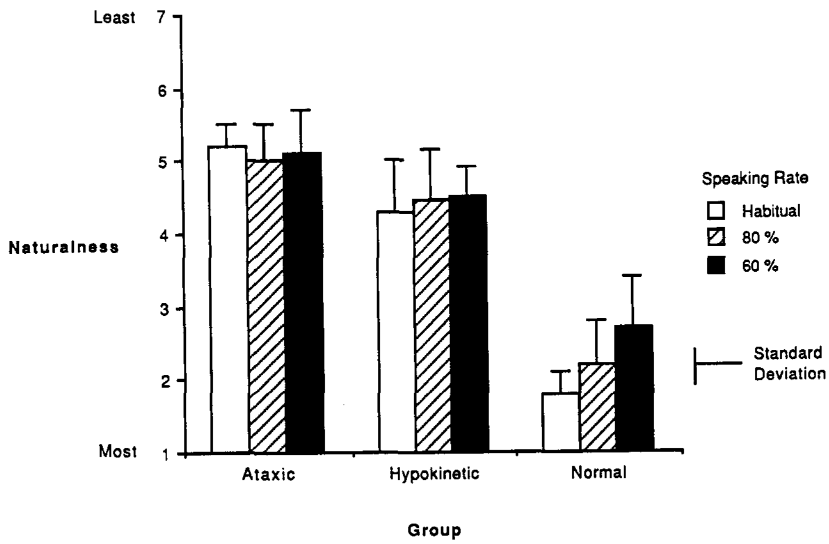

FIGURE 7. Mean ratings of speech naturalness averaged across nine judges for ataxic, hypokinetic, and normal groups at habitual, 80% and 60% of habitual conditions.

Thus, it would appear that both dysarthric groups were habitually quite unnatural and that slowing their rates did not cause substantial further deterioration. Normal speakers, who were, of course, judged to be more natural at habitual rates than were the dysarthric speakers, were considered less natural as their speaking rates were slowed.

Because data related to sentence intelligibility suggested that the metered pacing strategy produced the greatest changes in intelligibility, differences in naturalness ratings as a function of pacing strategy were also explored. Figure 8 illustrates the mean naturalness ratings across judges, subjects, and rates for the metered and rhythmic pacing strategies. Note that for all groups the metered pacing strategy was associated with the least natural productions. This trend was the most marked in the normal group.

CONCLUSIONS

Slowing the speaking rate of severely involved dysarthric individuals resulted in consistent improvement in sentence intelligibility scores for the ataxic and hypokinetic groups studied in this project. Somewhat surprisingly, the strategies that employed metered pacing were associated with the largest improvement in sentence intelligibility scores. These metered strategies tended to be judged as slightly less natural than habitual speech or speech produced with rhythmic pacing. Slowing the

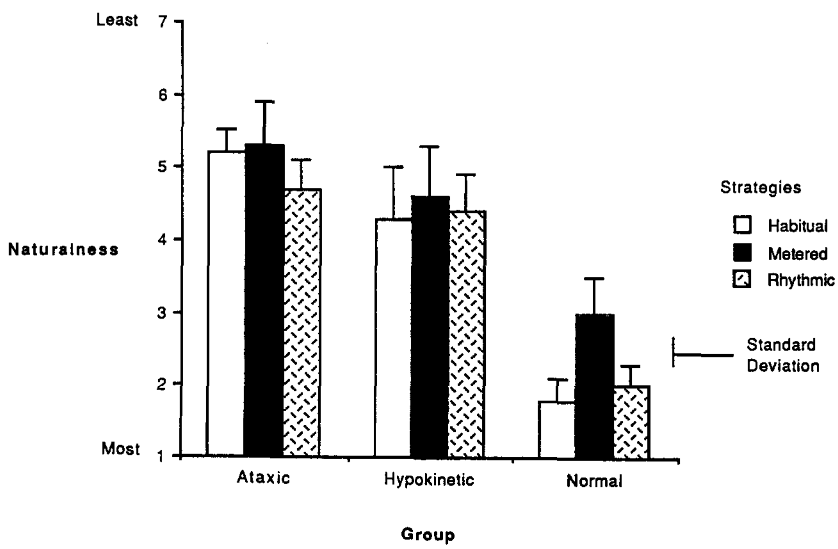

FIGURE 8. Mean naturalness ratings averaged across nine judges for the ataxic, hypokinetic, and normal groups at habitual rate and when paced with metered and rhythmic strategies.

speaking rate did not have as marked an impact on naturalness for dysarthric speakers as it did for normal speakers. Presumably, severely dysarthric speech is already so unnatural that changing rate did not have a further detrimental effect. In the clinical setting a slight reduction in speech naturalness may be an acceptable price to pay for a substantial improvement in intelligibility. Obviously, continued effort should focus on identifying pacing strategies that are effective in increasing speech intelligibility and at the same time do not reduce speech naturalness.

A number of additional research projects are needed if one wishes to apply these techniques to the improvement of speech intelligibility in the clinical population. Studies of the ability of dysarthric speakers to learn to pace their spontaneous speech production is an important next step. Investigations of the impact of various types of feedback on speakers' ability to control speaking rate are only beginning to appear in the literature (Hyland & Weismer, 1988). Also of critical interest to clinicians is the development of profiles of dysarthric speakers who will benefit from rate control and who, perhaps more importantly, will learn to maintain the slowed rates when pacing is removed.

Other questions also arise from the results of the current project. It is difficult and perhaps impossible without further data to explain why the sentence intelligibility of selected dysarthric speakers consistently improved with slowed rate and phoneme intelligibility does not. The following suggestion is offered as a possible but certainly not definitive explanation. The first consideration is the fact that at habitual speaking rates, sentence intelligibility is lower than phoneme intelligibility (compare Figure 2 with Figures 5A and 5B). This may be partially explained by the fact that the judging tasks for sentence intelligibility and phoneme intelligibility are more different from one another than they may initially appear. When performing the sentence intelligibility judging task, listeners report that they search for the complete meaning of the utterance; if they understand the general content, then they can fill in the details and in effect guess at some words that would otherwise be unintelligible. In the phoneme intelligibility task, the judges are already provided with the context or the frame of the sentence and they need only attend to one segment of the utterance, namely the target phoneme. In addition, slowing the speaker's rate may give the listener extra processing time to extract the general content of meaning of the sentence and thus facilitate "filling in the missing pieces." This explanation has also been put forth by Parkhurst and Levitt (1978), who inserted short pauses into sentences produced by deaf speakers. Using multiple regression analyses, pause insertion was positively correlated with orthographically transcribed intelligibility scores. Their interpretation of the results included the suggestion that the pauses may have allowed listeners more time to process distorted speech.

An increase in the number of pauses that may occur as the result of slowing the speaking rate may also help to identify word boundaries for the listener. Again, researchers interested in deaf speech have begun to pursue this theory. Maasen (1986) investigated the effect of marking word boundaries with short pauses on orthographically transcribed speech intelligibility measures. A small, significant increase in intelligibility was obtained for the pause-inserted sentences. Word boundary information is more likely to influence sentence intelligibility than phoneme intelligibility when the listener is already given the sentence and word frame.

A number of questions that await future research are raised by the finding that phoneme intelligibility does not consistently change as a function of speaking rate. Are speakers inserting more pauses into their speech at the slowed rates? If so, are they marking word boundaries more accurately? Finally, does artificially inserting pause time into the unintelligible utterances of dysarthric speakers improve intelligibility scores? Evidence that it does would suggest that listener-processing variables are an important contributor to improved scores. The current project focuses exclusively on the perceptual impact of rate control. Future research is also needed to examine the consequences of slowing the speaking rate on acoustic segment characteristics (e.g., voice onset time, stop closure duration), as well as on the physiologic processes underlying speech production.

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APPENDIX A

Sentence intelligibility sample randomly generated from Yorkston, Beukelman, and Traynor (1984)

Word length	*Sentence*
5	They will make many friends.
6	We all sat down and relaxed.
7	They had no natural interest in sports.
8	Night after night, they received annoying phone calls.
9	I never worried about being in someone else's way.
10	I typed the letter and put it on his desk.
11	As the day flicked by, he asked a thousand crucial questions.
12	About that time, two young men were painting my neighbor's house white.
13	Her position is basically the same as it was a few weeks ago.
14	No one will ever play what you could consider a perfect game of golf.
15	He was so good at it that I urged him to have his recipes printed.

APPENDIX B

Phoneme Identification Task Sample (Yorkston, Beukelman, & TRAYNOR, 1988)

1. "MADGE" is between "LOAN" and "THOUGHT."
2. "MOTH" and "RUNG" are first and "MAN" is last.
3. He said "MUM"; she said "LOVE" or "WHO'LL."
4. "MASH" and "HAM" come before "BAKE."
5. I thought it was "NEAT" or "BATHE"; you thought "RAIN."
6. Spell the words "SHOWED," "TOM," and "VAT."
7. Spell "PAN," then say "FUEL" and "SHOULD."
8. "HEAL" is before "TAUGHT" or "LOAF."
9. "THERE" and "HOWL" were correct; "FAN" was spelled wrong.
10. Remember the words "GAIN," "IAN," and "MAIN."
11. First come "MOSS" and "LUG"; later comes "LOB."
12. I said "YEAR" and "MEN" not "MAP."
13. Write the words "ZONE," "SEAT," and "LOT."
14. "LOWELL," "WIN," and "DANE" are the words he spelled.
15. Say "BOY" and "MATCH," then say "MALE."
16. "BAN" is after "HAL" and "WILL."
17. You said, "MALL"; I said, "LEARN" and "MOD."
18. Read the words "SHAM" and "MAZE"; say the word "MOM."
19. He spelled "CHIN"; I spelled "CANE" and "BY."

Note. Target phonemes are underlined.

APPENDIX C

Mount Rainier Passage

Believe me, my goal is not to perfect your knowledge of nature or any of its attributes, but let's record the story of Sam's first day on the mountain. Unbelievably, this was the first time that he had seen Mt. Rainier. It was a perfect day. I didn't know what to show him first. "Show Sam some snow," someone said. I pointed to the mountain covered with snow, but someone said, "Don't try to show him all that snow, show Sam some snow." I picked up a handful of snow and began to show everyone, but they interrupted again and said, "Show Sam some snow." Pretending to be angry I questioned, "Show Sam some snow?" What a ridiculous idea.